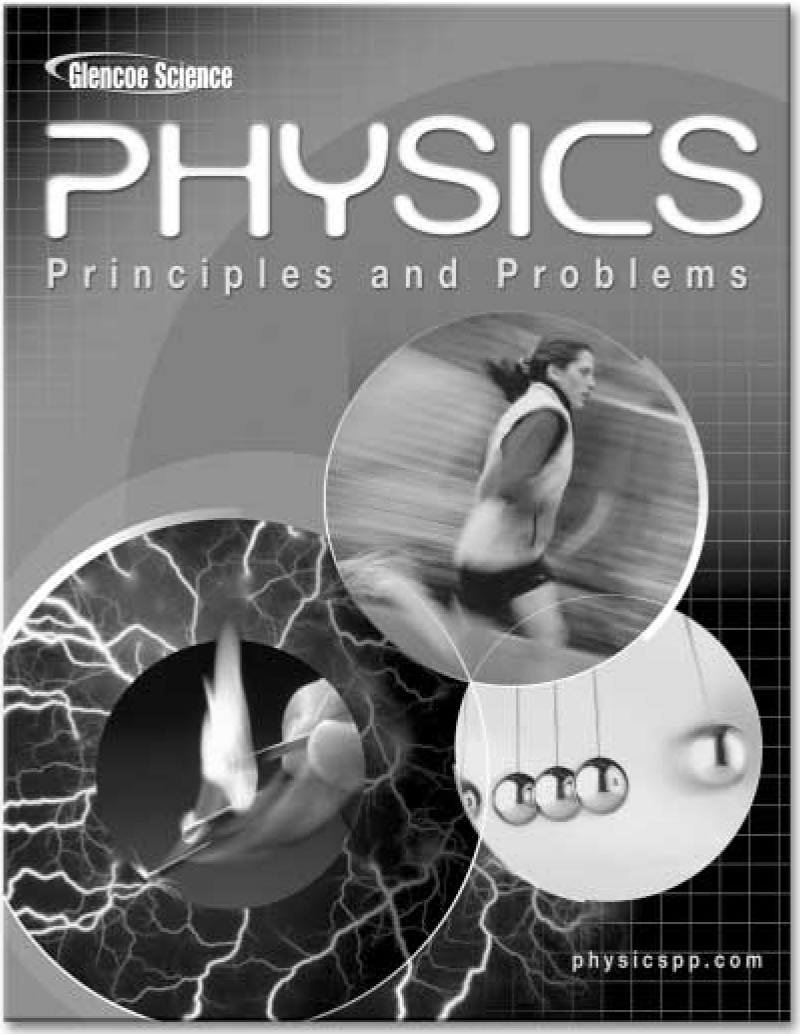

Solutions Manual

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A Glencoe Program

PHYSICS

Principles and Problems

Student Edition

Teacher Wraparound Edition

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Contents

To the Teacher

The *Solutions Manual* is a comprehensive guide to the questions and problems in the Student Edition of ***Physics: Principles and Problems.*** This includes the Practice Problems, Section Reviews, Chapter Assessments, and Challenge Problems for each chapter, as well as the Additional Problems that appear in Appendix B of the Student Edition. The *Solutions Manual* restates every question and problem so that you do not have to look back at the text when reviewing problems with students.

CHAPTER

1 A Physics Toolkit

Practice Problems

1.1 Mathematics and Physics pages 3–10

page 5

For each problem, give the rewritten equation you would use and the answer.

1. A lightbulb with a resistance of 50.0 ohms is used in a circuit with a 9.0-volt battery. What is the current through the bulb?

$$I = \frac{V}{R} = \frac{9.0 \text{ volt}}{50.0 \text{ ohms}} = 0.18 \text{ ampere}$$

2. An object with uniform acceleration a, starting from rest, will reach a speed of v in time t according to the formula $v = at$. What is the acceleration of a bicyclist who accelerates from rest to 7 m/s in 4 s?

$$a = \frac{v}{t} = \frac{7 \text{ m/s}}{4 \text{ s}} = 1.75 \text{ m/s}^2$$

3. How long will it take a scooter accelerating at 0.400 m/s^2 to go from rest to a speed of 4.00 m/s?

$$t = \frac{v}{a} = \frac{4.00 \text{ m/s}}{0.400 \text{ m/s}^2} = 10.0 \text{ s}$$

4. The pressure on a surface is equal to the force divided by the area: $P = F/A$. A 53-kg woman exerts a force (weight) of 520 Newtons. If the pressure exerted on the floor is 32,500 N/m^2, what is the area of the soles of her shoes?

$$A = \frac{F}{P} = \frac{520 \text{ N}}{32{,}500 \text{ N/m}^2} = 0.016 \text{ m}^2$$

page 7

Use dimensional analysis to check your equation before multiplying.

5. How many megahertz is 750 kilohertz?

$$750 \cancel{\text{kHz}}\left(\frac{1000 \cancel{\text{Hz}}}{1 \cancel{\text{kHz}}}\right)\left(\frac{1 \text{ MHz}}{1{,}000{,}000 \cancel{\text{Hz}}}\right) =$$

0.75 MHz

6. Convert 5021 centimeters to kilometers.

$$5021 \cancel{\text{cm}}\left(\frac{1 \cancel{\text{m}}}{100 \cancel{\text{cm}}}\right)\left(\frac{1 \text{ km}}{1000 \cancel{\text{m}}}\right) =$$

5.021×10^{-2} **km**

7. How many seconds are in a leap year?

$$366 \cancel{\text{days}}\left(\frac{24 \cancel{\text{h}}}{1 \cancel{\text{day}}}\right)\left(\frac{60 \cancel{\text{min}}}{1 \cancel{\text{h}}}\right)\left(\frac{60 \text{ s}}{1 \cancel{\text{min}}}\right) =$$

31,622,400 s

8. Convert the speed 5.30 m/s to km/h.

$$\left(\frac{5.30 \cancel{\text{m}}}{1 \cancel{\text{s}}}\right)\left(\frac{60 \cancel{\text{s}}}{1 \cancel{\text{min}}}\right)\left(\frac{60 \cancel{\text{min}}}{1 \text{ h}}\right)\left(\frac{1 \text{ km}}{1000 \cancel{\text{m}}}\right) =$$

19.08 km/h

page 8

Solve the following problems.

9. a. 6.201 cm + 7.4 cm + 0.68 cm + 12.0 cm

```
   6.201 cm
   7.4   cm
   0.68  cm
 + 12.0  cm
 ----------
  26.281 cm
```

= 26.3 cm after rounding

b. 1.6 km + 1.62 m + 1200 cm

```
  1.6 km =   1600    m
  1.62 m =      1.62 m
1200  cm = +   12    m
           -----------
             1613.62 m
```

= 1600 m or 1.6 km after rounding

10. a. 10.8 g − 8.264 g

```
  10.8   g
−  8.264 g
 ---------
   2.536 g
```

= 2.5 g after rounding

b. 4.75 m − 0.4168 m

$$\begin{array}{r} 4.75\ \text{m} \\ \underline{-0.4168\ \text{m}} \\ 4.3332\ \text{m} \end{array}$$

= 4.33 m after rounding

11. a. 139 cm × 2.3 cm

320 cm^2 or 3.2×10^2 cm^2

b. 3.2145 km × 4.23 km

13.6 km^2

12. a. 13.78 g ÷ 11.3 mL

1.22 g/mL

b. 18.21 g ÷ 4.4 cm^3

4.1 g/cm^3

Section Review

1.1 Mathematics and Physics pages 3–10

page 10

13. Math Why are concepts in physics described with formulas?

The formulas are concise and can be used to predict new data.

14. Magnetism The force of a magnetic field on a charged, moving particle is given by $F = Bqv$, where F is the force in kg·m/s^2, q is the charge in A·s, and v is the speed in m/s. B is the strength of the magnetic field, measured in teslas, T. What is 1 tesla described in base units?

$F = Bqv$, so $B = \frac{F}{qv}$

$$T = \frac{\text{kg·m/s}^2}{(\text{A·s})(\text{m/s})} = \frac{\text{kg}}{\text{A·s}^2}$$

1 T = 1 kg/A·s^2

15. Magnetism A proton with charge 1.60×10^{-19} A·s is moving at 2.4×10^5 m/s through a magnetic field of 4.5 T. You want to find the force on the proton.

a. Substitute the values into the equation you will use. Are the units correct?

$F = Bqv$

$= (4.5\ \text{kg/A·s}^2)(1.60\times10^{-19}\ \text{A·s})(2.4\times10^5\ \text{m/s})$

Force will be measured in kg·m/s^2, which is correct.

b. The values are written in scientific notation, $m\times10^n$. Calculate the 10^n part of the equation to estimate the size of the answer.

$10^{-19}\times10^5 = 10^{-14}$; the answer will be about 20×10^{-14}, or 2×10^{-13}.

c. Calculate your answer. Check it against your estimate from part **b.**

1.7×10^{-13} kg·m/s^2

d. Justify the number of significant digits in your answer.

The least-precise value is 4.5 T, with 2 significant digits, so the answer is rounded to 2 significant digits.

16. Magnetism Rewrite $F = Bqv$ to find v in terms of F, q, and B.

$v = \frac{F}{Bq}$

17. Critical Thinking An accepted value for the acceleration due to gravity is 9.801 m/s^2. In an experiment with pendulums, you calculate that the value is 9.4 m/s^2. Should the accepted value be tossed out to accommodate your new finding? Explain.

No. The value 9.801 m/s^2 has been established by many other experiments, and to discard the finding you would have to explain why they were wrong. There are probably some factors affecting your calculation, such as friction and how precisely you can measure the different variables.

Section Review

1.2 Measurement pages 11–14

page 14

18. **Accuracy** Some wooden rulers do not start with 0 at the edge, but have it set in a few millimeters. How could this improve the accuracy of the ruler?

As the edge of the ruler gets worn away over time, the first millimeter or two of the scale would also be worn away if the scale started at the edge.

19. **Tools** You find a micrometer (a tool used to measure objects to the nearest 0.01 mm) that has been badly bent. How would it compare to a new, high-quality meterstick in terms of its precision? Its accuracy?

It would be more precise but less accurate.

20. **Parallax** Does parallax affect the precision of a measurement that you make? Explain.

No, it doesn't change the fineness of the divisions on its scale.

21. **Error** Your friend tells you that his height is 182 cm. In your own words, explain the range of heights implied by this statement.

His height would be between 181.5 and 182.5 cm. Precision of a measurement is one-half the smallest division on the instrument. The height 182 cm would range ± 0.5 cm.

22. **Precision** A box has a length of 18.1 cm and a width of 19.2 cm, and it is 20.3 cm tall.

a. What is its volume?

7.05×10^3 cm^3

b. How precise is the measure of length? Of volume?

nearest tenth of a cm; nearest 10 cm^3

c. How tall is a stack of 12 of these boxes?

243.6 cm

d. How precise is the measure of the height of one box? Of 12 boxes?

nearest tenth of a cm; nearest tenth of a cm

23. **Critical Thinking** Your friend states in a report that the average time required to circle a 1.5-mi track was 65.414 s. This was measured by timing 7 laps using a clock with a precision of 0.1 s. How much confidence do you have in the results of the report? Explain.

A result can never be more precise than the least precise measurement. The calculated average lap time exceeds the precision possible with the clock.

Practice Problems

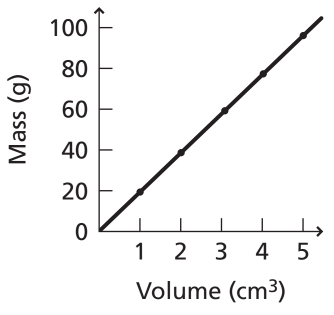
1.3 Graphing Data pages 15–19

page 18

24. The mass values of specified volumes of pure gold nuggets are given in **Table 1-4.**

Table 1-4	
Mass of Pure Gold Nuggets	
Volume (cm^3)	Mass (g)
1.0	19.4
2.0	38.6
3.0	58.1
4.0	77.4
5.0	96.5

a. Plot mass versus volume from the values given in the table and draw the curve that best fits all points.



b. Describe the resulting curve.

a straight line

c. According to the graph, what type of relationship exists between the mass of the pure gold nuggets and their volume?

The relationship is linear.

d. What is the value of the slope of this graph? Include the proper units.

$$\text{slope} = \frac{\Delta y}{\Delta x} = \frac{96.5\ \text{g} - 19.4\ \text{g}}{5.0\ \text{cm}^3 - 1.0\ \text{cm}^3}$$

$$= 19.3\ \text{g/cm}^3$$

e. Write the equation showing mass as a function of volume for gold.

$m = (19.3\ \text{g/cm}^3)V$

f. Write a word interpretation for the slope of the line.

The mass for each cubic centimeter of pure gold is 19.3 g.

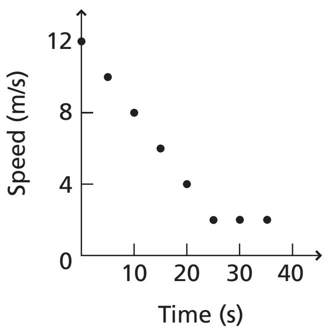
Section Review

1.3 Graphing Data pages 15–19

page 19

25. Make a Graph Graph the following data. Time is the independent variable.

Time (s)	0	5	10	15	20	25	30	35
Speed (m/s)	12	10	8	6	4	2	2	2



26. Interpret a Graph What would be the meaning of a nonzero *y*-intercept to a graph of total mass versus volume?

There is a nonzero total mass when the volume of the material is zero. This could happen if the mass value includes the material's container.

27. Predict Use the relation illustrated in Figure 1-16 to determine the mass required to stretch the spring 15 cm.

16 g

28. Predict Use the relation in Figure 1-18 to predict the current when the resistance is 16 ohms.

7.5 A

29. Critical Thinking In your own words, explain the meaning of a shallower line, or a smaller slope than the one in Figure 1-16, in the graph of stretch versus total mass for a different spring.

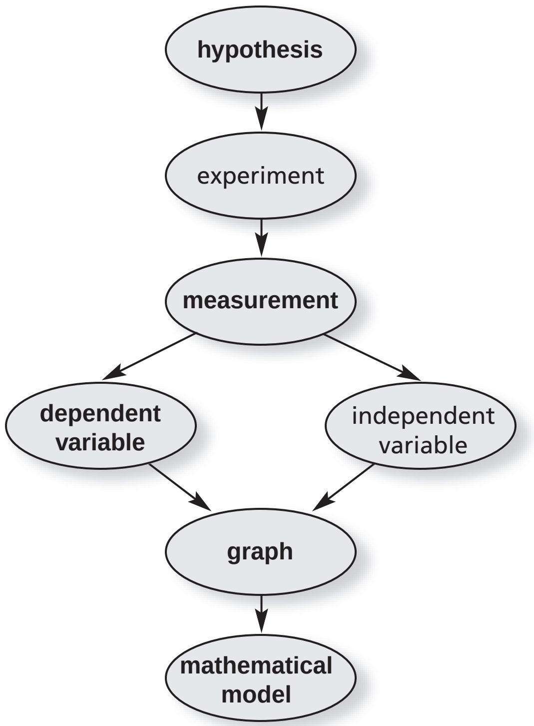
The spring whose line has a smaller slope is stiffer, and therefore requires more mass to stretch it one centimeter.

Chapter Assessment

Concept Mapping

page 24

30. Complete the following concept map using the following terms: *hypothesis, graph, mathematical model, dependent variable, measurement.*



Mastering Concepts

page 24

31. Describe a scientific method. (1.1)

Identify a problem; gather information about it by observing and experimenting; analyze the information to arrive at an answer.

32. Why is mathematics important to science? (1.1)

Mathematics allows you to be quantitative, to say "how fast," not just "fast."

33. What is the SI system? (1.1)

The International System of Units, or SI, is a base 10 system of measurement that is the standard in science. The base units are the meter, kilogram, second, kelvin, mole, ampere, and candela.

34. How are base units and derived units related? (1.1)

The derived units are combinations of the base units.

35. Suppose your lab partner recorded a measurement as 100 g. (1.1)

a. Why is it difficult to tell the number of significant digits in this measurement?

Zeros are necessary to indicate the magnitude of the value, but there is no way of knowing whether or not the instrument used to measure the values actually measured the zeros. The zeros may serve only to locate the 1.

b. How can the number of significant digits in such a number be made clear?

Write the number in scientific notation, including only the significant digits.

36. Give the name for each of the following multiples of the meter. (1.1)

a. $\frac{1}{100}$ m

centimeter

b. $\frac{1}{1000}$ m

millimeter

c. 1000 m

kilometer

37. To convert 1.8 h to minutes, by what conversion factor should you multiply? (1.1)

$\frac{\textbf{60 min}}{\textbf{1 h}}$**, because the units will cancel correctly.**

38. Solve each problem. Give the correct number of significant digits in the answers. (1.1)

a. 4.667×10^4 g + 3.02×10^5 g

3.49×10^5 g

b. $(1.70\times10^2$ J$)$ ÷ $(5.922\times10^{-4}$ cm$^3)$

2.87×10^5 J/cm^3

39. What determines the precision of a measurement? (1.2)

the precision of a measuring device, which is limited by the finest division on its scale

40. How does the last digit differ from the other digits in a measurement? (1.2)

The final digit is estimated.

41. A car's odometer measures the distance from home to school as 3.9 km. Using string on a map, you find the distance to be 4.2 km. Which answer do you think is more accurate? What does *accurate* mean? (1.2)

The most accurate measure is the measure closest to the actual distance. The odometer is probably more accurate as it actually covered the distance. The map is a model made from measurements, so your measurements from the map are more removed from the real distance.

42. How do you find the slope of a linear graph? (1.3)

The slope of a linear graph is the ratio of the vertical change to the horizontal change, or rise over run.

43. For a driver, the time between seeing a stoplight and stepping on the brakes is called reaction time. The distance traveled during this time is the reaction distance. Reaction distance for a given driver and vehicle depends linearly on speed. (1.3)

a. Would the graph of reaction distance versus speed have a positive or a negative slope?

Positive. As speed increases, reaction distance increases.

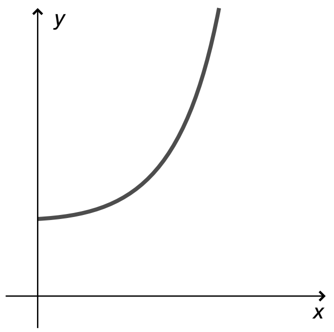
b. A driver who is distracted has a longer reaction time than a driver who is not. Would the graph of reaction distance versus speed for a distracted driver have a larger or smaller slope than for a normal driver? Explain.

Larger. The driver who was distracted would have a longer reaction time and thus a greater reaction distance at a given speed.

44. During a laboratory experiment, the temperature of the gas in a balloon is varied and the volume of the balloon is measured. Which quantity is the independent variable? Which quantity is the dependent variable? (1.3)

Temperature is the independent variable; volume is the dependent variable.

45. What type of relationship is shown in **Figure 1-20?** Give the general equation for this type of relation. (1.3)



■ **Figure 1-20**

quadratic; $y = ax^2 + bx + c$

46. Given the equation $F = mv^2/R$, what relationship exists between each of the following? (1.3)

a. *F* and *R*

inverse relationship

b. *F* and *m*

linear relationship

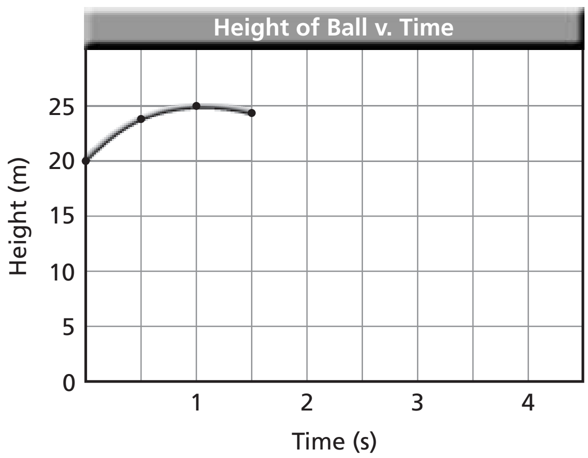
c. *F* and *v*

quadratic relationship

Applying Concepts

pages 25–26

47. **Figure 1-21** gives the height above the ground of a ball that is thrown upward from the roof of a building, for the first 1.5 s of its trajectory. What is the ball's height at $t = 0$? Predict the ball's height at $t = 2$ s and at $t = 5$ s.



■ **Figure 1-21**

When $t = 0$ and $t = 2$, the ball's height will be about 20 m. When $t = 5$, the ball will have landed on the ground so the height will be 0 m.

48. Is a scientific method one set of clearly defined steps? Support your answer.

There is no definite order of specific steps. However, whatever approach is used, it always includes close observation, controlled experimentation, summarizing, checking, and rechecking.

49. Explain the difference between a scientific theory and a scientific law.

A scientific law is a rule of nature, where a scientific theory is an explanation of the scientific law based on observation. A theory explains why something happens; a law describes what happens.

50. **Density** The density of a substance is its mass per unit volume.

a. Give a possible metric unit for density.

possible answers include g/cm^3 or kg/m^3

b. Is the unit for density a base unit or a derived unit?

derived unit

51. What metric unit would you use to measure each of the following?

a. the width of your hand

cm

b. the thickness of a book cover

mm

c. the height of your classroom

m

d. the distance from your home to your classroom

km

52. **Size** Make a chart of sizes of objects. Lengths should range from less than 1 mm to several kilometers. Samples might include the size of a cell, the distance light travels in 1 s, and the height of a room.

sample answer:
radius of the atom, 5×10^{-11} m; virus, 10^{-7} m; thickness of paper, 0.1 mm; width of paperback book, 10.7 cm; height of a door, 1.8 m; width of town, 7.8 km; radius of Earth, 6×10^{6} m; distance to the Moon, 4×10^{8} m

53. **Time** Make a chart of time intervals. Sample intervals might include the time between heartbeats, the time between presidential elections, the average lifetime of a human, and the age of the United States. Find as many very short and very long examples as you can.

sample answer:
half-life of polonium-194, 0.7 s; time between heartbeats, 0.8 s; time to walk between physics class and math class, 2.4 min; length of school year, 180 days; time between elections for the U.S. House of Representatives, 2 years; time between U.S. presidential elections, 4 years; age of the United States, (about) 230 years

54. **Speed of Light** Two students measure the speed of light. One obtains $(3.001 \pm 0.001)\times10^8$ m/s; the other obtains $(2.999 \pm 0.006)\times10^8$ m/s.

a. Which is more precise?

$(3.001 \pm 0.001)\times10^8$ m/s

b. Which is more accurate?

$(2.999 \pm 0.006)\times10^8$ m/s

55. You measure the dimensions of a desk as 132 cm, 83 cm, and 76 cm. The sum of these measures is 291 cm, while the product is 8.3×10^5 cm^3. Explain how the significant digits were determined in each case.

In addition and subtraction, you ask what place the least precise measure is known to: in this case, to the nearest cm. So the answer is rounded to the nearest cm. In multiplication and division, you look at the number of significant digits in the least precise answer: in this case, 2. So the answer is rounded to 2 significant digits.

56. **Money** Suppose you receive $5.00 at the beginning of a week and spend $1.00 each day for lunch. You prepare a graph of the amount you have left at the end of each day for one week. Would the slope of this graph be positive, zero, or negative? Why?

negative, because the change in vertical distance is negative for a positive change in horizontal distance

57. Data are plotted on a graph, and the value on the y-axis is the same for each value of the independent variable. What is the slope? Why? How does y depend on x?

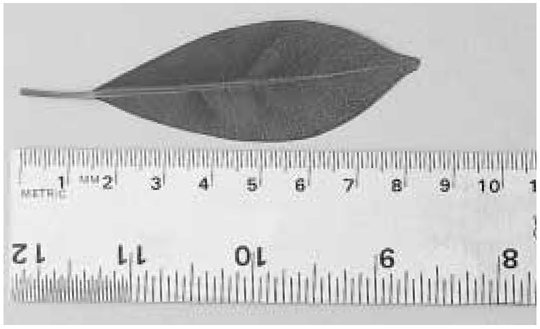
Zero. The change in vertical distance is zero. y does not depend on x.

58. Driving The graph of braking distance versus car speed is part of a parabola. Thus, the equation is written $d = av^2 + bv + c$. The distance, d, has units in meters, and velocity, v, has units in meters/second. How could you find the units of a, b, and c? What would they be?

The units in each term of the equation must be in meters because distance, d, is measured in meters.
$av^2 = a(\text{m/s})^2$, so a is in s^2/m;

$bv = b(\text{m/s})$, so b is in s^{-1}.

59. How long is the leaf in **Figure 1-22?** Include the uncertainty in your measurement.



■ **Figure 1-22**

8.3 cm ± 0.05 cm, or 83 mm ± 0.5 mm

60. The masses of two metal blocks are measured. Block A has a mass of 8.45 g and block B has a mass of 45.87 g.

a. How many significant digits are expressed in these measurements?

A: three; B: four

b. What is the total mass of block A plus block B?

54.32 g

c. What is the number of significant digits for the total mass?

four

d. Why is the number of significant digits different for the total mass and the individual masses?

When adding measurements, the precision matters: both masses are known to the nearest hundredth of a gram, so the total should be given to the nearest hundredth of a gram. Significant digits sometimes are gained when adding.

61. History Aristotle said that the speed of a falling object varies inversely with the density of the medium through which it falls.

a. According to Aristotle, would a rock fall faster in water (density 1000 kg/m^3), or in air (density 1 kg/m^3)?

Lower density means faster speed, so the rock falls faster in air.

b. How fast would a rock fall in a vacuum? Based on this, why would Aristotle say that there could be no such thing as a vacuum?

Because a vacuum would have a zero density, the rock should fall infinitely fast. Nothing can fall that fast.

62. Explain the difference between a hypothesis and a scientific theory.

A scientific theory has been tested and supported many times before it becomes accepted. A hypothesis is an idea about how things might work—it has much less support.

63. Give an example of a scientific law.

Newton's laws of motion, law of conservation of energy, law of conservation of charge, law of reflection

64. What reason might the ancient Greeks have had not to question the hypothesis that heavier objects fall faster than lighter objects? *Hint: Did you ever question which falls faster?*

Air resistance affects many light objects. Without controlled experiments, their everyday observations told them that heavier objects did fall faster.

65. **Mars** Explain what observations led to changes in scientists' ideas about the surface of Mars.

As telescopes improved and later probes were sent into space, scientists gained more information about the surface. When the information did not support old hypotheses, the hypotheses changed.

66. A graduated cylinder is marked every mL. How precise a measurement can you make with this instrument?

±0.5 mL

Mastering Problems

pages 26–28

1.1 Mathematics and Physics

67. Convert each of the following measurements to meters.

a. 42.3 cm

0.423 m

b. 6.2 pm

6.2×10^{-12} m

c. 21 km

2.1×10^{4} m

d. 0.023 mm

2.3×10^{-5} m

e. 214 μm

2.14×10^{-4} m

f. 57 nm

5.7×10^{-8} m

68. Add or subtract as indicated.

a. 5.80×10^{9} s + 3.20×10^{8} s

6.12×10^{9} s

b. 4.87×10^{-6} m − 1.93×10^{-6} m

2.94×10^{-6} m

c. 3.14×10^{-5} kg + 9.36×10^{-5} kg

1.250×10^{-4} kg

d. 8.12×10^{7} g − 6.20×10^{6} g

7.50×10^{7} g

69. Rank the following mass measurements from least to greatest: 11.6 mg, 1021 μg, 0.000006 kg, 0.31 mg.

0.31 mg, 1021 μg, 0.000006 kg, 11.6 mg

70. State the number of significant digits in each of the following measurements.

a. 0.00003 m

1

b. 64.01 fm

4

c. 80.001 m

5

d. 0.720 μg

3

e. 2.40×10^{6} kg

3

f. 6×10^{8} kg

1

g. 4.07×10^{16} m

3

71. Add or subtract as indicated.

a. 16.2 m + 5.008 m + 13.48 m

34.7 m

b. 5.006 m + 12.0077 m + 8.0084 m

25.022 m

c. 78.05 cm^2 − 32.046 cm^2

46.00 cm^2

d. 15.07 kg − 12.0 kg

3.1 kg

72. Multiply or divide as indicated.

a. $(6.2\times10^{18}\ \text{m})(4.7\times10^{-10}\ \text{m})$

$2.9\times10^{9}\ \text{m}^2$

b. $(5.6\times10^{-7}\ \text{m})/(2.8\times10^{-12}\ \text{s})$

$2.0\times10^{5}\ \text{m/s}$

c. $(8.1\times10^{-4}\ \text{km})(1.6\times10^{-3}\ \text{km})$

$1.3\times10^{-6}\ \text{km}^2$

d. $(6.5\times10^{5}\ \text{kg})/(3.4\times10^{3}\ \text{m}^3)$

$1.9\times10^{2}\ \text{kg/m}^3$

73. Gravity The force due to gravity is $F = mg$ where $g = 9.80\ \text{m/s}^2$.

a. Find the force due to gravity on a 41.63-kg object.

$408\ \text{kg}\cdot\text{m/s}^2$

b. The force due to gravity on an object is $632\ \text{kg}\cdot\text{m/s}^2$. What is its mass?

64.5 kg

74. Dimensional Analysis Pressure is measured in pascals, where $1\ \text{Pa} = 1\ \text{kg/m}\cdot\text{s}^2$. Will the following expression give a pressure in the correct units?

$$\frac{(0.55\ \text{kg})(2.1\ \text{m/s})}{9.8\ \text{m/s}^2}$$

No; it is in kg/s^3

1.2 Measurement

75. A water tank has a mass of 3.64 kg when it is empty and a mass of 51.8 kg when it is filled to a certain level. What is the mass of the water in the tank?

48.2 kg

76. The length of a room is 16.40 m, its width is 4.5 m, and its height is 3.26 m. What volume does the room enclose?

$2.4\times10^{2}\ \text{m}^3$

77. The sides of a quadrangular plot of land are 132.68 m, 48.3 m, 132.736 m, and 48.37 m. What is the perimeter of the plot?

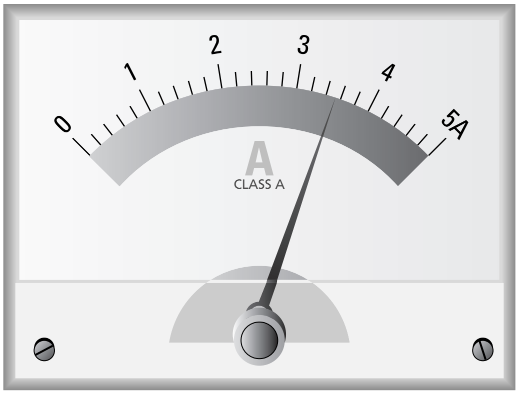
362.1 m

78. How precise a measurement could you make with the scale shown in **Figure 1-23?**

■ **Figure 1-23**

±0.5 g

79. Give the measure shown on the meter in **Figure 1-24** as precisely as you can. Include the uncertainty in your answer.



■ **Figure 1-24**

3.6 ± 0.1 A

80. Estimate the height of the nearest door frame in centimeters. Then measure it. How accurate was your estimate? How precise was your estimate? How precise was your measurement? Why are the two precisions different?

A standard residential doorframe height is 80 inches, which is about 200 cm. The precision depends on the measurement instrument used.

81. Base Units Give six examples of quantities you might measure in a physics lab. Include the units you would use.

Sample: distance, cm; volume, mL; mass, g; current, A; time, s; temperature, °C

82. Temperature The temperature drops from 24°C to 10°C in 12 hours.

a. Find the average temperature change per hour.

1.2°C/h

b. Predict the temperature in 2 more hours if the trend continues.

8°C

c. Could you accurately predict the temperature in 24 hours?

No. Temperature is unlikely to continue falling sharply and steadily that long.

1.3 Graphing Data

83. Figure 1-25 shows the masses of three substances for volumes between 0 and 60 cm^3.

a. What is the mass of 30 cm^3 of each substance?

(a) 80 g, (b) 260 g, (c) 400 g

b. If you had 100 g of each substance, what would be their volumes?

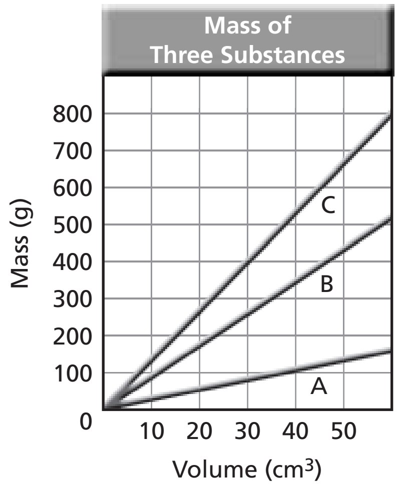
(a) 36 cm^3, (b) 11 cm^3, (c) 7 cm^3

c. In one or two sentences, describe the meaning of the slopes of the lines in this graph.

The slope represents the increased mass of each additional cubic centimeter of the substance.

d. What is the *y*-intercept of each line? What does it mean?

The *y*-intercept is (0,0). It means that when $V = 0$ cm^3, there is none of the substance present ($m = 0$ g).

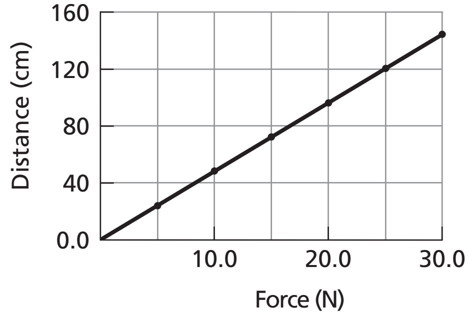


■ **Figure 1-25**

84. During a class demonstration, a physics instructor placed a mass on a horizontal table that was nearly frictionless. The instructor then applied various horizontal forces to the mass and measured the distance it traveled in 5 seconds for each force applied. The results of the experiment are shown in **Table 1-5.**

Table 1-5 Distance Traveled with Different Forces	
Force (N)	**Distance (cm)**
5.0	24
10.0	49
15.0	75
20.0	99
25.0	120
30.0	145

a. Plot the values given in the table and draw the curve that best fits all points.



b. Describe the resulting curve.

a straight line

c. Use the graph to write an equation relating the distance to the force.

$d = 4.9F$

d. What is the constant in the equation? Find its units.

The constant is 4.9 and has units cm/N.

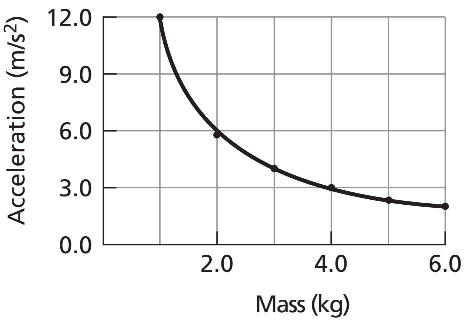
e. Predict the distance traveled when a 22.0-N force is exerted on the object for 5 s.

108 cm or 110 cm using 2 significant digits

85. The physics instructor from the previous problem changed the procedure. The mass was varied while the force was kept constant. Time and distance were measured, and the acceleration of each mass was calculated. The results of the experiment are shown in **Table 1-6.**

Table 1-6	
Acceleration of Different Masses	
Mass (kg)	**Acceleration (m/s^2)**
1.0	12.0
2.0	5.9
3.0	4.1
4.0	3.0
5.0	2.5
6.0	2.0

a. Plot the values given in the table and draw the curve that best fits all points.



b. Describe the resulting curve.

a hyperbola

c. According to the graph, what is the relationship between mass and the acceleration produced by a constant force?

Acceleration varies inversely with mass.

d. Write the equation relating acceleration to mass given by the data in the graph.

$a = \frac{12}{m}$

e. Find the units of the constant in the equation.

kg·m/s^2

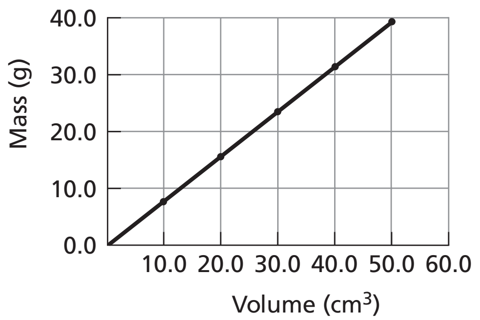
f. Predict the acceleration of an 8.0-kg mass.

1.5 m/s^2

86. During an experiment, a student measured the mass of 10.0 cm^3 of alcohol. The student then measured the mass of 20.0 cm^3 of alcohol. In this way, the data in **Table 1-7** were collected.

Table 1-7	
The Mass Values of Specific Volumes of Alcohol	
Volume (cm^3)	**Mass (g)**
10.0	7.9
20.0	15.8
30.0	23.7
40.0	31.6
50.0	39.6

a. Plot the values given in the table and draw the curve that best fits all the points.



b. Describe the resulting curve.

a straight line

c. Use the graph to write an equation relating the volume to the mass of the alcohol.

$\boldsymbol{m = 0.79V}$

d. Find the units of the slope of the graph. What is the name given to this quantity?

g/cm^3; density

e. What is the mass of 32.5 cm^3 of alcohol?

25.7 g

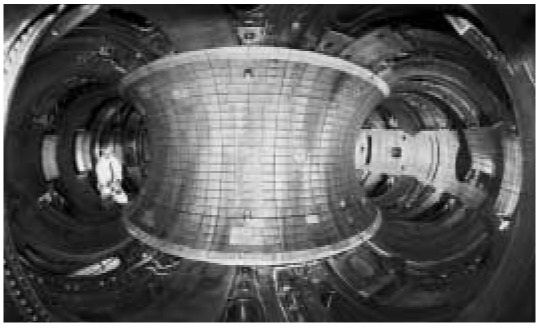
Mixed Review

page 28

87. Arrange the following numbers from most precise to least precise
0.0034 m 45.6 m 1234 m

0.0034 m, 45.6 m, 1234 m

88. **Figure 1-26** shows the toroidal (doughnut-shaped) interior of the now-dismantled Tokamak Fusion Test Reactor. Explain why a width of 80 m would be an unreasonable value for the width of the toroid. What would be a reasonable value?



■ **Figure 1-26**

80 meters is equivalent to about 260 feet, which would be very large. 10 meters would be a more reasonable value.

89. You are cracking a code and have discovered the following conversion factors: 1.23 longs = 23.0 mediums, and 74.5 mediums = 645 shorts. How many shorts are equal to one long?

$$1\text{ long}\left(\frac{23.0\text{ med}}{1.23\text{ long}}\right)\left(\frac{645\text{ short}}{74.5\text{ med}}\right) = 162\text{ shorts}$$

90. You are given the following measurements of a rectangular bar: length = 2.347 m, thickness = 3.452 cm, height = 2.31 mm, mass = 1659 g. Determine the volume, in cubic meters, and density, in g/cm^3, of the beam. Express your results in proper form.

volume = 1.87×10^{-4} m^3, or 187 cm^3; density = 8.87 g/cm^3

91. A drop of water contains 1.7×10^{21} molecules. If the water evaporated at the rate of one million molecules per second, how many years would it take for the drop to completely evaporate?

$$\frac{1.7\times10^{21}\text{ molecules}}{\left(\frac{1{,}000{,}000\text{ molecules}}{1\text{ s}}\right)} = 1.7\times10^{15}\text{ s}$$

$$(1.7\times10^{15}\text{ s})\left(\frac{1\text{ h}}{3600\text{ s}}\right)\left(\frac{1\text{ day}}{24\text{ h}}\right)\left(\frac{1\text{ y}}{365\text{ days}}\right) =$$

$$5.4\times10^{7}\text{ y}$$

92. A 17.6-gram sample of metal is placed in a graduated cylinder containing 10.0 cm^3 of water. If the water level rises to 12.20 cm^3, what is the density of the metal?

$$\text{density} = \frac{m}{V}$$

$$= \frac{17.6\text{ g}}{12.20\text{ cm}^3 - 10.0\text{ cm}^3}$$

$$= 8.00\text{ g/cm}^3$$

Thinking Critically

page 28

93. **Apply Concepts** It has been said that fools can ask more questions than the wise can answer. In science, it is frequently the case that one wise person is needed to ask the right question rather than to answer it. Explain.

The “right” question is one that points to fruitful research and to other questions that can be answered.

94. **Apply Concepts** Find the approximate mass of water in kilograms needed to fill a container that is 1.40 m long and 0.600 m wide to a depth of 34.0 cm. Report your result to one significant digit. (Use a reference source to find the density of water.)

V_W = (140 cm)(60.0 cm)(34.0 cm) = 285,600 cm^3. Because the density of water is 1.00 g/cm^3, the mass of water in kilograms is 286 kg.

95. **Analyze and Conclude** A container of gas with a pressure of 101 kPa has a volume of 324 cm^3 and a mass of 4.00 g. If the pressure is increased to 404 kPa, what is the density of the gas? Pressure and volume are inversely proportional.

Pressure and volume are inversely proportional. Since the pressure is 4 times greater, the volume will be $\frac{1}{4}$ of the original volume.

$$\frac{324\ \text{cm}^3}{4} = 81.0\ \text{cm}^3$$

$$\frac{4.00\ \text{g}}{81.0\ \text{cm}^3} = 0.0494\ \text{g/cm}^3$$

96. **Design an Experiment** How high can you throw a ball? What variables might affect the answer to this question?

mass of ball, footing, practice, and conditioning

97. **Calculate** If the Sun suddenly ceased to shine, how long would it take Earth to become dark? (You will have to look up the speed of light in a vacuum and the distance from the Sun to Earth.) How long would it take the surface of Jupiter to become dark?

$$t_E = \frac{d_E}{v} = \frac{1.496\times10^{11}\ \text{m}}{3.00\times10^{8}\ \text{m/s}}$$

$$= 499\ \text{s} = 8.31\ \text{min}$$

$$t_J = \frac{d_J}{v} = \frac{7.78\times10^{11}\ \text{m}}{3.00\times10^{8}\ \text{m/s}}$$

$$= 2593\ \text{s} = 43.2\ \text{min}$$

Writing in Physics

page 28

98. Research and describe a topic in the history of physics. Explain how ideas about the topic changed over time. Be sure to include the contributions of scientists and to evaluate the impact of their contributions on scientific thought and the world outside the laboratory.

Answers will vary.

99. Explain how improved precision in measuring time would have led to more accurate predictions about how an object falls.

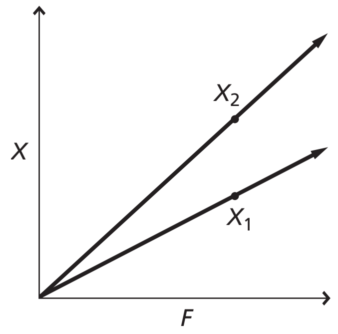
Answers will vary. For example, students might suggest that improved precision can lead to better observations.

Challenge Problem

page 17

An object is suspended from spring 1, and the spring's elongation (the distance it stretches) is X_1. Then the same object is removed from the first spring and suspended from a second spring. The elongation of spring 2 is X_2. X_2 is greater than X_1.

1. On the same axes, sketch the graphs of the mass versus elongation for both springs.



2. Is the origin included in the graph? Why or why not?

Yes; the origin corresponds to 0 elongation when the force is 0.

3. Which slope is steeper?

The slope for X_2 is steeper.

4. At a given mass, $X_2 = 1.6\ X_1$. If X_2 = 5.3 cm, what is X_1?

$$X_2 = 1.6X_1$$

$$5.3\ \text{cm} = 1.6X_1$$

$$3.3\ \text{cm} = X_1$$

CHAPTER

2 Representing Motion

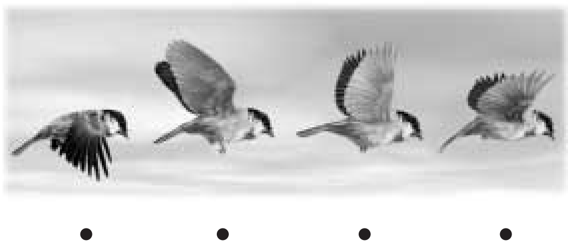
Section Review

2.1 Picturing Motion pages 31–33

page 33

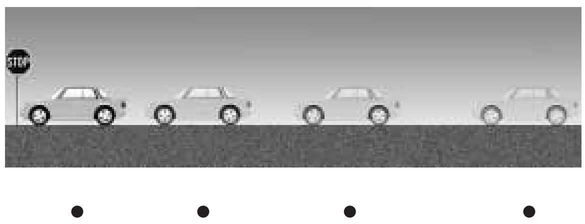
1. **Motion Diagram of a Runner** Use the particle model to draw a motion diagram for a bike rider riding at a constant pace.

2. **Motion Diagram of a Bird** Use the particle model to draw a simplified motion diagram corresponding to the motion diagram in **Figure 2-4** for a flying bird. What point on the bird did you choose to represent it?



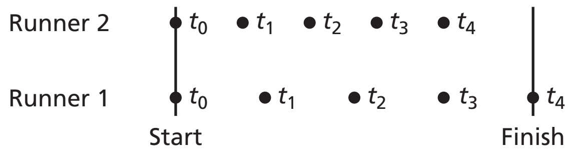
■ **Figure 2-4**

3. **Motion Diagram of a Car** Use the particle model to draw a simplified motion diagram corresponding to the motion diagram in **Figure 2-5** for a car coming to a stop at a stop sign. What point on the car did you use to represent it?



■ **Figure 2-5**

4. **Critical Thinking** Use the particle model to draw motion diagrams for two runners in a race, when the first runner crosses the finish line as the other runner is three-fourths of the way to the finish line.



Section Review

2.2 Where and When? pages 34–37

page 37

5. **Displacement** The particle model for a car traveling on an interstate highway is shown below. The starting point is shown.

Make a copy of the particle model, and draw a vector to represent the displacement of the car from the starting time to the end of the third time interval.

6. **Displacement** The particle model for a boy walking to school is shown below.

Make a copy of the particle model, and draw vectors to represent the displacement between each pair of dots.

7. **Position** Two students compared the position vectors they each had drawn on a motion diagram to show the position of a moving object at the same time. They found that their vectors did not point in the same direction. Explain.

   A position vector goes from the origin to the object. When the origins are different, the position vectors are different. On the other hand, a displacement vector has nothing to do with the origin.

8. **Critical Thinking** A car travels straight along the street from the grocery store to the post office. To represent its motion you use a coordinate system with its origin at the grocery store and the direction the car is moving in as the positive direction. Your friend uses a coordinate system with its origin at the post office and the opposite direction as the positive direction. Would the two of you agree on the car's position? Displacement? Distance? The time interval the trip took? Explain.

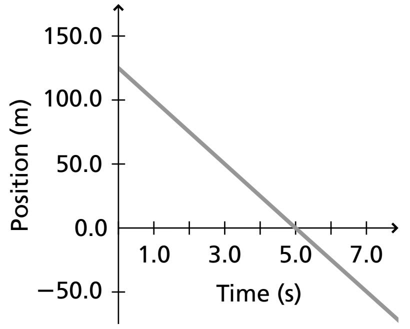
   The two students should agree on the displacement, distance, and time interval for the trip, because these three quantities are independent of where the origin of the coordinate system is placed. The two students would not agree on the car's position, because the position is measured from the origin of the coordinate system to the location of the car.

Practice Problems

2.3 Position-Time Graphs pages 38–42

page 39

For problems 9–11, refer to ***Figure 2-13.***

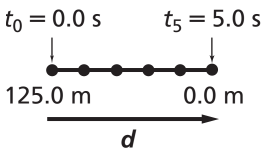


■ **Figure 2-13**

9. Describe the motion of the car shown by the graph.

   The car begins at a position of 125.0 m and moves toward the origin, arriving at the origin 5.0 s after it begins moving. The car continues beyond the origin.

10. Draw a motion diagram that corresponds to the graph.



11. Answer the following questions about the car's motion. Assume that the positive *d*-direction is east and the negative *d*-direction is west.

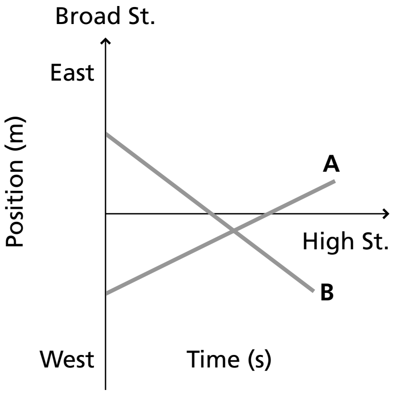
    a. When was the car 25.0 m east of the origin?

    at 4.0 s

    b. Where was the car at 1.0 s?

    100.0 m

12. Describe, in words, the motion of the two pedestrians shown by the lines in **Figure 2-14.** Assume that the positive direction is east on Broad Street and the origin is the intersection of Broad and High Streets.



■ **Figure 2-14**

Pedestrian A starts west of High Street and walks east (the positive direction). Pedestrian B begins east of High Street and walks west (the negative direction). Sometime after B crosses High Street, A and B pass each other. Sometime after they pass, Pedestrian A crosses High Street.

13. Odina walked down the hall at school from the cafeteria to the band room, a distance of 100.0 m. A class of physics students recorded and graphed her position every 2.0 s, noting that she moved 2.6 m every 2.0 s. When was Odina in the following positions?

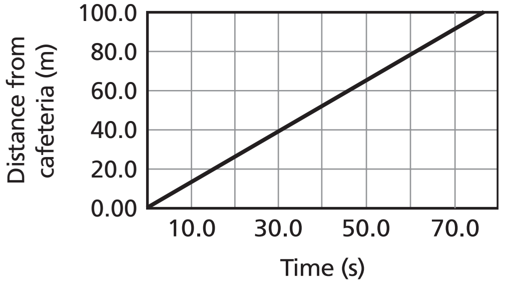
a. 25.0 m from the cafeteria

19 s

b. 25.0 m from the band room

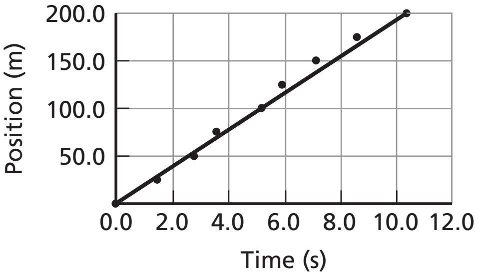
58 s

c. Create a graph showing Odina's motion.



page 41

For problems 14–17, refer to the figure in Example Problem 2.



■ **Example Problem 2 Figure**

14. What event occurred at $t = 0.0$ s?

Runner A passed the origin.

15. Which runner was ahead at $t = 48.0$ s?

runner B

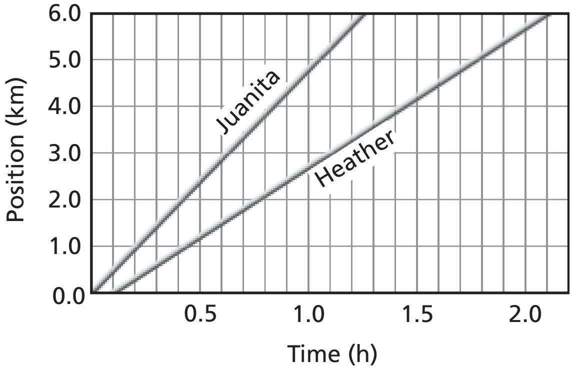
16. When runner A was at 0.0 m, where was runner B?

at −50.0 m

17. How far apart were runners A and B at $t = 20.0$ s?

approximately 30 m

18. Juanita goes for a walk. Sometime later, her friend Heather starts to walk after her. Their motions are represented by the position-time graphs in **Figure 2-16.**



■ **Figure 2-16**

a. How long had Juanita been walking when Heather started her walk?

6.0 min

b. Will Heather catch up to Juanita? How can you tell?

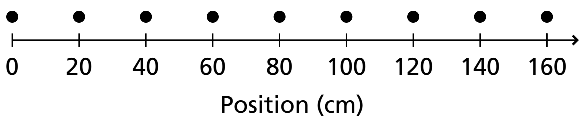
No. The lines representing Juanita's and Heather's motions get farther apart as time increases. The lines will not intersect.

Section Review

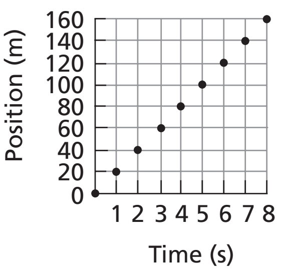
2.3 Position-Time Graphs pages 38–42

page 42

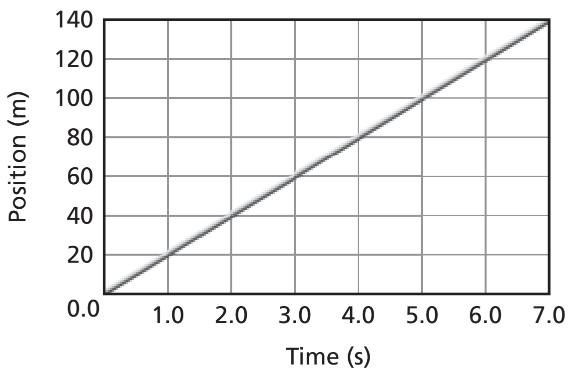
19. Position-Time Graph From the particle model in **Figure 2-17** of a baby crawling across a kitchen floor, plot a position-time graph to represent his motion. The time interval between successive dots is 1 s.



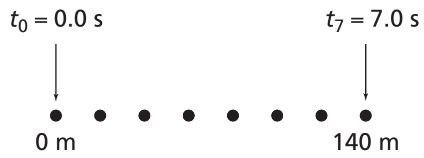
■ **Figure 2-17**



20. Motion Diagram Create a particle model from the position-time graph of a hockey puck gliding across a frozen pond in **Figure 2-18.**



■ **Figure 2-18**



For problems 21–23, refer to Figure 2-18.

21. Time Use the position-time graph of the hockey puck to determine when it was 10.0 m beyond the origin.

0.5 s

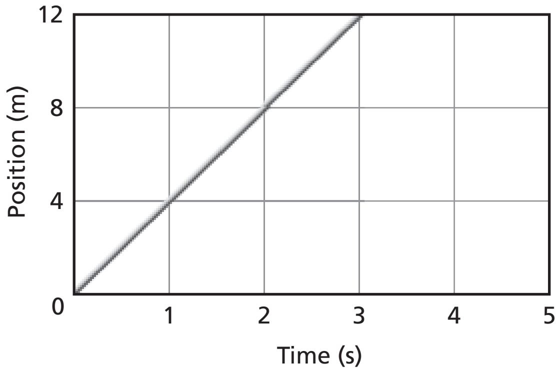
22. Distance Use the position-time graph of the hockey puck to determine how far it moved between 0.0 s and 5.0 s.

100 m

23. Time Interval Use the position-time graph for the hockey puck to determine how much time it took for the puck to go from 40 m beyond the origin to 80 m beyond the origin.

2.0 s

24. Critical Thinking Look at the particle model and position-time graph shown in **Figure 2-19.** Do they describe the same motion? How do you know? Do not confuse the position coordinate system in the particle model with the horizontal axis in the position-time graph. The time intervals in the particle model are 2 s.



■ **Figure 2-19**

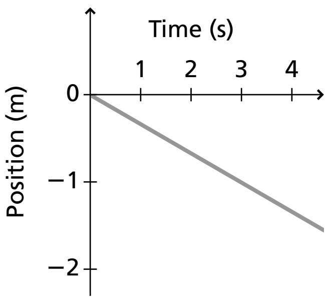
No, they don't describe the same motion. Although both objects are traveling in the positive direction, one is moving more quickly than the other. Students can cite a number of different specific examples from the graph and particle model to back this up.

Practice Problems

2.4 How Fast? pages 43–47

page 45

25. The graph in **Figure 2-22** describes the motion of a cruise ship during its voyage through calm waters. The positive *d*-direction is defined to be south.



■ **Figure 2-22**

a. What is the ship's average speed?

Using the points (0.0 s, 0.0 m) and (3.0 s, −1.0 m)

$$\bar{v} = \left|\frac{\Delta d}{\Delta t}\right|$$
$$= \left|\frac{d_2 - d_1}{t_2 - t_1}\right|$$
$$= \left|\frac{-1.0\text{ m} - 0.0\text{ m}}{3.0\text{ s} - 0.0\text{ s}}\right|$$
$$= \left|-0.33\text{ m/s}\right|$$
$$= 0.33\text{ m/s}$$

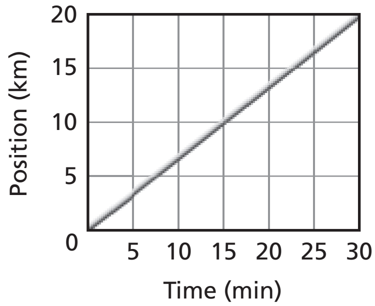
b. What is its average velocity?

The average velocity is the slope of the line, including the sign, so it is −0.33 m/s or 0.33 m/s north.

26. Describe, in words, the motion of the cruise ship in the previous problem.

The ship is moving to the north at a speed of 0.33 m/s.

27. The graph in **Figure 2-23** represents the motion of a bicycle. Determine the bicycle's average speed and average velocity, and describe its motion in words.



■ **Figure 2-23**

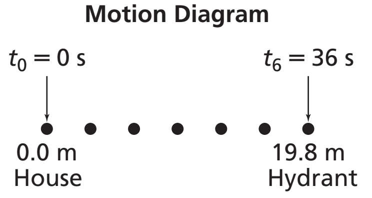
Because the bicycle is moving in the positive direction, the average speed and average velocity are the same. Using the points (0.0 min, 0.0 km) and (15.0 min, 10.0 km),

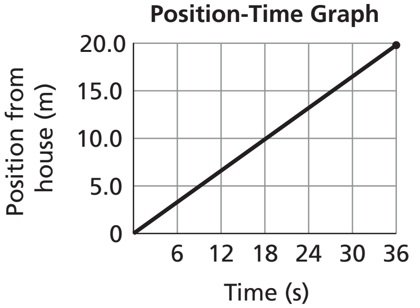
$$\bar{v} = \left|\frac{\Delta d}{\Delta t}\right|$$
$$= \left|\frac{d_2 - d_1}{t_2 - t_1}\right|$$
$$= \left|\frac{10.0\text{ km} - 0.0\text{ km}}{15.0\text{ min} - 0.0\text{ min}}\right|$$
$$= 0.67\text{ km/min}$$

$\bar{v}$ = 0.67 km/min in the positive direction

The bicycle is moving in the positive direction at a speed of 0.67 km/min.

28. When Marilyn takes her pet dog for a walk, the dog walks at a very consistent pace of 0.55 m/s. Draw a motion diagram and position-time graph to represent Marilyn's dog walking the 19.8-m distance from in front of her house to the nearest fire hydrant.





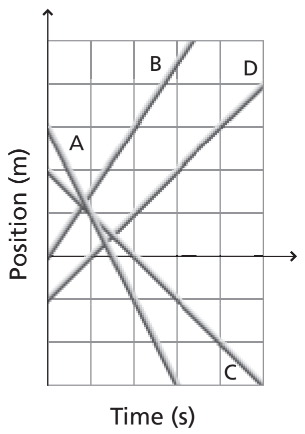
Section Review

2.4 How Fast? pages 43–47

page 47

For problems 29–31, refer to ***Figure 2-25.***

29. Average Speed Rank the position-time graphs according to the average speed of the object, from greatest average speed to least average speed. Specifically indicate any ties.



■ **Figure 2-25**

For speed use the absolute value, therefore A, B, C = D

$Slope_A = -2$

$Slope_B = \frac{3}{2}$

$Slope_C = -1$

$Slope_D = 1$

30. Average Velocity Rank the graphs according to average velocity, from greatest average velocity to least average velocity. Specifically indicate any ties.

B, D, C, A

$Slope_A = -2$

$Slope_B = \frac{3}{2}$

$Slope_C = -1$

$Slope_D = 1$

31. Initial Position Rank the graphs according to the object's initial position, from most positive position to most negative position. Specifically indicate any ties. Would your ranking be different if you had been asked to do the ranking according to initial distance from the origin?

A, C, B, D. Yes, the ranking from greatest to least distance would be A, C, D, B.

32. Average Speed and Average Velocity Explain how average speed and average velocity are related to each other.

Average speed is the absolute value of the average velocity. Speed is only a magnitude, while velocity is a magnitude and a direction.

33. **Critical Thinking** In solving a physics problem, why is it important to create pictorial and physical models before trying to solve an equation?

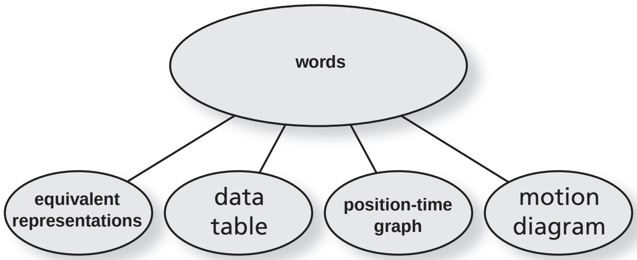
Answers will vary, but here are some of the important points. Drawing the models before writing down the equation helps you to get the problem situation organized in your head. It's difficult to write down the proper equation if you don't have a clear picture of how things are situated and/or moving. Also, you choose the coordinate system in this step, and this is essential in making sure you use the proper signs on the quantities you will substitute into the equation later.

Chapter Assessment

Concept Mapping

page 52

34. Complete the concept map below using the following terms: *words, equivalent representations, position-time graph.*



Mastering Concepts

page 52

35. What is the purpose of drawing a motion diagram? (2.1)

A motion diagram gives you a picture of motion that helps you visualize displacement and velocity.

36. Under what circumstances is it legitimate to treat an object as a point particle? (2.1)

An object can be treated as a point particle if internal motions are not important and if the object is small in comparison to the distance it moves.

37. The following quantities describe location or its change: position, distance, and displacement. Briefly describe the differences among them. (2.2)

Position and displacement are different from distance because position and displacement both contain information about the direction in which an object has moved, while distance does not. Distance and displacement are different from position because they describe how an object's location has changed during a time interval, where position tells exactly where an object is located at a precise time.

38. How can you use a clock to find a time interval? (2.2)

Read the clock at the beginning and end of the interval and subtract the beginning time from the ending time.

39. **In-line Skating** How can you use the position-time graphs for two in-line skaters to determine if and when one in-line skater will pass the other one? (2.3)

Draw the two graphs on the same set of axes. One inline skater will pass the other if the lines representing each of their motions intersect. The position coordinate of the point where the lines intersect is the position where the passing occurs.

40. **Walking Versus Running** A walker and a runner leave your front door at the same time. They move in the same direction at different constant velocities. Describe the position-time graphs of each. (2.4)

Both are straight lines that start at the same position, but the slope of the runner's line is steeper.

41. What does the slope of a position-time graph measure? (2.4)

velocity

42. If you know the positions of a moving object at two points along its path, and you also know the time it took for the object to get from one point to the other, can you determine the particle's instantaneous velocity? Its average velocity? Explain. (2.4)

It is possible to calculate the average velocity from the information given, but it is not possible to find the instantaneous velocity.

Applying Concepts

page 52

43. Test the following combinations and explain why each does not have the properties needed to describe the concept of velocity: $\Delta d + \Delta t$, $\Delta d - \Delta t$, $\Delta d \times \Delta t$, $\Delta t/\Delta d$.

$\Delta d + \Delta t$ increases when either term increases. The sign of $\Delta d - \Delta t$ depends upon the relative sizes of Δd and Δt. $\Delta d \times \Delta t$ increases when either increases. $\Delta t/\Delta d$ decreases with increasing displacement and increases with increasing time interval, which is backwards from velocity.

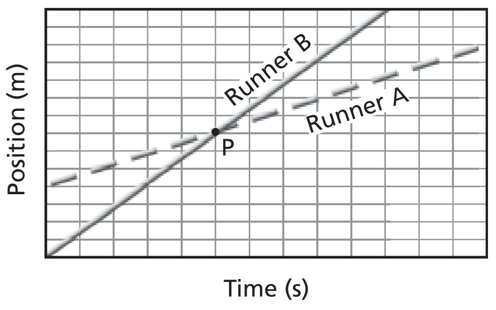
44. Football When can a football be considered a point particle?

A football can be treated as a point particle if its rotations are not important and if it is small in comparison to the distance it moves — for distances of 1 yard or more.

45. When can a football player be treated as a point particle?

A football player can be treated as a point particle if his or her internal motions are not important and if he or she is small in comparison to the distance he or she moves — for distances of several yards or more.

46. Figure 2-26 is a graph of two people running.



■ **Figure 2-26**

a. Describe the position of runner A relative to runner B at the *y*-intercept.

Runner A has a head start by four units.

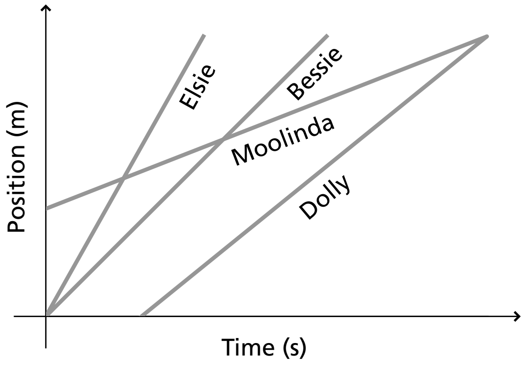
b. Which runner is faster?

Runner B is faster, as shown by the steeper slope.

c. What occurs at point P and beyond?

Runner B passes runner A at point P.

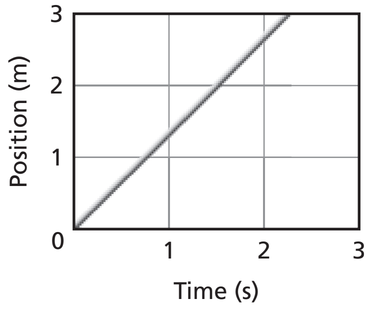
47. The position-time graph in **Figure 2-27** shows the motion of four cows walking from the pasture back to the barn. Rank the cows according to their average velocity, from slowest to fastest.



■ **Figure 2-27**

Moolinda, Dolly, Bessie, Elsie

48. **Figure 2-28** is a position-time graph for a rabbit running away from a dog.



■ **Figure 2-28**

a. Describe how this graph would be different if the rabbit ran twice as fast.

The only difference is that the slope of the graph would be twice as steep.

b. Describe how this graph would be different if the rabbit ran in the opposite direction.

The magnitude of the slope would be the same, but it would be negative.

Mastering Problems

2.4 How Fast?

page 53

Level 1

49. A bike travels at a constant speed of 4.0 m/s for 5.0 s. How far does it go?

$$d = vt$$
$$= (4.0\text{ m/s})(5\text{ s})$$
$$= 20\text{ m}$$

50. **Astronomy** Light from the Sun reaches Earth in 8.3 min. The speed of light is 3.00×10^8 m/s. How far is Earth from the Sun?

$$d = vt$$
$$= (3.00\times10^{8}\text{ m/s})(8.3\text{ min})\left(\frac{60\text{ s}}{1\text{ min}}\right)$$
$$= 1.5\times10^{11}\text{ m}$$

Level 2

51. A car is moving down a street at 55 km/h. A child suddenly runs into the street. If it takes the driver 0.75 s to react and apply the brakes, how many meters will the car have moved before it begins to slow down?

$$d = vt$$
$$= (55\text{ km/h})(0.75\text{ s})\left(\frac{1000\text{ m}}{1\text{ km}}\right)\left(\frac{1\text{ h}}{3600\text{ s}}\right)$$
$$= 11\text{ m}$$

52. Nora jogs several times a week and always keeps track of how much time she runs each time she goes out. One day she forgets to take her stopwatch with her and wonders if there's a way she can still have some idea of her time. As she passes a particular bank, she remembers that it is 4.3 km from her house. She knows from her previous training that she has a consistent pace of 4.0 m/s. How long has Nora been jogging when she reaches the bank?

$$d = vt$$
$$t = \frac{d}{v} = \frac{(4.3\text{ km})\left(\frac{1000\text{m}}{1\text{ km}}\right)}{4.0\text{ m/s}}$$
$$= 1075\text{ s}$$
$$= (1075\text{ s})\left(\frac{1\text{ min}}{60\text{ s}}\right)$$
$$= 18\text{ min}$$

Level 3

53. Driving You and a friend each drive 50.0 km. You travel at 90.0 km/h; your friend travels at 95.0 km/h. How long will your friend have to wait for you at the end of the trip?

$$d = vt$$
$$t_1 = \frac{d}{v} = \frac{50.0\text{ km}}{90.0\text{ km/h}}$$
$$= 0.556\text{ h}$$
$$t_2 = \frac{d}{v} = \frac{50.0\text{ km}}{95.0\text{ km/h}}$$
$$= 0.526\text{ h}$$
$$t_1 - t_2 = (0.556\text{ h} - 0.526\text{ h})\left(\frac{60\text{ min}}{1\text{ h}}\right)$$
$$= 1.8\text{ min}$$

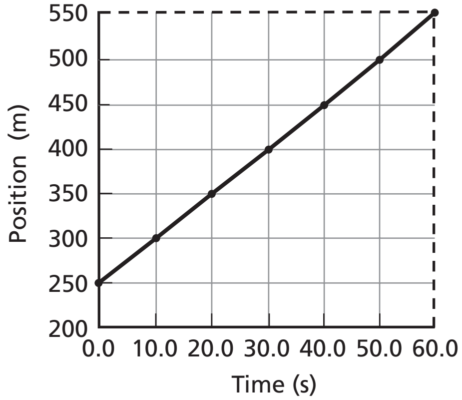
Mixed Review

pages 53–54

Level 1

54. Cycling A cyclist maintains a constant velocity of +5.0 m/s. At time $t = 0.0$ s, the cyclist is +250 m from point A.

a. Plot a position-time graph of the cyclist's location from point A at 10.0-s intervals for 60.0 s.



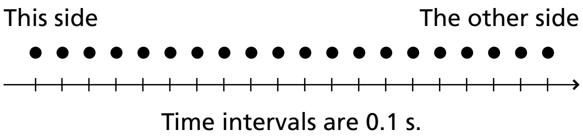
b. What is the cyclist's position from point A at 60.0 s?

550 m

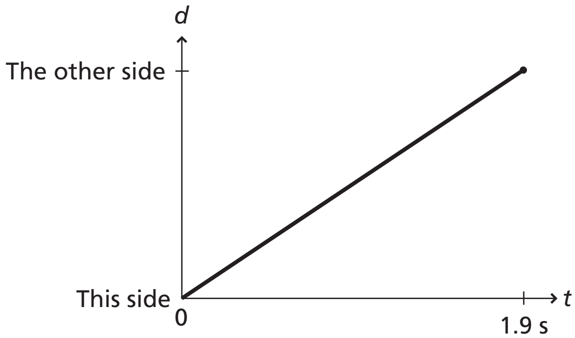
c. What is the displacement from the starting position at 60.0 s?

$$550\text{ m} - 250\text{ m} = 3.0\times10^2\text{ m}$$

55. Figure 2-29 is a particle model for a chicken casually walking across the road. Time intervals are every 0.1 s. Draw the corresponding position-time graph and equation to describe the chicken's motion.

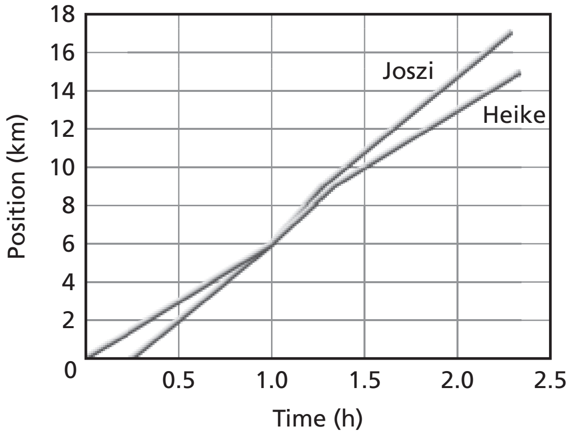


■ **Figure 2-29**



56. Figure 2-30 shows position-time graphs for

Joszi and Heike paddling canoes in a local river.



■ **Figure 2-30**

a. At what time(s) are Joszi and Heike in the same place?

1.0 h

b. How much time does Joszi spend on the river before he passes Heike?

45 min

c. Where on the river does it appear that there might be a swift current?

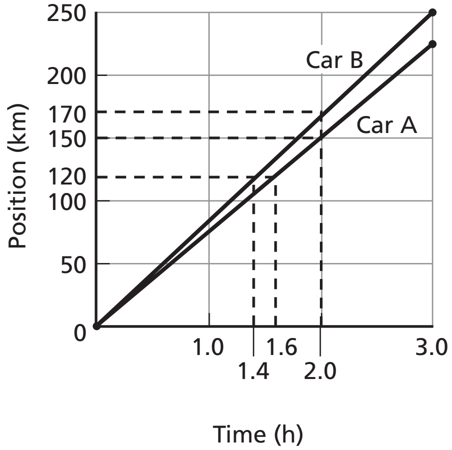
from 6.0 to 9.0 km from the origin

Level 2

57. Driving Both car A and car B leave school when a stopwatch reads zero. Car A travels at a constant 75 km/h, and car B travels at a constant 85 km/h.

a. Draw a position-time graph showing the motion of both cars. How far are the two cars from school when the stopwatch reads 2.0 h? Calculate the distances and show them on your graph.

$$d_A = v_A t$$
$$= (75\ \text{km/h})(2.0\ \text{h})$$
$$= 150\ \text{km}$$
$$d_B = v_B t$$
$$= (85\ \text{km/h})(2.0\ \text{h})$$
$$= 170\ \text{km}$$

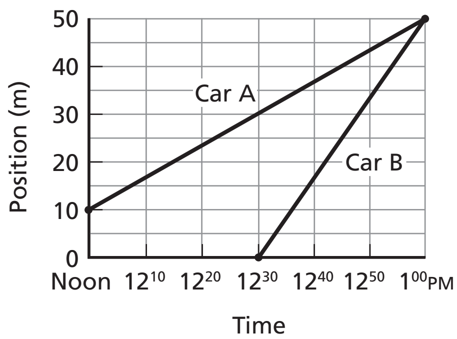


b. Both cars passed a gas station 120 km from the school. When did each car pass the gas station? Calculate the times and show them on your graph.

$$t_A = \frac{d}{v_A} = \frac{120\ \text{km}}{75\ \text{km/h}} = 1.6\ \text{h}$$

$$t_B = \frac{d}{v_B} = \frac{120\ \text{km}}{85\ \text{km/h}} = 1.4\ \text{h}$$

58. Draw a position-time graph for two cars traveling to the beach, which is 50 km from school. At noon, Car A leaves a store that is 10 km closer to the beach than the school is and moves at 40 km/h. Car B starts from school at 12:30 P.M. and moves at 100 km/h. When does each car get to the beach?

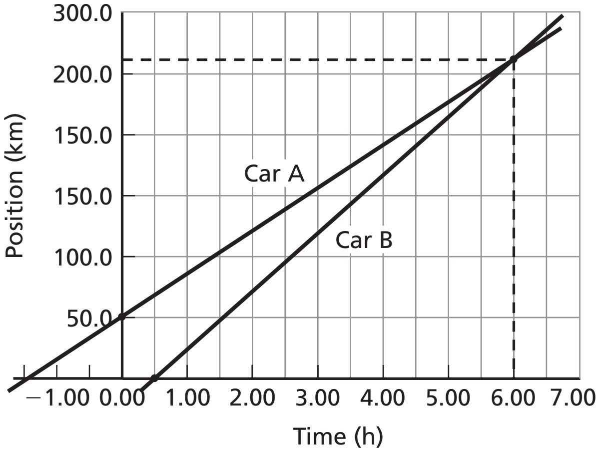


Both cars arrive at the beach at 1:00 P.M.

Level 3

59. Two cars travel along a straight road. When a stopwatch reads $t = 0.00$ h, car A is at $d_A = 48.0$ km moving at a constant 36.0 km/h. Later, when the watch reads $t = 0.50$ h, car B is at $d_B = 0.00$ km moving at 48.0 km/h. Answer the following questions, first, graphically by creating a position-time graph, and second, algebraically by writing equations for the positions d_A and d_B as a function of the stopwatch time, t.

a. What will the watch read when car B passes car A?



Cars pass when the distances are equal, $d_A = d_B$

$d_A = 48.0\text{ km} + (36.0\text{ km/h})t$

and $d_B = 0 + (48.0\text{ km/h})(t - 0.50\text{ h})$

so $48.0\text{ km} + (36.0\text{ km/h})t$
$= (48.0\text{ km/h})(t - 0.50\text{ h})$

$(48.0\text{ km}) + (36.0\text{ km/h})t$
$= (48.0\text{ km/h})t - 24\text{ km}$

$72\text{ km} = (12.0\text{ km/h})t$

$t = 6.0\text{ h}$

b. At what position will car B pass car A?

$d_A = 48.0\text{ km} + (36.0\text{ km/h})(6.0\text{ h})$
$= 2.6\times10^2\text{ km}$

c. When the cars pass, how long will it have been since car A was at the reference point?

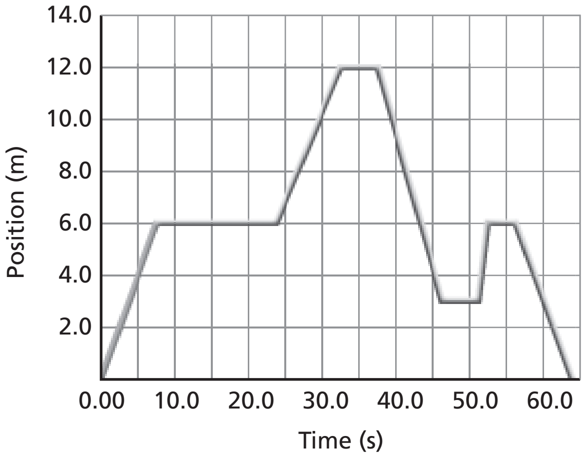
$d = vt$

so $t = \frac{d}{v} = \frac{-48.0\text{ km}}{36.0\text{ km/h}} = -1.33\text{ h}$

Car A has started 1.33 h before the clock started.

$t = 6.0\text{ h} + 1.33\text{ h} = 7.3\text{ h}$

60. **Figure 2-31** shows the position-time graph depicting Jim's movement up and down the aisle at a store. The origin is at one end of the aisle.



■ **Figure 2-31**

a. Write a story describing Jim's movements at the store that would correspond to the motion represented by the graph.

Answers will vary.

b. When does Jim have a position of 6.0 m?

from 8.0 to 18.0 s, 53.0 to 56.0 s, and at 43.0 s

c. How much time passes between when Jim enters the aisle and when he gets to a position of 12.0 m? What is Jim's average velocity between 37.0 s and 46.0 s?

$t = 33.0\text{ s}$

Using the points (37.0 s, 12.0 m) and (46.0 s, 3.00 m)

$\bar{v} = \frac{d_f - d_i}{t_f - t_i} = \frac{3.00\text{ m} - 12.0\text{ m}}{46.0\text{ s} - 37.0\text{ s}}$

$= -1.00\text{ m/s}$

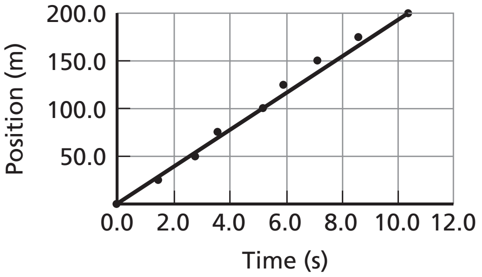
Thinking Critically

page 54

61. Apply Calculators Members of a physics class stood 25 m apart and used stopwatches to measure the time which a car traveling on the highway passed each person. Their data are shown in **Table 2-3.**

Table 2-3	
Position v. Time	
Time (s)	Position (m)
0.0	0.0
1.3	25.0
2.7	50.0
3.6	75.0
5.1	100.0
5.9	125.0
7.0	150.0
8.6	175.0
10.3	200.0

Use a graphing calculator to fit a line to a position-time graph of the data and to plot this line. Be sure to set the display range of the graph so that all the data fit on it. Find the slope of the line. What was the speed of the car?



The slope of the line and the speed of the car are 19.7 m/s.

62. Apply Concepts You plan a car trip for which you want to average 90 km/h. You cover the first half of the distance at an average speed of only 48 km/h. What must your average speed be in the second half of the trip to meet your goal? Is this reasonable? Note that the velocities are based on half the distance, not half the time.

720 km/h; No

Explanation:

Assume you want to travel 90 km in 1 h. If you cover the first half of the distance at 48 km/h, then you've gone 45 km in 0.9375 h (because $t = \frac{d}{v}$). This means you have used 93.75% of your time for the first half of the distance leaving 6.25% of the time to go the remaining 45 km.

$$v = \frac{45\ \text{km}}{0.0625\ \text{h}}$$

$$= 720\ \text{km/h}$$

63. Design an Experiment Every time a particular red motorcycle is driven past your friend's home, his father becomes angry because he thinks the motorcycle is going too fast for the posted 25 mph (40 km/h) speed limit. Describe a simple experiment you could do to determine whether or not the motorcycle is speeding the next time it is driven past your friend's house.

There are actually several good possibilities for answers on this one. Two that should be among the most popular are briefly described here. 1) Get several people together and give everyone a watch. Synchronize the watches and stand along the street separated by a consistent distance, maybe 10 m or so. When the motorcycle passes, have each person record the time (at least to an accuracy of seconds) that the motorcycle crossed in front of them. Plot a position time graph, and compute the slope of the best-fit line. If the slope is greater than 25 mph, the motorcycle is speeding. 2) Get someone with a driver's license to drive a car along the street at 25 mph in the same direction as you expect the motorcycle to go. If the motorcycle gets closer to the car (if the distance between them decreases), the motorcycle is speeding. If the distance between them stays the same, the motorcycle is driving at the speed limit. If the distance increases, the motorcycle is driving less than the speed limit.

64. Interpret Graphs Is it possible for an object's position-time graph to be a horizontal line? A vertical line? If you answer yes to either situation, describe the associated motion in words.

It is possible to have a horizontal line as a position-time graph; this would indicate that the object's position is not changing, or in other words, that it is not moving. It is not possible to have a position-time graph that is a vertical line, because this would mean the object is moving at an infinite speed.

Writing in Physics

page 54

65. Physicists have determined that the speed of light is 3.00×10^8 m/s. How did they arrive at this number? Read about some of the series of experiments that were done to determine light's speed. Describe how the experimental techniques improved to make the results of the experiments more accurate.

Answers will vary. Galileo attempted to determine the speed of light but was unsuccessful. Danish astronomer Olaus Roemer successfully measured the speed of light in 1676 by observing the eclipses of the moons of Jupiter. His estimate was 140,000 miles/s (225,308 km/s). Many others since have tried to measure it more accurately using rotating toothed wheels, rotating mirrors and the Kerr cell shutter.

66. Some species of animals have good endurance, while others have the ability to move very quickly, but for only a short amount of time. Use reference sources to find two examples of each quality and describe how it is helpful to that animal.

Answers will vary. Examples of animals with high endurance to outlast predators or prey include mules, bears, and coyotes. Animals with the speed to quickly escape predators or capture prey include cheetahs, antelopes and deer.

Cumulative Review

page 54

67. Convert each of the following time measurements to its equivalent in seconds. (Chapter 1)

a. 58 ns

5.8×10^{-8} s

b. 0.046 Gs

4.6×10^{7} s

c. 9270 ms

9.27 s

d. 12.3 ks

1.23×10^{4} s

68. State the number of significant digits in the following measurements. (Chapter 1)

a. 3218 kg

4

b. 60.080 kg

5

c. 801 kg

3

d. 0.000534 kg

3

69. Using a calculator, Chris obtained the following results. Rewrite the answer to each operation using the correct number of significant digits. (Chapter 1)

a. 5.32 mm + 2.1 mm = 7.4200000 mm

7.4 mm

b. 13.597 m × 3.65 m = 49.62905 m^2

49.6 m^2

c. 83.2 kg − 12.804 kg = 70.3960000 kg

70.4 kg

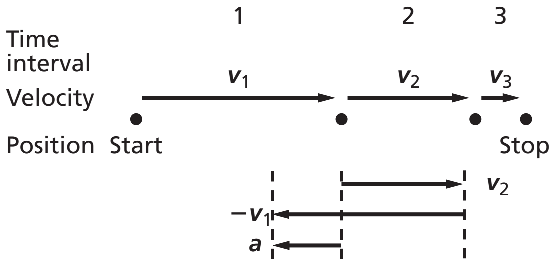
CHAPTER 3 Accelerated Motion

Practice Problems

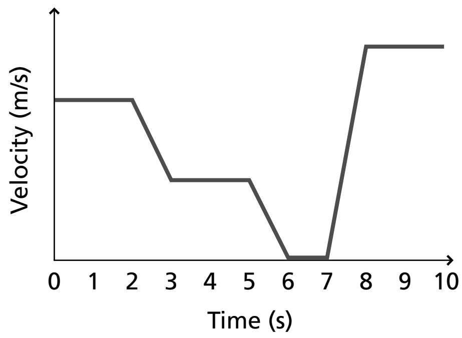
3.1 Acceleration pages 57–64

page 61

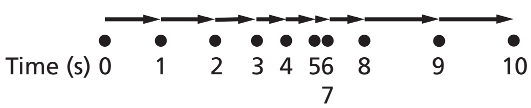
1. A dog runs into a room and sees a cat at the other end of the room. The dog instantly stops running but slides along the wood floor until he stops, by slowing down with a constant acceleration. Sketch a motion diagram for this situation, and use the velocity vectors to find the acceleration vector.



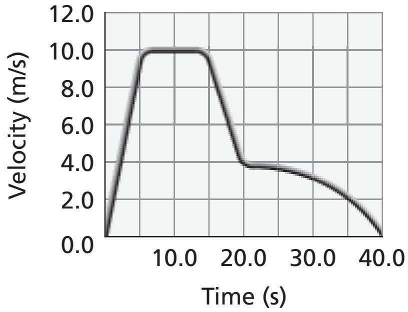
2. **Figure 3-5** is a *v-t* graph for Steven as he walks along the midway at the state fair. Sketch the corresponding motion diagram, complete with velocity vectors.



■ **Figure 3-5**



3. Refer to the *v-t* graph of the toy train in **Figure 3-6** to answer the following questions.



■ **Figure 3-6**

a. When is the train's speed constant?

5.0 to 15.0 s

b. During which time interval is the train's acceleration positive?

0.0 to 5.0 s

c. When is the train's acceleration most negative?

15.0 to 20.0 s

4. Refer to Figure 3-6 to find the average acceleration of the train during the following time intervals.

a. 0.0 s to 5.0 s

$$\bar{a} = \frac{v_2 - v_1}{t_2 - t_1}$$

$$= \frac{10.0\text{ m/s} - 0.0\text{ m/s}}{5.0\text{ s} - 0.0\text{ s}}$$

$$= 2.0\text{ m/s}^2$$

b. 15.0 s to 20.0 s

$$\bar{a} = \frac{v_2 - v_1}{t_2 - t_1}$$

$$= \frac{4.0\text{ m/s} - 10.0\text{ m/s}}{20.0\text{ s} - 15.0\text{ s}}$$

$$= -1.2\text{ m/s}^2$$

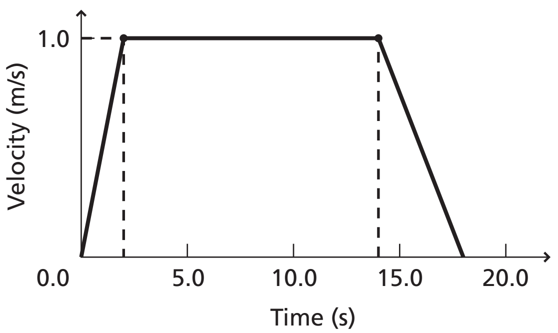
c. 0.0 s to 40.0 s

$$\bar{a} = \frac{v_2 - v_1}{t_2 - t_1}$$

$$= \frac{0.0\ \text{m/s} - 0.0\ \text{m/s}}{40.0\ \text{s} - 0.0\ \text{s}}$$

$$= \mathbf{0.0\ m/s^2}$$

5. Plot a *v-t* graph representing the following motion. An elevator starts at rest from the ground floor of a three-story shopping mall. It accelerates upward for 2.0 s at a rate of 0.5 m/s^2, continues up at a constant velocity of 1.0 m/s for 12.0 s, and then experiences a constant downward acceleration of 0.25 m/s^2 for 4.0 s as it reaches the third floor.



page 64

6. A race car's velocity increases from 4.0 m/s to 36 m/s over a 4.0-s time interval. What is its average acceleration?

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{36\ \text{m/s} - 4.0\ \text{m/s}}{4.0\ \text{s}} = \mathbf{8.0\ m/s^2}$$

7. The race car in the previous problem slows from 36 m/s to 15 m/s over 3.0 s. What is its average acceleration?

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{15\ \text{m/s} - 36\ \text{m/s}}{3.0\ \text{s}} = \mathbf{-7.0\ m/s^2}$$

8. A car is coasting backwards downhill at a speed of 3.0 m/s when the driver gets the engine started. After 2.5 s, the car is moving uphill at 4.5 m/s. If uphill is chosen as the positive direction, what is the car's average acceleration?

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{4.5\ \text{m/s} - (-3.0\ \text{m/s})}{2.5\ \text{s}} = \mathbf{3.0\ m/s^2}$$

9. A bus is moving at 25 m/s when the driver steps on the brakes and brings the bus to a stop in 3.0 s.

a. What is the average acceleration of the bus while braking?

$$\bar{a} = \frac{\Delta v}{\Delta t}$$

$$= \frac{0.0\ \text{m/s} - 25\ \text{m/s}}{3.0\ \text{s}} = \mathbf{-8.3\ m/s^2}$$

b. If the bus took twice as long to stop, how would the acceleration compare with what you found in part **a?**

half as great (−4.2 m/s^2)

10. Rohith has been jogging to the bus stop for 2.0 min at 3.5 m/s when he looks at his watch and sees that he has plenty of time before the bus arrives. Over the next 10.0 s, he slows his pace to a leisurely 0.75 m/s. What was his average acceleration during this 10.0 s?

$$\bar{a} = \frac{\Delta v}{\Delta t}$$

$$= \frac{0.75\ \text{m/s} - 3.5\ \text{m/s}}{10.0\ \text{s}}$$

$$= \mathbf{-0.28\ m/s^2}$$

11. If the rate of continental drift were to abruptly slow from 1.0 cm/yr to 0.5 cm/yr over the time interval of a year, what would be the average acceleration?

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{0.5\ \text{cm/yr} - 1.0\ \text{cm/yr}}{1.0\ \text{yr}}$$

$$= \mathbf{-0.5\ cm/yr^2}$$

Section Review

3.1 Acceleration pages 57–64

page 64

12. Velocity-Time Graph What information can you obtain from a velocity-time graph?

The velocity at any time, the time at which the object had a particular velocity, the sign of the velocity, and the displacement.

13. Position-Time and Velocity-Time Graphs Two joggers run at a constant velocity of 7.5 m/s toward the east. At time $t = 0$, one is 15 m east of the origin and the other is 15 m west.

a. What would be the difference(s) in the position-time graphs of their motion?

Both lines would have the same slope, but they would rise from the *d*-axis at different points, +15 m, and −15 m.

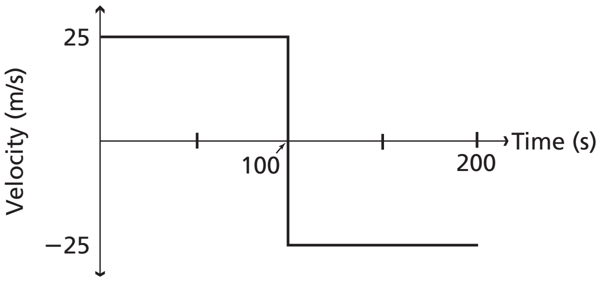
b. What would be the difference(s) in their velocity-time graphs?

Their velocity-time graphs would be identical.

14. Velocity Explain how you would use a velocity-time graph to find the time at which an object had a specified velocity.

Draw or imagine a horizontal line at the specified velocity. Find the point where the graph intersects this line. Drop a line straight down to the *t*-axis. This would be the required time.

15. Velocity-Time Graph Sketch a velocity-time graph for a car that goes east at 25 m/s for 100 s, then west at 25 m/s for another 100 s.



16. Average Velocity and Average Acceleration A canoeist paddles upstream at 2 m/s and then turns around and floats downstream at 4 m/s. The turnaround time is 8 s.

a. What is the average velocity of the canoe?

Choose a coordinate system with the positive direction upstream.

$$\bar{v} = \frac{v_i + v_f}{2}$$

$$= \frac{2\text{ m/s} + (-4\text{ m/s})}{2}$$

$$= -1\text{ m/s}$$

b. What is the average acceleration of the canoe?

$$\bar{a} = \frac{\Delta v}{\Delta t}$$

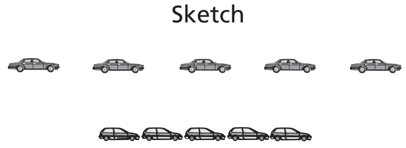
$$= \frac{v_f - v_i}{\Delta t}$$

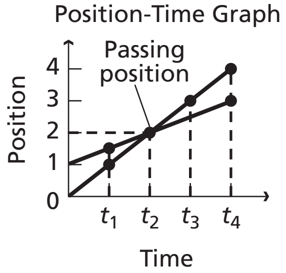
$$= \frac{(-4\text{ m/s}) - (2\text{ m/s})}{8\text{ s}}$$

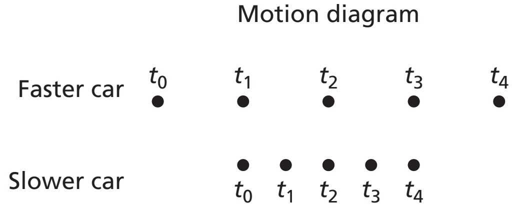
$$= 0.8\text{ m/s}^2$$

17. Critical Thinking A police officer clocked a driver going 32 km/h over the speed limit just as the driver passed a slower car. Both drivers were issued speeding tickets. The judge agreed with the officer that both were guilty. The judgement was issued based on the assumption that the cars must have been going the same speed because they were observed next to each other. Are the judge and the police officer correct? Explain with a sketch, a motion diagram, and a position-time graph.

No, they had the same position, not velocity. To have the same velocity, they would have had to have the same relative position for a length of time.







Practice Problems

3.2 Motion with Constant Acceleration pages 65–71

page 65

18. A golf ball rolls up a hill toward a miniature-golf hole. Assume that the direction toward the hole is positive.

a. If the golf ball starts with a speed of 2.0 m/s and slows at a constant rate of 0.50 m/s^2, what is its velocity after 2.0 s?

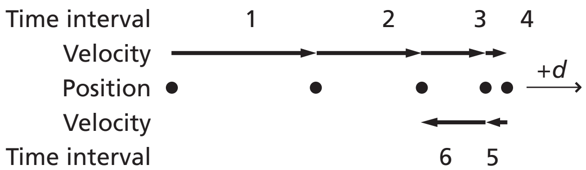
$$\mathbf{v_f = v_i + at}$$
$$\mathbf{= 2.0\ m/s + (-0.50\ m/s^2)(2.0\ s)}$$
$$\mathbf{= 1.0\ m/s}$$

b. What is the golf ball's velocity if the constant acceleration continues for 6.0 s?

$$\mathbf{v_f = v_i + at}$$
$$\mathbf{= 2.0\ m/s + (-0.50\ m/s^2)(6.0\ s)}$$
$$\mathbf{= -1.0\ m/s}$$

c. Describe the motion of the golf ball in words and with a motion diagram.

The ball's velocity simply decreased in the first case. In the second case, the ball slowed to a stop and then began rolling back down the hill.



19. A bus that is traveling at 30.0 km/h speeds up at a constant rate of 3.5 m/s^2. What velocity does it reach 6.8 s later?

$$\mathbf{v_f = v_i + at}$$
$$\mathbf{= 30.0\ km/h + (3.5\ m/s^2)(6.8\ s)\left(\frac{1\ km}{1000\ m}\right)\left(\frac{3600\ s}{1\ h}\right)}$$
$$\mathbf{= 120\ km/h}$$

20. If a car accelerates from rest at a constant 5.5 m/s^2, how long will it take for the car to reach a velocity of 28 m/s?

$$v_f = v_i + at$$

$$\text{so } t = \frac{v_f - v_i}{a}$$

$$= \frac{28 \text{ m/s} - 0.0 \text{ m/s}}{5.5 \text{ m/s}^2}$$

$$= 5.1 \text{ s}$$

21. A car slows from 22 m/s to 3.0 m/s at a constant rate of 2.1 m/s^2. How many seconds are required before the car is traveling at 3.0 m/s?

$$v_f = v_i + at$$

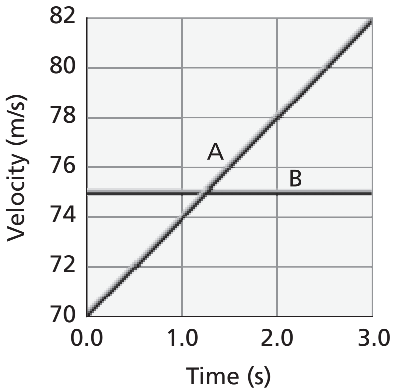
$$\text{so } t = \frac{v_f - v_i}{a}$$

$$= \frac{3.0 \text{ m/s} - 22 \text{ m/s}}{-2.1 \text{ m/s}^2}$$

$$= 9.0 \text{ s}$$

page 67

22. Use **Figure 3-11** to determine the velocity of an airplane that is speeding up at each of the following times.



■ **Figure 3-11**

Graph B represents constant speed. So graph A should be used for the following calculations.

a. 1.0 s

At 1.0 s, v = 74 m/s

b. 2.0 s

At 2.0 s, v = 78 m/s

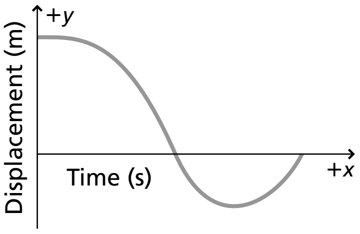
c. 2.5 s

At 2.5 s, v = 80 m/s

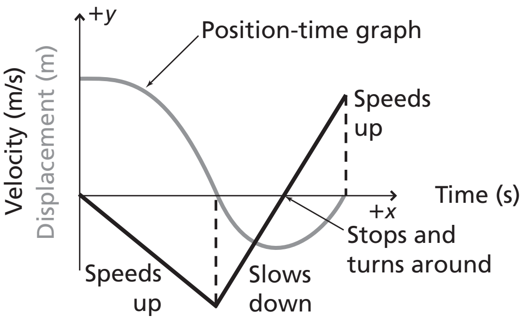
23. Use dimensional analysis to convert an airplane's speed of 75 m/s to km/h.

$$(75 \text{ m/s})\left(\frac{3600 \text{ s}}{1 \text{ h}}\right)\left(\frac{1 \text{ km}}{1000 \text{ m}}\right) = 2.7\times10^2 \text{ km/h}$$

24. A position-time graph for a pony running in a field is shown in **Figure 3-12.** Draw the corresponding velocity-time graph using the same time scale.

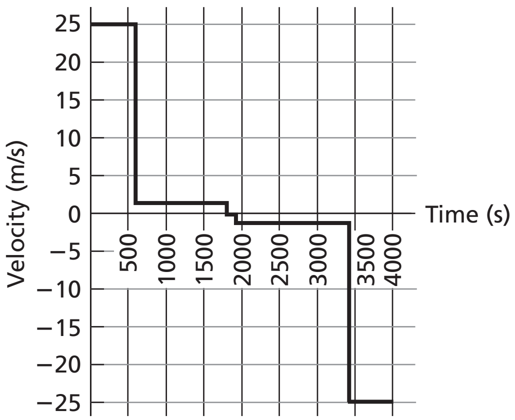


■ **Figure 3-12**



25. A car is driven at a constant velocity of 25 m/s for 10.0 min. The car runs out of gas and the driver walks in the same direction at 1.5 m/s for 20.0 min to the nearest gas station. The driver takes 2.0 min to fill a gasoline can, then walks back to the car at 1.2 m/s and eventually drives home at 25 m/s in the direction opposite that of the original trip.

a. Draw a *v-t* graph using seconds as your time unit. Calculate the distance the driver walked to the gas station to find the time it took him to walk back to the car.



distance the driver walked to the gas station:

$$d = vt$$

$$= (1.5\ \text{m/s})(20.0\ \text{min})(60\ \text{s/min})$$

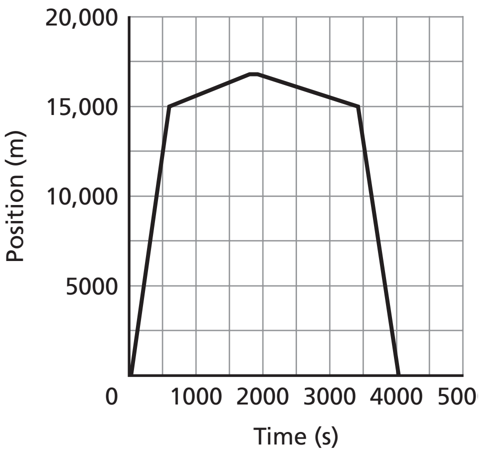
$$= 1800\ \text{m}$$

$$= 1.8\ \text{km}$$

time to walk back to the car:

$$t = \frac{d}{v} = \frac{1800\ \text{m}}{1.2\ \text{m/s}} = 1500\ \text{s} = 25\ \text{min}$$

b. Draw a position-time graph for the situation using the areas under the velocity-time graph.



page 69

26. A skateboarder is moving at a constant velocity of 1.75 m/s when she starts up an incline that causes her to slow down with a constant acceleration of −0.20 m/s^2. How much time passes from when she begins to slow down until she begins to move back down the incline?

$$v_f = v_i + at$$

$$t = \frac{v_f - v_i}{a} = \frac{0.0\ \text{m/s} - 1.75\ \text{m/s}}{-0.20\ \text{m/s}^2} = 8.8\ \text{s}$$

27. A race car travels on a racetrack at 44 m/s and slows at a constant rate to a velocity of 22 m/s over 11 s. How far does it move during this time?

$$\bar{v} = \frac{\Delta v}{2} = \frac{(v_f - v_i)}{2}$$

$$\Delta d = \bar{v}\Delta t$$

$$= \frac{(v_f - v_i)\Delta t}{2}$$

$$= \frac{(22\ \text{m/s} - 44\ \text{m/s})(11\ \text{s})}{2}$$

$$= -1.2\times10^2\ \text{m}$$

28. A car accelerates at a constant rate from 15 m/s to 25 m/s while it travels a distance of 125 m. How long does it take to achieve this speed?

$$\bar{v} = \frac{\Delta v}{2} = \frac{(v_f - v_i)}{2}$$

$$\Delta d = \bar{v}\Delta t$$

$$= \frac{(v_f - v_i)\Delta t}{2}$$

$$\Delta t = \frac{2\Delta d}{(v_f - v_i)}$$

$$= \frac{(2)(125\ \text{m})}{25\ \text{m/s} - 15\ \text{m/s}}$$

$$= 25\ \text{s}$$

29. A bike rider pedals with constant acceleration to reach a velocity of 7.5 m/s over a time of 4.5 s. During the period of acceleration, the bike's displacement is 19 m. What was the initial velocity of the bike?

$$\bar{v} = \frac{\Delta v}{2} = \frac{(v_f - v_i)}{2}$$

$$\Delta d = \bar{v}\Delta t = \frac{(v_f - v_i)\Delta t}{2}$$

$$\text{so } v_i = \frac{2\Delta d}{\Delta t} - v_f$$

$$= \frac{(2)(19\ \text{m})}{4.5\ \text{s} - 7.5\ \text{m/s}}$$

$$= 0.94\ \text{m/s}$$

page 71

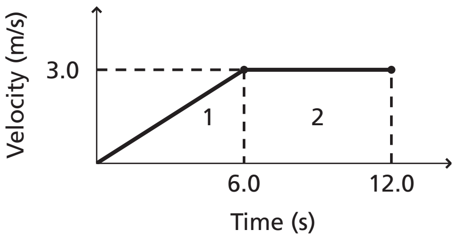
30. A man runs at a velocity of 4.5 m/s for 15.0 min. When going up an increasingly steep hill, he slows down at a constant rate of 0.05 m/s^2 for 90.0 s and comes to a stop. How far did he run?

$$d = v_1t_1 + \frac{1}{2}(v_{2f} + v_{2i})t_2$$

$$= (4.5 \text{ m/s})(15.0 \text{ min})(60 \text{ s/min}) + \frac{1}{2}(0.0 \text{ m/s} + 4.5 \text{ m/s})(90.0 \text{ s})$$

$$= 4.3\times10^3 \text{ m}$$

31. Sekazi is learning to ride a bike without training wheels. His father pushes him with a constant acceleration of 0.50 m/s^2 for 6.0 s, and then Sekazi continues at 3.0 m/s for another 6.0 s before falling. What is Sekazi's displacement? Solve this problem by constructing a velocity-time graph for Sekazi's motion and computing the area underneath the graphed line.



Part 1: Constant acceleration:

$$d_1 = \frac{1}{2}(3.0 \text{ m/s})(6.0 \text{ s})$$

$$= 9.0 \text{ m}$$

Part 2: Constant velocity:

$$d_2 = (3.0 \text{ m/s})(12.0 \text{ s} - 6.0 \text{ s})$$

$$= 18 \text{ m}$$

Thus $d = d_1 + d_2 = 9.0 \text{ m} + 18 \text{ m} = 27 \text{ m}$

32. You start your bicycle ride at the top of a hill. You coast down the hill at a constant acceleration of 2.00 m/s^2. When you get to the bottom of the hill, you are moving at 18.0 m/s, and you pedal to maintain that speed. If you continue at this speed for 1.00 min, how far will you have gone from the time you left the hilltop?

Part 1: Constant acceleration:

$v_f^2 = v_i^2 + 2a(d_f - d_i)$ **and** $d_i = 0.00 \text{ m}$

so $d_f = \frac{v_f^2 - v_i^2}{2a}$

since $v_i = 0.00 \text{ m/s}$

$$d_f = \frac{v_f^2}{2a}$$

$$= \frac{(18.0 \text{ m/s})^2}{(2)(2.00 \text{ m/s}^2)}$$

$$= 81.0 \text{ m}$$

Part 2: Constant velocity:

$d_2 = vt = (18.0 \text{ m/s})(60.0 \text{ s}) = 1.08\times10^3 \text{ m}$

Thus $d = d_1 + d_2$

$= 81.0 \text{ m} + 1.08\times10^3 \text{ m}$

$= 1.16\times10^3 \text{ m}$

33. Sunee is training for an upcoming 5.0-km race. She starts out her training run by moving at a constant pace of 4.3 m/s for 19 min. Then she accelerates at a constant rate until she crosses the finish line, 19.4 s later. What is her acceleration during the last portion of the training run?

Part 1: Constant velocity:

$d = vt$

$= (4.3 \text{ m/s})(19 \text{ min})(60 \text{ s/min})$

$= 4902 \text{ m}$

Part 2: Constant acceleration:

$d_f = d_i + v_i t + \frac{1}{2}at^2$

$$a = \frac{2(d_f - d_i - v_i t)}{t^2} = \frac{(2)(5.0\times10^3 \text{ m} - 4902 \text{ m} - (4.3 \text{ m/s})(19.4 \text{ s}))}{(19.4 \text{ s})^2}$$

$= 0.077 \text{ m/s}^2$

Section Review

3.2 Motion with Constant Acceleration pages 65–71

page 71

34. Acceleration A woman driving at a speed of 23 m/s sees a deer on the road ahead and applies the brakes when she is 210 m from the deer. If the deer does not move and the car stops right before it hits the deer, what is the acceleration provided by the car's brakes?

$v_f^2 = v_i^2 + 2a(d_f - d_i)$

$$a = \frac{v_f^2 - v_i^2}{2(d_f - d_i)}$$

$$= \frac{0.0 \text{ m/s} - (23 \text{ m/s})^2}{(2)(210 \text{ m})}$$

$= -1.3 \text{ m/s}^2$

35. Displacement If you were given initial and final velocities and the constant acceleration of an object, and you were asked to find the displacement, what equation would you use?

$v_f^2 = v_i^2 + 2ad_f$

36. Distance An in-line skater first accelerates from 0.0 m/s to 5.0 m/s in 4.5 s, then continues at this constant speed for another 4.5 s. What is the total distance traveled by the in-line skater?

Accelerating

$$d_f = \bar{v}t_f = \frac{v_i + v_f}{2}(t_f)$$

$$= \left(\frac{0.0 \text{ m/s} + 5.0 \text{ m/s}}{2}\right)(4.5 \text{ s})$$

$$= 11.25 \text{ m}$$

Constant speed

$$d_f = v_f t_f$$

$$= (5.0 \text{ m/s})(4.5 \text{ s})$$

$$= 22.5 \text{ m}$$

total distance = 11.25 m + 22.5 m

= 34 m

37. Final Velocity A plane travels a distance of 5.0×10^2 m while being accelerated uniformly from rest at the rate of 5.0 m/s^2. What final velocity does it attain?

$v_f^2 = v_f^2 + 2a(d_f - d_i)$ **and** $d_i = 0$, **so**

$$v_f^2 = v_f^2 + 2ad_f$$

$$v_f = \sqrt{(0.0 \text{ m/s})^2 + 2(5.0 \text{ m/s}^2)(5.0\times10^2 \text{ m})}$$

$$= 71 \text{ m/s}$$

38. Final Velocity An airplane accelerated uniformly from rest at the rate of 5.0 m/s^2 for 14 s. What final velocity did it attain?

$$v_f = v_i + at_f$$

$$= 0 + (5.0 \text{ m/s}^2)(14 \text{ s}) = 7.0\times10^1 \text{ m/s}$$

39. Distance An airplane starts from rest and accelerates at a constant 3.00 m/s^2 for 30.0 s before leaving the ground.

a. How far did it move?

$$d_f = v_i t_f + \frac{1}{2}at_f^2$$

$$= (0.0 \text{ m/s})(30.0 \text{ s})^2 + \left(\frac{1}{2}\right)(3.00 \text{ m/s}^2)(30.0 \text{ s})^2$$

$$= 1.35\times10^3 \text{ m}$$

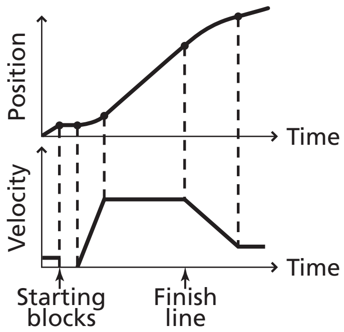
b. How fast was the airplane going when it took off?

$$v_f = v_i + at_f$$

$$= 0.0 \text{ m/s} + (3.00 \text{ m/s}^2)(30.0 \text{ s})$$

$$= 90.0 \text{ m/s}$$

40. Graphs A sprinter walks up to the starting blocks at a constant speed and positions herself for the start of the race. She waits until she hears the starting pistol go off, and then accelerates rapidly until she attains a constant velocity. She maintains this velocity until she crosses the finish line, and then she slows down to a walk, taking more time to slow down than she did to speed up at the beginning of the race. Sketch a velocity-time and a position-time graph to represent her motion. Draw them one above the other on the same time scale. Indicate on your *p-t* graph where the starting blocks and finish line are.



41. Critical Thinking Describe how you could calculate the acceleration of an automobile. Specify the measuring instruments and the procedures that you would use.

One person reads a stopwatch and calls out time intervals. Another person reads the speedometer at each time and records it. Plot speed versus time and find the slope.

Practice Problems

3.3 Free Fall pages 72–75

page 74

42. A construction worker accidentally drops a brick from a high scaffold.

a. What is the velocity of the brick after 4.0 s?

Say upward is the positive direction.

$$v_f = v_i + at,\ a = -g = -9.80\ \text{m/s}^2$$

$$v_f = 0.0\ \text{m/s} + (-9.80\ \text{m/s}^2)(4.0\ \text{s})$$

$$= -39\ \text{m/s when the upward direction is positive}$$

b. How far does the brick fall during this time?

$$d = v_i t + \frac{1}{2}at^2$$

$$= 0 + \left(\frac{1}{2}\right)(-9.80\ \text{m/s}^2)(4.0\ \text{s})^2$$

$$= -78\ \text{m}$$

The brick falls 78 m.

43. Suppose for the previous problem you choose your coordinate system so that the opposite direction is positive.

a. What is the brick's velocity after 4.0 s?

Now the positive direction is downward.

$v_f = v_i + at$, $a = g = 9.80\ m/s^2$

$v_f = 0.0\ m/s + (9.80\ m/s^2)(4.0\ s)$

$= +39\ m/s$ **when the downward direction is positive**

b. How far does the brick fall during this time?

$d = v_i t + \frac{1}{2}at^2$, $a = g = 9.80\ m/s^2$

$= (0.0\ m/s)(4.0\ s) + \left(\frac{1}{2}\right)(9.80\ m/s^2)(4.0\ s)^2$

$= +78\ m$

The brick still falls 78 m.

44. A student drops a ball from a window 3.5 m above the sidewalk. How fast is it moving when it hits the sidewalk?

$v_f^2 = v_i^2 + 2ad$, $a = g$ **and** $v_i = 0$

so $v_f = \sqrt{2gd}$

$= \sqrt{(2)(9.80\ m/s^2)(3.5\ m)}$

$= 8.3\ m/s$

45. A tennis ball is thrown straight up with an initial speed of 22.5 m/s. It is caught at the same distance above the ground.

a. How high does the ball rise?

$a = -g$, **and at the maximum height,** $v_f = 0$

$v_f^2 = v_i^2 + 2ad$ **becomes**

$v_i^2 = 2gd$

$$d = \frac{v_i^2}{2g} = \frac{(22.5\ m/s)^2}{(2)(9.80\ m/s^2)} = 25.8\ m$$

b. How long does the ball remain in the air? *Hint: The time it takes the ball to rise equals the time it takes to fall.*

Calculate time to rise using $v_f = v_i + at$, **with** $a = -g$ **and** $v_f = 0$

$$t = \frac{v_i}{g} = \frac{22.5\ m/s}{9.80\ m/s^2} = 2.30\ s$$

The time to fall equals the time to rise, so the time to remain in the air is $t_{air} = 2t_{rise} = (2)(2.30\ s) = 4.60\ s$

46. You decide to flip a coin to determine whether to do your physics or English homework first. The coin is flipped straight up.

a. If the coin reaches a high point of 0.25 m above where you released it, what was its initial speed?

$v_f^2 = v_i^2 + 2a\Delta d$

$v_i = \sqrt{v_f^2 + 2g\Delta d}$ **where** $a = -g$

and $v_f = 0$ **at the height of the toss, so**

$v_i = \sqrt{(0.0\ \text{m/s})^2 + (2)(9.80\ \text{m/s}^2)(0.25\ \text{m})}$

$= 2.2\ \text{m/s}$

b. If you catch it at the same height as you released it, how much time did it spend in the air?

$v_f = v_i + at$ **where** $a = -g$

$v_i = 2.2\ \text{m/s}$ **and**

$v_f = -2.2\ \text{m/s}$

$t = \frac{v_f - v_i}{-g}$

$= \frac{-2.2\ \text{m/s} - 2.2\ \text{m/s}}{-9.80\ \text{m/s}^2}$

$= 0.45\ \text{s}$

Section Review

3.3 Free Fall pages 72–75

page 75

47. Maximum Height and Flight Time Acceleration due to gravity on Mars is about one-third that on Earth. Suppose you throw a ball upward with the same velocity on Mars as on Earth.

a. How would the ball's maximum height compare to that on Earth?

At maximum height, $v_f = 0$,

so $d_f = \frac{v_i^2}{2g}$, **or three times higher.**

b. How would its flight time compare?

Time is found from $d_f = \frac{1}{2}gt_f^2$, **or**

$t_f = \sqrt{\frac{2d_f}{g}}$. **Distance is multiplied by 3 and** g **is divided by 3, so the flight time would be three times as long.**

48. Velocity and Acceleration Suppose you throw a ball straight up into the air. Describe the changes in the velocity of the ball. Describe the changes in the acceleration of the ball.

Velocity is reduced at a constant rate as the ball travels upward. At its highest point, velocity is zero. As the ball begins to drop, the velocity begins to increase in the negative direction until it reaches the height from which it was initially released. At that point, the ball has the same speed it had upon release. The acceleration is constant throughout the ball's flight.

49. **Final Velocity** Your sister drops your house keys down to you from the second floor window. If you catch them 4.3 m from where your sister dropped them, what is the velocity of the keys when you catch them?

Upward is positive

$v^2 = v_i^2 + 2a\Delta d$ where $a = -g$

$v = \sqrt{v_i^2 - 2g\Delta d}$

$= \sqrt{(0.0 \text{ m/s})^2 - (2)(9.80 \text{ m/s}^2)(-4.3 \text{ m})}$

$= 9.2$ m/s

50. **Initial Velocity** A student trying out for the football team kicks the football straight up in the air. The ball hits him on the way back down. If it took 3.0 s from the time when the student punted the ball until he gets hit by the ball, what was the football's initial velocity?

Choose a coordinate system with up as the positive direction and the origin at the punter. Choose the initial time at the punt and the final time at the top of the football's flight.

$v_f = v_i + at_f$ where $a = -g$

$v_i = v_f + gt_f$

$= 0.0 \text{ m/s} + (9.80 \text{ m/s}^2)(1.5 \text{ s})$

$= 15$ m/s

51. **Maximum Height** When the student in the previous problem kicked the football, approximately how high did the football travel?

$v_f^2 = v_i^2 + 2a(\Delta d)$ where $a = -g$

$$\Delta d = \frac{v_f^2 - v_i^2}{-2g}$$

$$= \frac{(0.0 \text{ m/s})^2 - (15 \text{ m/s})^2}{(-2)(9.80 \text{ m/s}^2)}$$

$= 11$ m

52. **Critical Thinking** When a ball is thrown vertically upward, it continues upward until it reaches a certain position, and then it falls downward. At that highest point, its velocity is instantaneously zero. Is the ball accelerating at the highest point? Devise an experiment to prove or disprove your answer.

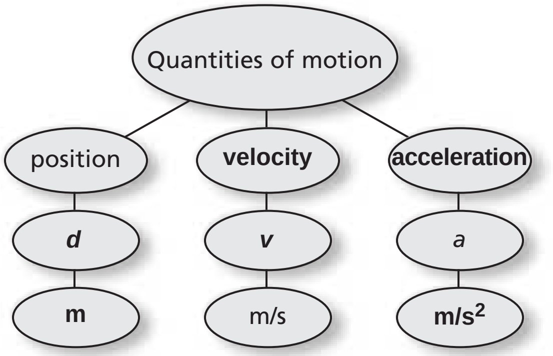
The ball is accelerating; its velocity is changing. Take a strobe photo to measure its position. From photos, calculate the ball's velocity.

Chapter Assessment

Concept Mapping

page 80

53. Complete the following concept map using the following symbols or terms: *d, velocity,* m/s^2, *v, m, acceleration.*



Mastering Concepts

page 80

54. How are velocity and acceleration related? (3.1)

Acceleration is the change in velocity divided by the time interval in which it occurs: it is the rate of change of velocity.

55. Give an example of each of the following. (3.1)

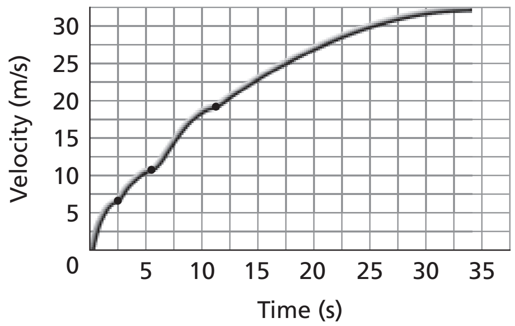
a. an object that is slowing down, but has a positive acceleration

if forward is the positive direction, a car moving backward at decreasing speed

b. an object that is speeding up, but has a negative acceleration

in the same coordinate system, a car moving backward at increasing speed

56. **Figure 3-16** shows the velocity-time graph for an automobile on a test track. Describe how the velocity changes with time. (3.1)



■ **Figure 3-16**

The car starts from rest and increases its speed. As the car's speed increases, the driver shifts gears.

57. What does the slope of the tangent to the curve on a velocity-time graph measure? (3.1)

instantaneous acceleration

58. Can a car traveling on an interstate highway have a negative velocity and a positive acceleration at the same time? Explain. Can the car's velocity change signs while it is traveling with constant acceleration? Explain. (3.1)

Yes, a car's velocity is positive or negative with respect to its direction of motion from some point of reference. One direction of motion is defined as positive, and velocities in that direction are considered positive. The opposite direction of motion is considered negative; all velocities in that direction are negative. An object undergoing positive acceleration is either increasing its velocity in the positive direction or reducing its velocity in the negative direction. A car's velocity can change signs when experiencing constant acceleration. For example, it can be traveling right, while the acceleration is to the left. The car slows down, stops, and then starts accelerating to the left.

59. Can the velocity of an object change when its acceleration is constant? If so, give an example. If not, explain. (3.1)

Yes, the velocity of an object can change when its acceleration is constant. Example: dropping a book. The

longer it drops, the faster it goes, but the acceleration is constant at *g*.

60. If an object's velocity-time graph is a straight line parallel to the *t*-axis, what can you conclude about the object's acceleration? (3.1)

When the velocity-time graph is a line parallel to the *t*-axis, the acceleration is zero.

61. What quantity is represented by the area under a velocity-time graph? (3.2)

the change in displacement

62. Write a summary of the equations for position, velocity, and time for an object experiencing motion with uniform acceleration. (3.2)

$$t_f = \frac{(v_f - v_i)}{a}$$

$$v_f = v_i + at_f$$

$$\bar{v} = \frac{\Delta v}{2} = \frac{v_f - v_i}{2}$$

$$\Delta d = \bar{v}\Delta t$$

$$= \frac{v_f - v_i}{2}\Delta t$$

assuming $t_i = 0$, then

$$\Delta t = t_f$$

$$\Delta d = \left(\frac{v_f - v_i}{2}\right)t_f$$

63. Explain why an aluminum ball and a steel ball of similar size and shape, dropped from the same height, reach the ground at the same time. (3.3)

All objects accelerate toward the ground at the same rate.

64. Give some examples of falling objects for which air resistance cannot be ignored. (3.3)

Student answers will vary. Some examples are sheets of paper, parachutes, leaves, and feathers.

65. Give some examples of falling objects for which air resistance can be ignored. (3.3)

Student answers will vary. Some examples are a steel ball, a rock, and a person falling through small distances.

Applying Concepts

pages 80–81

66. Does a car that is slowing down always have a negative acceleration? Explain.

No, if the positive axis points in the direction opposite the velocity, the acceleration will be positive.

67. **Croquet** A croquet ball, after being hit by a mallet, slows down and stops. Do the velocity and acceleration of the ball have the same signs?

No, they have opposite signs.

68. If an object has zero acceleration, does it mean its velocity is zero? Give an example.

No, $a = 0$ when velocity is constant.

69. If an object has zero velocity at some instant, is its acceleration zero? Give an example.

No, a ball rolling uphill has zero velocity at the instant it changes direction, but its acceleration is nonzero.

70. If you were given a table of velocities of an object at various times, how would you find out whether the acceleration was constant?

Draw a velocity-time graph and see whether the curve is a straight line or calculate accelerations using $\bar{a} = \frac{\Delta v}{\Delta t}$ and compare the answers to see if they are the same.

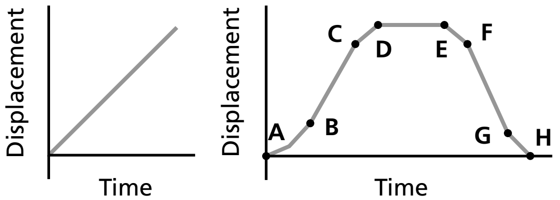
71. The three notches in the graph in Figure 3-16 occur where the driver changed gears. Describe the changes in velocity and acceleration of the car while in first gear. Is the acceleration just before a gear change larger or smaller than the acceleration just after the change? Explain your answer.

Velocity increases rapidly at first, then more slowly. Acceleration is greatest at the beginning but is reduced as velocity increases. Eventually, it is necessary for the driver to shift into second gear. The acceleration is smaller just before the gear change because the slope is less at that point on the graph. Once the driver shifts and the gears engage, acceleration and the slope of the curve increase.

72. Use the graph in Figure 3-16 and determine the time interval during which the acceleration is largest and the time interval during which the acceleration is smallest.

The acceleration is largest during an interval starting at $t = 0$ and lasting about $\frac{1}{2}$ s. It is smallest beyond 33 s.

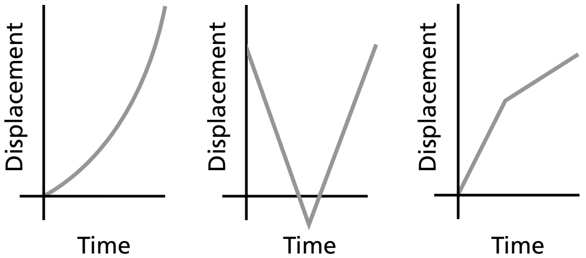
73. Explain how you would walk to produce each of the position-time graphs in **Figure 3-17.**



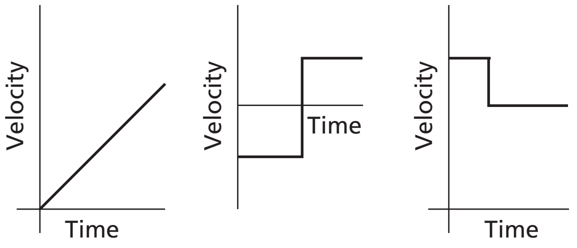
■ **Figure 3-17**

Walk in the positive direction at a constant speed. Walk in the positive direction at an increasing speed for a short time; keep walking at a moderate speed for twice that amount of time; slow down over a short time and stop; remain stopped; and turn around and repeat the procedure until the original position is reached.

74. Draw a velocity-time graph for each of the graphs in **Figure 3-18.**



■ **Figure 3-18**



75. An object shot straight up rises for 7.0 s before it reaches its maximum height. A second object falling from rest takes 7.0 s to reach the ground. Compare the displacements of the two objects during this time interval.

Both objects traveled the same distance. The object that is shot straight upward rises to the same height from which the other object fell.

76. The Moon The value of g on the Moon is one-sixth of its value on Earth.

a. Would a ball that is dropped by an astronaut hit the surface of the Moon with a greater, equal, or lesser speed than that of a ball dropped from the same height to Earth?

The ball will hit the Moon with a lesser speed because the acceleration due to gravity is less on the Moon.

b. Would it take the ball more, less, or equal time to fall?

The ball will take more time to fall.

77. Jupiter The planet Jupiter has about three times the gravitational acceleration of Earth. Suppose a ball is thrown vertically upward with the same initial velocity on Earth and on Jupiter. Neglect the effects of Jupiter's atmospheric resistance and assume that gravity is the only force on the ball.

a. How does the maximum height reached by the ball on Jupiter compare to the maximum height reached on Earth?

The relationship between d and g is an inverse one: $d_f = \frac{(v_f^2 - v_i^2)}{2g}$.

If g increases by three times, or $d_f = \frac{(v_f^2 - v_i^2)}{2(3g)}$, d_f changes by $\frac{1}{3}$. Therefore, a ball on Jupiter would rise to a height of $\frac{1}{3}$ that on Earth.

b. If the ball on Jupiter were thrown with an initial velocity that is three times greater, how would this affect your answer to part **a?**

With $v_f = 0$, the value d_f is directly proportional to the square of initial velocity, v_i. That is, $d_f = v_f^2 - \frac{(3v_i)^2}{2g}$.

On Earth, an initial velocity three times greater results in a ball rising nine times higher. On Jupiter, however, the height of nine times higher would be reduced to only three times higher because of d_f's inverse relationship to a g that is three times greater.

78. Rock A is dropped from a cliff and rock B is thrown upward from the same position.

a. When they reach the ground at the bottom of the cliff, which rock has a greater velocity?

Rock B hits the ground with a greater velocity.

b. Which has a greater acceleration?

They have the same acceleration, the acceleration due to gravity.

c. Which arrives first?

rock A

Mastering Problems

3.1 Acceleration

pages 81–82

Level 1

79. A car is driven for 2.0 h at 40.0 km/h, then for another 2.0 h at 60.0 km/h in the same direction.

a. What is the car's average velocity?

Total distance:
80.0 km + 120.0 km = 200.0 km
total time is 4.0 hours, so,

$$\bar{v} = \frac{\Delta d}{\Delta t} = \frac{200.0 \text{ km}}{4.0 \text{ h}} = 5.0\times10^1 \text{ km/h}$$

b. What is the car's average velocity if it is driven 1.0×10^2 km at each of the two speeds?

Total distance is 2.03102 km;

$$\text{total time} = \frac{1.0\times10^2\ \text{km}}{40.0\ \text{km/h}} + \frac{1.0\times10^2\ \text{km}}{60.0\ \text{km/h}}$$

$$= 4.2\ \text{h}$$

$$\text{so } \bar{v} = \frac{\Delta d}{\Delta t} = \frac{2.0\times10^2\ \text{km}}{4.2\ \text{h}}$$

$$= 48\ \text{km/h}$$

80. Find the uniform acceleration that causes a car's velocity to change from 32 m/s to 96 m/s in an 8.0-s period.

$$\bar{a} = \frac{\Delta v}{\Delta t}$$

$$= \frac{v_2 - v_1}{\Delta t}$$

$$= \frac{96\ \text{m/s} - 32\ \text{m/s}}{8.0\ \text{s}} = 8.0\ \text{m/s}^2$$

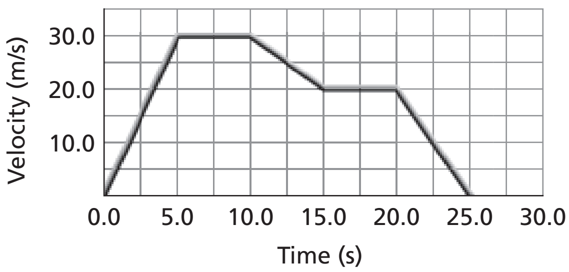
81. A car with a velocity of 22 m/s is accelerated uniformly at the rate of 1.6 m/s^2 for 6.8 s. What is its final velocity?

$$v_f = v_i + at_f$$

$$= 22\ \text{m/s} + (1.6\ \text{m/s}^2)(6.8\ \text{s})$$

$$= 33\ \text{m/s}$$

82. Refer to **Figure 3-19** to find the acceleration of the moving object at each of the following times.



■ **Figure 3-19**

a. during the first 5.0 s of travel

$$\bar{a} = \frac{\Delta v}{\Delta t}$$

$$= \frac{30.0\ \text{m/s} - 0.0\ \text{m/s}}{5.0\ \text{s}}$$

$$= 6.0\ \text{m/s}^2$$

b. between 5.0 s and 10.0 s

$$\bar{a} = \frac{\Delta v}{\Delta t}$$

$$= \frac{30.0\ \text{m/s} - 30.0\ \text{m/s}}{5.0\ \text{s}}$$

$$= 0.0\ \text{m/s}^2$$

c. between 10.0 s and 15.0 s

$$\bar{a} = \frac{\Delta v}{\Delta t}$$

$$= \frac{20.0 \text{ m/s} - 30.0 \text{ m/s}}{5.0 \text{ s}}$$

$$= -2.0 \text{ m/s}^2$$

d. between 20.0 s and 25.0 s

$$\bar{a} = \frac{\Delta v}{\Delta t}$$

$$= \frac{0.0 \text{ m/s} - 20.0 \text{ m/s}}{5.0 \text{ s}}$$

$$= -4.0 \text{ m/s}^2$$

Level 2

83. Plot a velocity-time graph using the information in **Table 3-4,** and answer the following questions.

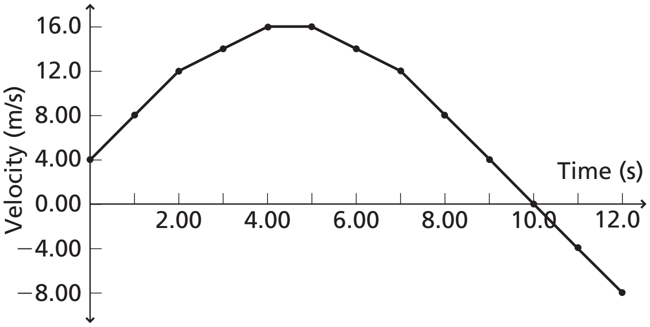


Table 3-4

Velocity v. Time

Time (s)	Velocity (m/s)
0.00	4.00
1.00	8.00
2.00	12.0
3.00	14.0
4.00	16.0
5.00	16.0
6.00	14.0
7.00	12.0
8.00	8.00
9.00	4.00
10.0	0.00
11.0	−4.00
12.0	−8.00

a. During what time interval is the object speeding up? Slowing down?

speeding up from 0.0 s to 4.0 s; slowing down from 5.0 s to 10.0 s

b. At what time does the object reverse direction?

at 10.0 s

c. How does the average acceleration of the object in the interval between 0.0 s and 2.0 s differ from the average acceleration in the interval between 7.0 s and 12.0 s?

$$\bar{a} = \frac{\Delta v}{\Delta t}$$

between 0.0 s and 2.0 s:

$$\bar{a} = \frac{12.0 \text{ m/s} - 4.0 \text{ m/s}}{2.0 \text{ s} - 0.0 \text{ s}} = 4.0 \text{ m/s}^2$$

between 7.0 s and 12.0 s:

$$\bar{a} = \frac{-8.0 \text{ m/s} - 12.0 \text{ m/s}}{12.0 \text{ s} - 7.0 \text{ s}} = -4.0 \text{ m/s}^2$$

84. Determine the final velocity of a proton that has an initial velocity of 2.35×10^5 m/s and then is accelerated uniformly in an electric field at the rate of -1.10×10^{12} m/s^2 for 1.50×10^{-7} s.

$$\mathbf{v_f = v_i + at_f}$$
$$= 2.35\times10^5 \text{ m/s} + (-1.10\times10^{12} \text{ m/s}^2)(1.50\times10^{-7} \text{ s})$$
$$= 7.0\times10^4 \text{ m/s}$$

Level 3

85. Sports Cars Marco is looking for a used sports car. He wants to buy the one with the greatest acceleration. Car A can go from 0 m/s to 17.9 m/s in 4.0 s; car B can accelerate from 0 m/s to 22.4 m/s in 3.5 s; and car C can go from 0 to 26.8 m/s in 6.0 s. Rank the three cars from greatest acceleration to least, specifically indicating any ties.

Car A:

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{17.9 \text{ m/s} - 0 \text{ m/s}}{4.0 \text{ s} - 0.0 \text{ s}} = 4.5 \text{ m/s}^2$$

Car B:

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{22.4 \text{ m/s} - 0 \text{ m/s}}{3.5 \text{ s} - 0.0 \text{ s}} = 6.4 \text{ m/s}^2$$

Car C:

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{26.8 \text{ m/s} - 0 \text{ m/s}}{6.0 \text{ s} - 0.0 \text{ s}} = 4.5 \text{ m/s}^2$$

Car B has the greatest acceleration of 6.4 m/s^2. Using significant digits, car A and car C tied at 4.5 m/s^2.

86. Supersonic Jet A supersonic jet flying at 145 m/s experiences uniform acceleration at the rate of 23.1 m/s^2 for 20.0 s.

a. What is its final velocity?

$$v_f = v_i + at_f$$
$$= 145 \text{ m/s} + (23.1 \text{ m/s}^2)(20.0 \text{ s})$$
$$= 607 \text{ m/s}$$

b. The speed of sound in air is 331 m/s. What is the plane's speed in terms of the speed of sound?

$$N = \frac{607 \text{ m/s}}{331 \text{ m/s}}$$
$$= 1.83 \text{ times the speed of sound}$$

3.2 Motion with Constant Acceleration

page 82

Level 1

87. Refer to **Figure 3-19** to find the distance traveled during the following time intervals.

a. $t = 0.0$ s and $t = 5.0$ s

$$\text{Area I} = \frac{1}{2}bh$$
$$= \left(\frac{1}{2}\right)(5.0 \text{ s})(30.0 \text{ m/s})$$
$$= 75 \text{ m}$$

b. $t = 5.0$ s and $t = 10.0$ s

$$\text{Area II} = bh$$
$$= (10.0 \text{ s} - 5.0 \text{ s})(30.0 \text{ m/s})$$
$$= 150 \text{ m}$$

c. $t = 10.0$ s and $t = 15.0$ s

$$\text{Area III} + \text{Area IV} = bh + \frac{1}{2}bh$$
$$= (15.0 \text{ s} - 10.0 \text{ s})(20.0 \text{ m/s}) + \left(\frac{1}{2}\right)(15.0 \text{ s} - 10.0 \text{ s})(10.0 \text{ m/s})$$
$$= 125 \text{ m}$$

d. $t = 0.0$ s and $t = 25.0$ s

Area I + Area II + (Area III + Area IV) + Area V + IV

$$= 75 \text{ m} + 150 \text{ m} + 125 \text{ m} + bh + \frac{1}{2}bh$$
$$= 75 \text{ m} + 150 \text{ m} + 125 \text{ m} + (20.0 \text{ s} - 15.0 \text{ s})(20.0 \text{ m/s}) + \left(\frac{1}{2}\right)(25.0 \text{ s} - 20.0 \text{ s})$$
$$= 5.0\times10^2 \text{ m}$$

Level 2

88. A dragster starting from rest accelerates at 49 m/s^2. How fast is it going when it has traveled 325 m?

$$v_f^2 = v_i^2 + 2a(d_f - d_i)$$
$$v_f = \sqrt{v_i^2 + 2a(d_f - d_i)}$$

$= \sqrt{(0.0\text{ m/s})^2 + (2)(49\text{ m/s}^2)(325\text{ m} - 0.0\text{ m})}$

$= 180\text{ m/s}$

89. A car moves at 12 m/s and coasts up a hill with a uniform acceleration of -1.6 m/s^2.

a. What is its displacement after 6.0 s?

$d_f = v_i t_f + \frac{1}{2}a t_f^2$

$= (12\text{ m/s})(6.0\text{ s}) + \left(\frac{1}{2}\right)(-1.6\text{ m/s}^2)(6.0\text{ s})^2$

$= 43\text{ m}$

b. What is its displacement after 9.0 s?

$d_f = v_i t_f + \frac{1}{2}a t_f^2$

$= (12\text{ m/s})(9.0\text{ s}) + \left(\frac{1}{2}\right)(-1.6\text{ m/s}^2)(9.0\text{ s})^2$

$= 43\text{ m}$

The car is on the way back down the hill. The odometer will show that the car traveled 45 m up the hill + 2 m back down = 47 m.

90. Race Car A race car can be slowed with a constant acceleration of -11 m/s^2.

a. If the car is going 55 m/s, how many meters will it travel before it stops?

$v_f^2 = v_i^2 + 2ad_f$

$d_f = \frac{v_f^2 - v_i^2}{2a}$

$= \frac{(0.0\text{ m/s})^2 - (+55\text{ m/s})^2}{(2)(-11\text{ m/s}^2)}$

$= 1.4\times10^2\text{ m}$

b. How many meters will it take to stop a car going twice as fast?

$v_f^2 = v_i^2 + 2ad_f$

$d_f = \frac{v_f^2 - v_i^2}{2a}$

$= \frac{(0.0\text{ m/s})^2 - (110\text{ m/s})^2}{(2)(-11\text{ m/s}^2)} = 550\text{ m},$

which is about 4 times longer than when going half the speed.

91. A car is traveling 20.0 m/s when the driver sees a child standing on the road. She takes 0.80 s to react, then steps on the brakes and slows at 7.0 m/s^2. How far does the car go before it stops?

reaction displacement $d_r = (20.0\text{ m/s})(0.80\text{ s}) = 16\text{ m}$

$$d_f = \frac{v_f^2 - v_i^2}{2a}$$

braking displacement

$$d_b = \frac{(0.0\text{ m/s})^2 - (20.0\text{ m/s})^2}{(2)(-7.0\text{ m/s}^2)}$$

$$= 29\text{ m}$$

total displacement is

$$d_r + d_b = 16\text{ m} + 29\text{ m} = 45\text{ m}$$

Level 3

92. Airplane Determine the displacement of a plane that experiences uniform acceleration from 66 m/s to 88 m/s in 12 s.

$$d_f = \bar{v}t = \frac{(v_f + v_i)t}{2}$$

$$= \frac{(88\text{ m/s} + 66\text{ m/s})(12\text{ s})}{2}$$

$$= 9.2\times10^2\text{ m}$$

93. How far does a plane fly in 15 s while its velocity is changing from 145 m/s to 75 m/s at a uniform rate of acceleration?

$$d = \bar{v}t = \frac{(v_f + v_i)t}{2}$$

$$= \frac{(75\text{ m/s} + 145\text{ m/s})(15\text{ m/s})}{2}$$

$$= 1.6\times10^3\text{ m}$$

94. Police Car A speeding car is traveling at a constant speed of 30.0 m/s when it passes a stopped police car. The police car accelerates at 7.0 m/s^2. How fast will it be going when it catches up with the speeding car?

$$d_{speeder} = v_{speeder}t$$

$$d_{police} = v_{i\ police}t + \frac{1}{2}a_{police}t^2$$

$$v_{speeder}t = v_{i\ police}t + \frac{1}{2}a_{police}t^2$$

since $v_{i\ police} = 0$ then

$$v_{speeder}t = \frac{1}{2}a_{police}t^2$$

$$0 = \frac{1}{2}a_{police}t^2 - v_{speeder}t$$

$$0 = t\left(\frac{1}{2}a_{police}t - v_{speeder}\right)$$

therefore

$$t = 0 \text{ and } \frac{1}{2}a_{police}t - v_{speeder} = 0$$

$$t = \frac{2v_{speeder}}{a_{police}}$$

$$= \frac{(2)(30.0\text{ m/s})}{7.0\text{ m/s}^2}$$

$$= 8.6\text{ s}$$

After $t = 8.6$ s, the police car's velocity was

$$v_f = v_i + at$$

$$= 0.0\text{ m/s} + (7.0\text{ m/s}^2)(8.6\text{ s})$$

$$= 6.0\times10^1\text{ m/s}$$

95. Road Barrier The driver of a car going 90.0 km/h suddenly sees the lights of a barrier 40.0 m ahead. It takes the driver 0.75 s to apply the brakes, and the average acceleration during braking is −10.0 m/s^2.

a. Determine whether the car hits the barrier.

The car will travel
$d = vt = (25.0\text{ m/s})(0.75\text{ s})$
$= 18.8$ m (Round off at the end.)
before the driver applies the brakes.

Convert km/h to m/s.

$$v_i = \frac{(90.0\text{ km/h})(1000\text{ m/km})}{3600\text{ s/h}}$$

$$= 25.0\text{ m/s}$$

$$v_f^2 = v_i^2 + 2a(d_f - d_i)$$

$$d_f = \frac{v_f^2 - v_i^2}{2a} + d_i$$

$$= \frac{(0.0\text{ m/s})^2 - (25.0\text{ m/s})^2}{(2)(-10.0\text{ m/s}^2)} + 18.8\text{ m}$$

$$= 5.0\times10^1\text{ m, yes it hits the barrier}$$

b. What is the maximum speed at which the car could be moving and not hit the barrier 40.0 m ahead? Assume that the acceleration doesn't change.

$$d_{total} = d_{constant} + d_{decelerating}$$
$$= 40.0 \text{ m}$$
$$d_c = vt = (0.75 \text{ s})v$$
$$d_d = \frac{0^2 - v^2}{2a} = \frac{-v^2}{2(-10.0 \text{ m/s}^2)}$$
$$= \frac{v^2}{20.0 \text{ m/s}^2}$$
$$40 \text{ m} = (0.75 \text{ s})v + \frac{v^2}{20.0 \text{ m/s}^2}$$
$$v^2 + (15 \text{ m/s})v - 800 \text{ m}^2/\text{s}^2 = 0$$

Using the quadratic equation: v = 22 m/s (The sense of the problem excludes the negative value.)

3.3 Free Fall

page 82

Level 1

96. A student drops a penny from the top of a tower and decides that she will establish a coordinate system in which the direction of the penny's motion is positive. What is the sign of the acceleration of the penny?

The direction of the velocity is positive, and velocity is increasing. Therefore, the acceleration is also positive.

97. Suppose an astronaut drops a feather from 1.2 m above the surface of the Moon. If the acceleration due to gravity on the Moon is 1.62 m/s^2 downward, how long does it take the feather to hit the Moon's surface?

$$d_f = v_i t_f + a t_f^2 = (0 \text{ m/s})t_f + a t_f^2$$
$$t_f = \sqrt{\frac{2d_f}{a}} = \sqrt{\frac{(2)(1.2 \text{ m})}{(1.62 \text{ m/s}^2)}} = 1.2 \text{ s}$$

98. A stone that starts at rest is in free fall for 8.0 s.

a. Calculate the stone's velocity after 8.0 s.

$$v_f = v_i + a t_f \text{ where } a = -g$$
$$= v_i - g t_f$$
$$= 0.0 \text{ m/s} - (9.80 \text{ m/s}^2)(8.0 \text{ s})$$
$$= -78 \text{ m/s (downward)}$$

b. What is the stone's displacement during this time?

Choose the coordinate system to have the origin where the stone is at rest and positive to be upward.

$$d_f = v_i t + \tfrac{1}{2} a t_f^2 \text{ where } a = -g$$
$$= v_i t - \tfrac{1}{2} g t_f^2$$
$$= 0.0 \text{ m} - \left(\tfrac{1}{2}\right)(9.80 \text{ m/s}^2)(8.0 \text{ s})^2$$
$$= -3.1\times10^2 \text{ m}$$

99. A bag is dropped from a hovering helicopter. The bag has fallen for 2.0 s. What is the bag's velocity? How far has the bag fallen?

Velocity:

$$v_f = v_i + a t_f \text{ where } a = -g$$
$$= v_i - g t_f$$
$$= 0.0 \text{ m/s} - (9.80 \text{ m/s}^2)(2.0 \text{ s})$$
$$= -2.0\times10^1 \text{ m/s}$$

Displacement:

$$d_f = v_i t_f + \tfrac{1}{2} a t_f^2 \text{ where } a = -g$$
$$= v_i t_f - \tfrac{1}{2} g t^2$$
$$= 0.0 \text{ m} - \left(\tfrac{1}{2}\right)(9.80 \text{ m/s}^2)(2.0 \text{ s})^2$$
$$= -2.0\times10^1 \text{ m}$$

Level 2

100. You throw a ball downward from a window at a speed of 2.0 m/s. How fast will it be moving when it hits the sidewalk 2.5 m below?

Choose a coordinate system with the positive direction downward and the origin at the point where the ball leaves your hand.

$v_f^2 = v_i^2 + 2ad_f$ where $a = g$

$v_f = \sqrt{v_i^2 + 2gd_f}$

$= \sqrt{(2.0\ \text{m/s})^2 + (2)(9.80\ \text{m/s}^2)(2.5\ \text{m})}$

$= 7.3$ m/s

101. If you throw the ball in the previous problem up instead of down, how fast will it be moving when it hits the sidewalk?

Choose the same coordinate system.

$v_f^2 = v_i^2 + 2ad_f$ where $a = g$

$v_f = \sqrt{v_i^2 + 2gd_f}$

$= \sqrt{(2.0\ \text{m/s})^2 + (2)(9.80\ \text{m/s}^2)(2.5\ \text{m})}$

$= 7.3$ m/s

(d_f is the displacement, not the total distance traveled.)

Level 3

102. Beanbag You throw a beanbag in the air and catch it 2.2 s later.

a. How high did it go?

Choose a coordinate system with the upward direction positive and the origin at the point where the beanbag left your hand. Assume that you catch the beanbag at the same place where you threw it. Therefore, the time to reach the maximum height is half of the time in the air. Choose t_i to be the time when the beanbag left your hand and t_f to be the time at the maximum height. Each formula that you know includes v_i, so you will have to calculate that first.

$v_f = v_i + at_f$ where $a = -g$

$v_i = v_f + gt_f$

$= 0.0\ \text{m/s} + (9.80\ \text{m/s}^2)(1.1\ \text{s})$

$= 11$ m/s

Now you can use an equation that includes the displacement.

$d_f = d_i + v_it_f + \frac{1}{2}at_f^2$ where $a = -g$

$= d_i + v_it_f - \frac{1}{2}gt_f^2$

$= 0.0\ \text{m} + (11\ \text{m/s})(1.1\ \text{s}) - \left(\frac{1}{2}\right)(9.80\ \text{m/s}^2)(1.1\ \text{s})^2$

$= 6.2$ m

b. What was its initial velocity?

$v_i = 11$ m/s

Mixed Review

pages 82–84

Level 1

103. A spaceship far from any star or planet experiences uniform acceleration from 65.0 m/s to 162.0 m/s in 10.0 s. How far does it move?

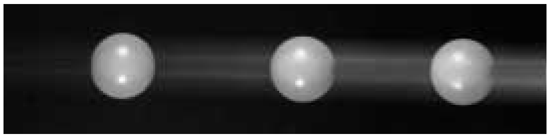
Choosing a coordinate system with the origin at the point where the speed is 65.0 m/s and given v_i = 65.0 m/s, v_f = 162.0 m/s, and t_f = 10.0 s and needing d_f, we use the formula with the average velocity.

$$d_f = d_i + \frac{1}{2}(v_i + v_f)t_f$$

$$d_f = 0 + \frac{1}{2}(65.0\text{ m/s} + 162.0\text{ m/s})(10.0\text{ s})$$

$$= 1.14\times10^3\text{ m}$$

104. **Figure 3-20** is a strobe photo of a horizontally moving ball. What information about the photo would you need and what measurements would you make to estimate the acceleration?



■ **Figure 3-20**

You need to know the time between flashes and the distance between the first two images and the distance between the last two. From these, you get two velocities. Between these two velocities, a time interval of *t* seconds occurred. Divide the difference between the two velocities by *t*.

105. **Bicycle** A bicycle accelerates from 0.0 m/s to 4.0 m/s in 4.0 s. What distance does it travel?

$$d_f = \bar{v}t_f = \frac{v_i + v_f}{2}t_f$$

$$= \left(\frac{0.0\text{ m/s} + 4.0\text{ m/s}}{2}\right)(4.0\text{ s})$$

$$= 8.0\text{ m}$$

106. A weather balloon is floating at a constant height above Earth when it releases a pack of instruments.

a. If the pack hits the ground with a velocity of −73.5 m/s, how far did the pack fall?

$$v_f^2 = v_i^2 + 2ad_f$$

$$d_f = \frac{v_f^2 - v_i^2}{2a}$$

$$= \frac{(-73.5\text{ m/s})^2 - (0.00\text{ m/s})^2}{(2)(-9.80\text{ m/s}^2)}$$

$$= -276\text{ m}$$

b. How long did it take for the pack to fall?

$v_f = v_i + at_f$ **where** $a = -g$

$$t_f = \frac{v_f - v_i}{-g}$$

$$= \frac{-73.5\text{ m/s} - 0.00\text{ m/s}}{-9.80\text{ m/s}^2}$$

$$= 7.50\text{ s}$$

Level 2

107. **Baseball** A baseball pitcher throws a fastball at a speed of 44 m/s. The acceleration occurs as the pitcher holds the ball in his hand and moves it through an almost straight-line distance of 3.5 m. Calculate the acceleration, assuming that it is constant and uniform. Compare this acceleration to the acceleration due to gravity.

$$v_f^2 = v_i^2 + 2ad_f$$

$$a = \frac{v_f^2 - v_i^2}{2d_f}$$

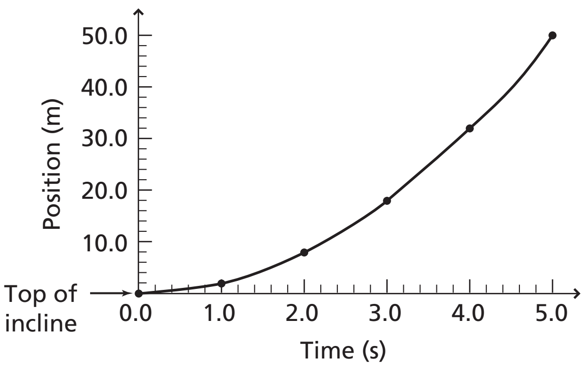
$$= \frac{(44\text{ m/s})^2 - 0}{(2)(3.5\text{ m})} = 2.8\times10^2\text{ m/s}^2$$

$$\frac{2.8\times10^2\text{ m/s}^2}{9.80\text{ m/s}^2} = 29\text{, or 29 times } g$$

108. The total distance a steel ball rolls down an incline at various times is given in **Table 3-5.**

Table 3-5	
Distance v. Time	
Time (s)	**Distance (m)**
0.0	0.0
1.0	2.0
2.0	8.0
3.0	18.0
4.0	32.0
5.0	50.0

a. Draw a position-time graph of the motion of the ball. When setting up the axes, use five divisions for each 10 m of travel on the *d*-axis. Use five divisions for 1 s of time on the *t*-axis.



b. Calculate the distance the ball has rolled at the end of 2.2 s.

After 2.2 seconds the ball has rolled approximately 10 m.

109. Engineers are developing new types of guns that might someday be used to launch satellites as if they were bullets. One such gun can give a small object a velocity of 3.5 km/s while moving it through a distance of only 2.0 cm.

a. What acceleration does the gun give this object?

$$v_f^2 = v_i^2 + 2ad_f$$

or $v_f^2 = 2ad_f$

$$a = \frac{v_f^2}{2d_f} = \frac{(3.5\times10^3 \text{ m/s})^2}{(2)(0.020 \text{ m})}$$

$$= 3.1\times10^8 \text{ m/s}^2$$

b. Over what time interval does the acceleration take place?

$$d = \frac{(v_f + v_i)t}{2}$$

$$t = \frac{2d_f}{v_f + v_i} = \frac{(2)(0.020 \text{ m})}{3.5\times10^3 \text{ m/s} + 0.0 \text{ m/s}}$$

$$= 11\times10^{-6} \text{ s}$$

= 11 microseconds

110. Sleds Rocket-powered sleds are used to test the responses of humans to acceleration. Starting from rest, one sled can reach a speed of 444 m/s in 1.80 s and can be brought to a stop again in 2.15 s.

a. Calculate the acceleration of the sled when starting, and compare it to the magnitude of the acceleration due to gravity, 9.80 m/s^2.

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{\Delta t}$$

$$= \frac{444 \text{ m/s} - 0.00 \text{ m/s}}{1.80 \text{ s}}$$

$$= 247 \text{ m/s}^2$$

$$\frac{247 \text{ m/s}^2}{9.80 \text{ m/s}^2} = 25 \text{ times } g$$

b. Find the acceleration of the sled as it is braking and compare it to the magnitude of the acceleration due to gravity.

$$a = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{\Delta t}$$

$$= \frac{0.00 \text{ m/s} - 444 \text{ m/s}}{2.15 \text{ s}}$$

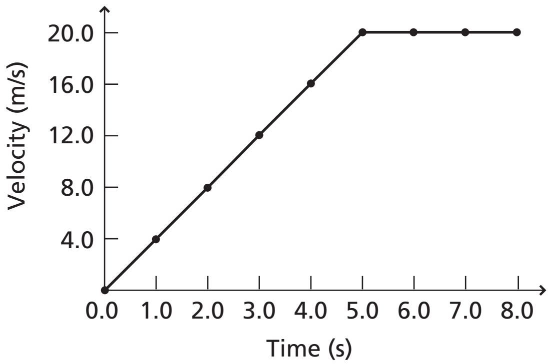
$$= -207 \text{ m/s}^2$$

$$\frac{207 \text{ m/s}^2}{9.80 \text{ m/s}^2} = 21 \text{ times } g$$

111. The velocity of a car changes over an 8.0-s time period, as shown in **Table 3-6.**

Table 3-6	
Velocity v. Time	
Time (s)	Velocity (m/s)
0.0	0.0
1.0	4.0
2.0	8.0
3.0	12.0
4.0	16.0
5.0	20.0
6.0	20.0
7.0	20.0
8.0	20.0

a. Plot the velocity-time graph of the motion.



b. Determine the displacement of the car during the first 2.0 s.

Find the area under the *v-t* curve.

$$d = \frac{1}{2}bh$$

$$= \left(\frac{1}{2}\right)(2.0\text{ s})(8.0\text{ m/s} - 0.0\text{ m/s})$$

$$= 8.0\text{ m}$$

c. What displacement does the car have during the first 4.0 s?

Find the area under the *v-t* curve.

$$d = \frac{1}{2}bh$$

$$= \left(\frac{1}{2}\right)(4.0\text{ s})(16.0\text{ m/s} - 0.0\text{ m/s})$$

$$= 32\text{ m}$$

d. What is the displacement of the car during the entire 8.0 s?

Find the area under the *v-t* curve.

$$d = \frac{1}{2}bh + bh$$

$$= \left(\frac{1}{2}\right)(5.0\text{ s})(20.0\text{ m/s} - 0.0\text{ m/s}) + (8.0\text{ s} - 5.0\text{ s})(20.0\text{ m/s})$$

$$= 110\text{ m}$$

e. Find the slope of the line between $t = 0.0$ s and $t = 4.0$ s. What does this slope represent?

$$a = \frac{\Delta v}{\Delta t} = \frac{16.0\text{ m/s} - 0.00\text{ m/s}}{4.0\text{ s} - 0.0\text{ s}}$$

$$= 4.0\text{ m/s}^2\text{, acceleration}$$

f. Find the slope of the line between $t = 5.0$ s and $t = 7.0$ s. What does this slope indicate?

$$a = \frac{\Delta v}{\Delta t} = \frac{20.0\text{ m/s} - 20.0\text{ m/s}}{7.0\text{ s} - 5.0\text{ s}}$$

$$= 0.0\text{ m/s}^2\text{, constant velocity}$$

Level 3

112. A truck is stopped at a stoplight. When the light turns green, the truck accelerates at 2.5 m/s^2. At the same instant, a car passes the truck going 15 m/s. Where and when does the truck catch up with the car?

Car:

$$d_f = d_i + vt_f$$

$$d_{car} = d_i + v_{car}t_f = v_{car}t_f$$

$$= 0 + (15\text{ m/s})t_f$$

Truck:

$$d_f = d_i + v_it_f + \frac{1}{2}at_f^2$$

$$d_{truck} = \frac{1}{2}a_{truck}t_f^2$$

$$= 0 + 0 + \left(\frac{1}{2}\right)(2.5\text{ m/s}^2)t_f^2$$

When the truck catches up, the displacements are equal.

$$v_{car}t_f = \frac{1}{2}a_{truck}t_f^2$$

$$0 = \frac{1}{2}a_{truck}t_f^2 - v_{car}t_f$$

$$0 = t_f\left(\frac{1}{2}a_{truck}t_f - v_{car}\right)$$

therefore

$$t_f = 0 \text{ and } \frac{1}{2}a_{truck}t_f - v_{car} = 0$$

$$t_f = \frac{2v_{car}}{a_{truck}}$$

$$= \frac{(2)(15 \text{ m/s})}{2.5 \text{ m/s}}$$

$$= 12 \text{ s}$$

$$d_f = (15 \text{ m/s})t_f$$

$$= (15 \text{ m/s})(12 \text{ s})$$

$$= 180 \text{ m}$$

113. Safety Barriers Highway safety engineers build soft barriers, such as the one shown in **Figure 3-21,** so that cars hitting them will slow down at a safe rate. A person wearing a safety belt can withstand an acceleration of -3.0×10^2 m/s^2. How thick should barriers be to safely stop a car that hits a barrier at 110 km/h?

■ **Figure 3-21**

$$v_i = \frac{(110 \text{ km/h})(1000 \text{ m/km})}{3600 \text{ s/h}} = 31 \text{ m/s}$$

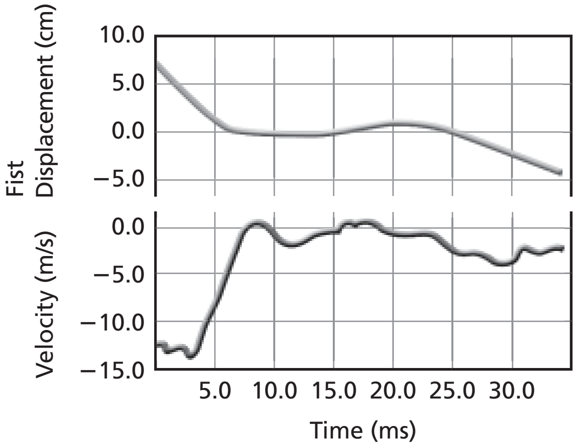
$$v_f^2 = v_i^2 + 2ad_f$$

with $v_f = 0$ **m/s,** $v_i^2 = -2ad_f$**, or**

$$d_f = \frac{-v_i^2}{2a} = \frac{-(31 \text{ m/s})^2}{(2)(-3.0\times10^2 \text{ m/s}^2)}$$

$$= 1.6 \text{ m thick}$$

114. Karate The position-time and velocity-time graphs of George's fist breaking a wooden board during karate practice are shown in **Figure 3-22.**



■ **Figure 3-22**

a. Use the velocity-time graph to describe the motion of George's fist during the first 10 ms.

The fist moves downward at about −13 m/s for about 4 ms. It then suddenly comes to a halt (accelerates).

b. Estimate the slope of the velocity-time graph to determine the acceleration of his fist when it suddenly stops.

$$a = \frac{\Delta v}{\Delta t} = \frac{0 \text{ m/s} - (-13 \text{ m/s})}{7.5 \text{ ms} - 4.0 \text{ ms}}$$

$$= 3.7\times10^3 \text{ m/s}^2$$

c. Express the acceleration as a multiple of the gravitational acceleration, $g = 9.80$ m/s^2.

$$\frac{3.7\times10^3 \text{ m/s}^2}{9.80 \text{ m/s}^2} = 3.8\times10^2$$

The acceleration is about 380*g*.

d. Determine the area under the velocity-time curve to find the displacement of the fist in the first 6 ms. Compare this with the position-time graph.

The area can be approximated by a rectangle:

$$(-13 \text{ m/s})(0.006 \text{ s}) = -8 \text{ cm}$$

This is in agreement with the position-time graph where the hand moves from +8 cm to 0 cm, for a net displacement of −8 cm.

115. **Cargo** A helicopter is rising at 5.0 m/s when a bag of its cargo is dropped. The bag falls for 2.0 s.

a. What is the bag's velocity?

$v_f = v_i + at_f$ **where** $a = -g$

$= v_i - gt_f$

$= 5.0\ m/s - (9.80\ m/s^2)(2.0\ s)$

$= -15\ m/s$

b. How far has the bag fallen?

$d_f = v_i t_f + \frac{1}{2}at_f^2$ **where** $a = -g$

$= v_i t_f - \frac{1}{2}gt_f^2$

$= (5.0\ m/s)(2.0\ s) - \left(\frac{1}{2}\right)(9.80\ m/s^2)(2.0\ s)^2$

$= -1.0\times10^1\ m$

The bag has fallen 1.0×10^1 **m**

c. How far below the helicopter is the bag?

The helicopter has risen

$d_f = v_i t_f = (5.0\ m/s^2)(2.0\ s)$

$= 1.0\times10^1\ m$

The bag is 1.0×10^1 **m below the origin and** 2.0×10^1 **m below the helicopter.**

Thinking Critically

page 84

116. **Apply CBLs** Design a lab to measure the distance an accelerated object moves over time. Use equal time intervals so that you can plot velocity over time as well as distance. A pulley at the edge of a table with a mass attached is a good way to achieve uniform acceleration. Suggested materials include a motion detector, CBL, lab cart, string, pulley, C-clamp, and masses. Generate distance-time and velocity-time graphs using different masses on the pulley. How does the change in mass affect your graphs?

Students' labs will vary. Students should find that a change in the mass over the edge of the table will not change the distance the cart moves, because the acceleration is always the same: *g*.

117. **Analyze and Conclude** Which has the greater acceleration: a car that increases its speed from 50 km/h to 60 km/h, or a bike that goes from 0 km/h to 10 km/h in the same time? Explain.

$a = \frac{v_f - v_i}{\Delta t}$

For car, $a = \frac{60\ km/h - 50\ km/h}{\Delta t}$

$= \frac{10\ km/h}{\Delta t}$

For bike, $a = \frac{10\ km/h - 0\ km/h}{\Delta t}$

$= \frac{10\ km/h}{\Delta t}$

The change in velocity is the same.

118. **Analyze and Conclude** An express train, traveling at 36.0 m/s, is accidentally sidetracked onto a local train track. The express engineer spots a local train exactly 1.00×10^2 m ahead on the same track and traveling in the same direction. The local engineer is unaware of the situation. The express engineer jams on the brakes and slows the express train at a constant rate of 3.00 m/s^2. If the speed of the local train is 11.0 m/s, will the express train be able to stop in time, or will there be a collision? To solve this problem, take the position of the express train when the engineer first sights the local train as a point of origin. Next, keeping in mind that the local train has exactly a 1.00×10^2 m lead, calculate how far each train is from the origin at the end of the 12.0 s it would take the express train to stop (accelerate at −3.00 m/s^2 from 36 m/s to 0 m/s).

a. On the basis of your calculations, would you conclude that a collision will occur?

Express:

$d_f = v_i t_f + \frac{1}{2}at_f^2$

$= (36.0\ m/s)(12.0\ s) +$

$$\left(\frac{1}{2}\right)(-3.00 \text{ m/s}^2)(12.0 \text{ s})^2$$

= 432 m − 216 m = 216 m

Local:

$$d_f = d_i + v_i t_f + a t_f^2$$

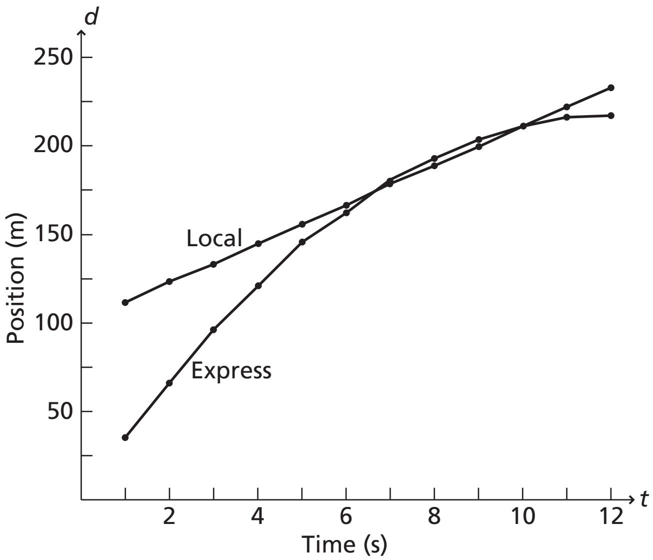
= 100 m + (11.0 m/s)(12.0 s) + 0

= 232 m

On this basis, no collision will occur.

b. The calculations that you made do not allow for the possibility that a collision might take place before the end of the 12 s required for the express train to come to a halt. To check this, take the position of the express train when the engineer first sights the local train as the point of origin and calculate the position of each train at the end of each second after the sighting. Make a table showing the distance of each train from the origin at the end of each second. Plot these positions on the same graph and draw two lines. Use your graph to check your answer to part **a.**

t (s)	*d* (Local) (m)	*d* (Express) (m)
1	111	35
2	122	66
3	133	95
4	144	120
5	155	145
6	166	162
7	177	179
8	188	192
9	199	203
10	210	210
11	221	215
12	232	216



They collide between 6 and 7 s.

Writing in Physics

page 84

119. Research and describe Galileo's contributions to physics.

Student answers will vary. Answers should include Galileo's experiments demonstrating how objects accelerate as they fall. Answers might include his use of a telescope to discover the moons of Jupiter and the rings of Saturn, and his reliance on experimental results rather than authority.

120. Research the maximum acceleration a human body can withstand without blacking out. Discuss how this impacts the design of three common entertainment or transportation devices.

Answers will vary. Because humans can experience negative effects, like blackouts, the designers of roller coasters need to structure the downward slopes in such a way that the coaster does not reach accelerations that cause blackouts. Likewise, engineers working on bullet trains, elevators, or airplanes need to design the system in such a way that allows the object to rapidly accelerate to high speeds, without causing the passengers to black out.

Cumulative Review

page 84

121. Solve the following problems. Express your answers in scientific notation. (Chapter 1)

a. 6.2×10^{-4} m + 5.7×10^{-3} m

6.3×10^{-3} m

b. 8.7×10^{8} km − 3.4×10^{7} m

8.4×10^{8} km

c. $(9.21\times10^{-5}\text{ cm})(1.83\times10^{8}\text{ cm})$

1.69×10^{4} cm^2

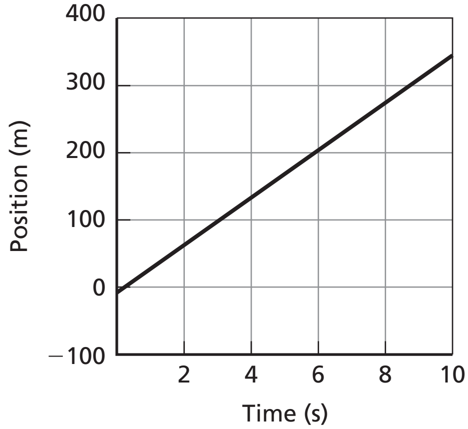
d. $(2.63\times10^{-6}\text{ m})/(4.08\times10^{6}\text{ s})$

6.45×10^{-13} m/s

122. The equation below describes the motion of an object. Create the corresponding position-time graph and motion diagram. Then write a physics problem that could be solved using that equation. Be creative. $d = (35.0\text{ m/s})\,t - 5.0\text{ m}$ (Chapter 2)

Graph and motion diagram indicate constant velocity motion with a velocity of 35.0 m/s and initial position of −5.0 m. Answers will vary for the create-a-problem part.

Position-Time Graph



Motion Diagram

Challenge Problem

page 75

You notice a water balloon fall past your classroom window. You estimate that it took the balloon about t seconds to fall the length of the window and that the window is about y meters high. Suppose the balloon started from rest, approximately how high above the top of the window was it released? Your answer should be in terms of t, y, g, and numerical constants.

Down is positive. Work this problem in two stages. Stage 1 is falling the distance *D* to the top of the window. Stage 2 is falling the distance *y* from the top of the window to the bottom of the window.

Stage 1: the origin is at the top of the fall.

$$v_{f1}^2 = v_{i1}^2 + 2a(d_{f1} - d_{i1})$$
$$= 0 + 2g(D - 0)$$
$$v_{f1} = \sqrt{2gD}$$

Stage 2: the origin is at the top of the window.

$$d_{f2} = d_{i1} + v_{i1}t_{f2} + \tfrac{1}{2}at_{f2}^2$$
$$y = 0 + v_{f1}t + \tfrac{1}{2}gt^2$$
$$= 0 + \left(\sqrt{2gD}\right)(t) + \tfrac{1}{2}gt^2$$
$$\sqrt{2gD} = \frac{y}{t} - \frac{gt}{2}$$
$$D = \frac{1}{2g}\left(\frac{y}{t} - \frac{gt}{2}\right)^2$$

CHAPTER

4 Forces in One Dimension

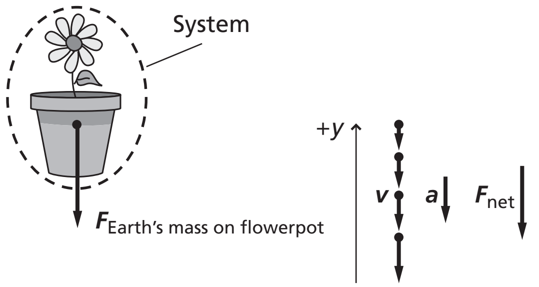
Practice Problems

4.1 Force and Motion pages 87–95

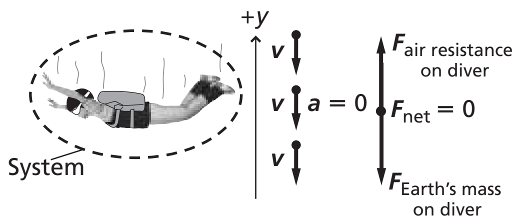
page 89

For each of the following situations, specify the system and draw a motion diagram and a free-body diagram. Label all forces with their agents, and indicate the direction of the acceleration and of the net force. Draw vectors of appropriate lengths.

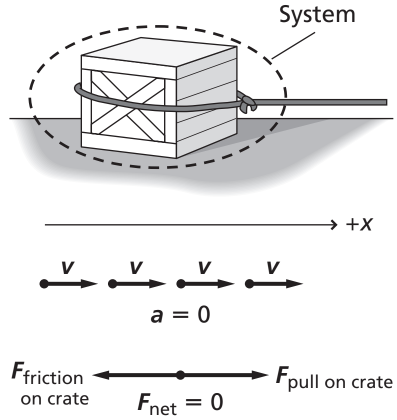
1. A flowerpot falls freely from a windowsill. (Ignore any forces due to air resistance.)



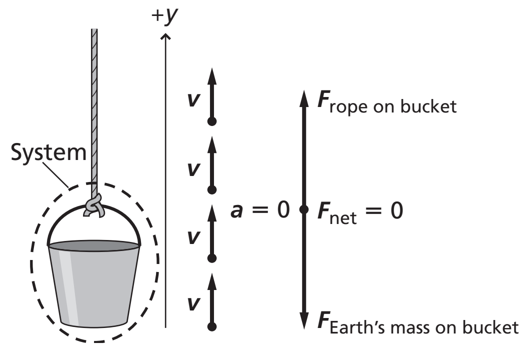
2. A sky diver falls downward through the air at constant velocity. (The air exerts an upward force on the person.)



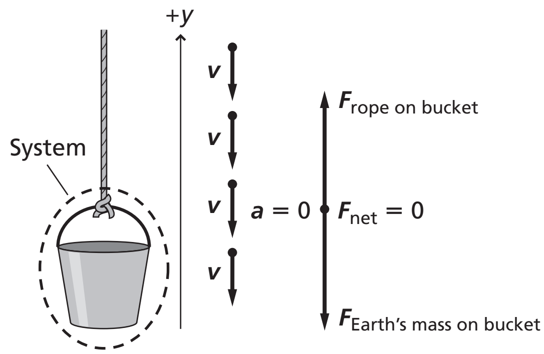
3. A cable pulls a crate at a constant speed across a horizontal surface. The surface provides a force that resists the crate's motion.



4. A rope lifts a bucket at a constant speed. (Ignore air resistance.)



5. A rope lowers a bucket at a constant speed. (Ignore air resistance.)



page 93

6. Two horizontal forces, 225 N and 165 N, are exerted on a canoe. If these forces are applied in the same direction, find the net horizontal force on the canoe.

$F_{net} = 225\text{ N} + 165\text{ N} = 3.90\times10^2\text{ N}$

in the direction of the two forces

7. If the same two forces as in the previous problem are exerted on the canoe in opposite directions, what is the net horizontal force on the canoe? Be sure to indicate the direction of the net force.

$F_{net} = 225\text{ N} - 165\text{ N} = 6.0\times10^1\text{ N}$

in the direction of the larger force

8. Three confused sleigh dogs are trying to pull a sled across the Alaskan snow. Alutia pulls east with a force of 35 N, Seward also pulls east but with a force of 42 N, and big Kodiak pulls west with a force of 53 N. What is the net force on the sled?

Identify east as positive and the sled as the system.

$$F_{net} = F_{\text{Alutia on sled}} + F_{\text{Seward on sled}} - F_{\text{Kodiak on sled}}$$
$$= 35\text{ N} + 42\text{ N} - 53\text{ N}$$
$$= 24\text{ N}$$
$$F_{net} = 24\text{ N east}$$

Section Review

4.1 Force and Motion pages 87–95

page 95

9. Force Identify each of the following as either **a, b,** or **c:** weight, mass, inertia, the push of a hand, thrust, resistance, air resistance, spring force, and acceleration.

a. a contact force

b. a field force

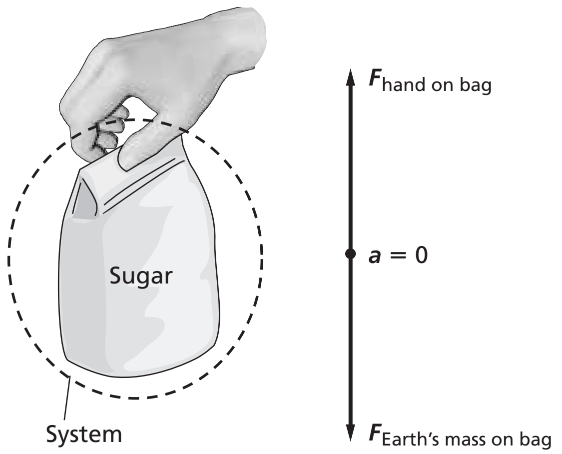
c. not a force

weight (b), mass (c), inertia (c), push of a hand (a), thrust (a), resistance (a), air resistance (a), spring force (a), acceleration (c)

10. Inertia Can you feel the inertia of a pencil? Of a book? If you can, describe how.

Yes, you can feel the inertia of either object by using your hand to give either object an acceleration; that is, try to change the objects velocity.

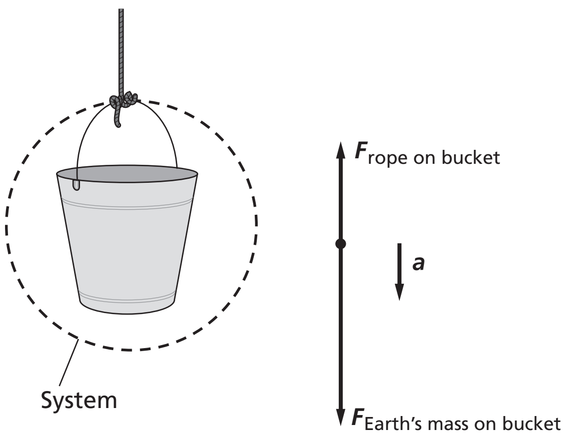
11. Free-Body Diagram Draw a free-body diagram of a bag of sugar being lifted by your hand at a constant speed. Specifically identify the system. Label all forces with their agents and make the arrows the correct lengths.



12. Direction of Velocity If you push a book in the forward direction, does this mean its velocity has to be forward?

No, it could be moving backward and you would be reducing that velocity.

13. Free-Body Diagram Draw a free-body diagram of a water bucket being lifted by a rope at a decreasing speed. Specifically identify the system. Label all forces with their agents and make the arrows the correct lengths.



14. **Critical Thinking** A force of 1 N is the only force exerted on a block, and the acceleration of the block is measured. When the same force is the only force exerted on a second block, the acceleration is three times as large. What can you conclude about the masses of the two blocks?

Because $m = F/a$ and the forces are the same, the mass of the second block is one-third the mass of the first block.

Practice Problems

4.2 Using Newton's Laws pages 96–101

page 97

15. You place a watermelon on a spring scale at the supermarket. If the mass of the watermelon is 4.0 kg, what is the reading on the scale?

The scale reads the weight of the watermelon:

$$F_g = mg = (4.0\text{ kg})(9.80\text{ m/s}^2) = 39\text{ N}$$

16. Kamaria is learning how to ice-skate. She wants her mother to pull her along so that she has an acceleration of 0.80 m/s^2. If Kamaria's mass is 27.2 kg, with what force does her mother need to pull her? (Neglect any resistance between the ice and Kamaria's skates.)

$$F_{net} = ma = (27.2\text{ kg})(0.80\text{ m/s}^2) = 22\text{ N}$$

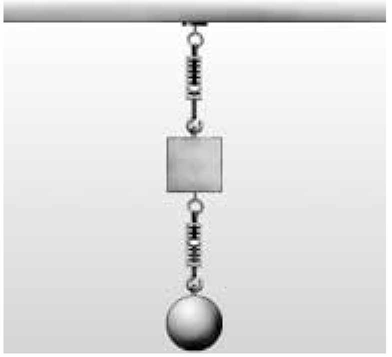
17. Taru and Reiko simultaneously grab a 0.75-kg piece of rope and begin tugging on it in opposite directions. If Taru pulls with a force of 16.0 N and the rope accelerates away from her at 1.25 m/s^2, with what force is Reiko pulling?

Identify Reiko's direction as positive and the rope as the system.

$$F_{net} = F_{\text{Rieko on rope}} - F_{\text{Taru on rope}} = ma$$

$$F_{\text{Rieko on rope}} = ma + F_{\text{Taru on rope}} = (0.75\text{ kg})(1.25\text{ m/s}^2) + 16.0\text{ N} = 17\text{ N}$$

18. In **Figure 4-8,** the block has a mass of 1.2 kg and the sphere has a mass of 3.0 kg. What are the readings on the two scales? (Neglect the masses of the scales.)



■ Figure 4-8

Bottom scale: Identify the sphere as the system and up as positive.

$$F_{net} = F_{\text{scale on sphere}} - F_{\text{Earth's mass on sphere}} = ma = 0$$

$$F_{\text{scale on sphere}} = F_{\text{Earth's mass on sphere}} = m_{\text{sphere}}g = (3.0\text{ kg})(9.80\text{ m/s}^2) = 29\text{ N}$$

Top scale: Identify the block as the system and up as positive.

$$F_{net} = F_{\text{top scale on block}} - F_{\text{bottom scale on block}} - F_{\text{Earth's mass on block}} = ma = 0$$

$$F_{\text{top scale on block}} = F_{\text{bottom scale on block}} + F_{\text{Earth's mass on block}} = F_{\text{bottom scale on block}} + m_{\text{block}}g = 29\text{ N} + (1.2\text{ kg})(9.80\text{ m/s}^2) = 41\text{ N}$$

page 100

19. On Earth, a scale shows that you weigh 585 N.

a. What is your mass?

The scale reads 585 N. Since there is no acceleration, your weight equals the downward force of gravity:

$F_g = mg$

so $m = \frac{F_g}{g} = \frac{585\ N}{9.80\ m/s^2} = 59.7\ kg$

b. What would the scale read on the Moon ($g = 1.60\ m/s^2$)?

On the moon, *g* changes:

$F_g = mg_{Moon}$

$= (59.7\ kg)(1.60\ m/s^2)$

$= 95.5\ N$

20. Use the results from Example Problem 2 to answer questions about a scale in an elevator on Earth. What force would be exerted by the scale on a person in the following situations?

a. The elevator moves at constant speed.

Constant speed, so $a = 0$ and $F_{net} = 0$.

$F_{scale} = F_g$

$= mg = (75.0\ kg)(9.80\ m/s^2)$

$= 735\ N$

b. It slows at $2.00\ m/s^2$ while moving upward.

Slowing while moving upward, so

$a = -2.00\ m/s^2$

$F_{scale} = F_{net} + F_g$

$= ma + mg$

$= m(a + g)$

$= (75.0\ kg)(-2.00\ m/s^2 + 9.80\ m/s^2)$

$= 585\ N$

c. It speeds up at $2.00\ m/s^2$ while moving downward.

Accelerating downward,

so $a = -2.00\ m/s^2$

$F_{scale} = F_{net} + F_g$

$= ma + mg$

$= m(a + g)$

$= (75.0\ kg)(-2.00\ m/s^2 + 9.80\ m/s^2)$

$= 585\ N$

d. It moves downward at constant speed.

Constant speed, so $a = 0$ and $F_{net} = 0$

$F_{scale} = F_g = mg$

$= (75.0\ kg)(9.80\ m/s^2)$

$= 735\ N$

e. It slows to a stop at a constant magnitude of acceleration.

Constant acceleration = *a*, though the sign of *a* depends on the direction of the motion that is ending.

$F_{scale} = F_{net} + F_g$

$= ma + mg$

$= (75.0\ kg)(a) + (75.0\ kg)(9.80\ m/s^2)$

$= (75.0\ kg)(a) + 735\ N$

Section Review

4.2 Using Newton's Laws pages 96–101

page 101

21. Lunar Gravity Compare the force holding a 10.0-kg rock on Earth and on the Moon. The acceleration due to gravity on the Moon is 1.62 m/s^2.

To hold the rock on Earth:

$F_{net} = F_{Earth\ on\ rock} - F_{hold\ on\ rock} = 0$

$F_{hold\ on\ rock} = F_{Earth\ on\ rock} = mg_{Earth}$

$= (10.0\text{ kg})(9.80\text{ m/s}^2)$

$= 98.0\text{ N}$

To hold the rock on the Moon:

$F_{net} = F_{Moon\ on\ rock} - F_{hold\ on\ rock} = 0$

$F_{hold\ on\ rock} = F_{Moon\ on\ rock} = mg_{Moon}$

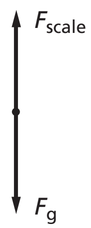
$= (10.0\text{ kg})(1.62\text{ m/s}^2)$

$= 16.2\text{ N}$

22. Real and Apparent Weight You take a ride in a fast elevator to the top of a tall building and ride back down while standing on a bathroom scale. During which parts of the ride will your apparent and real weights be the same? During which parts will your apparent weight be less than your real weight? More than your real weight? Sketch free-body diagrams to support your answers.

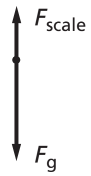
Apparent weight and real weight are the same when you are traveling either up or down at a constant velocity. Apparent weight is less than real weight when the elevator is slowing while rising or speeding up while descending. Apparent weight is greater when speeding up while rising or slowing while going down.

Constant Velocity



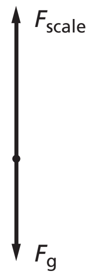
apparent weight = real weight

Slowing While Rising/ Speeding Up While Descending



apparent weight < real weight

Speeding Up While Rising/ Slowing While Descending



apparent weight > real weight

23. Acceleration Tecle, with a mass of 65.0 kg, is standing by the boards at the side of an ice-skating rink. He pushes off the boards with a force of 9.0 N. What is his resulting acceleration?

Identify Tecle as the system and the direction away from the boards as positive. The ice can be treated as a resistance-free surface.

$F_{net} = F_{boards\ on\ Tecle} = ma$

$a = \frac{F_{boards\ on\ Tecle}}{m}$

$= \frac{9.0\text{ N}}{65.0\text{ kg}}$

$= 0.14\text{ m/s}^2$ **away from the boards**

24. Motion of an Elevator You are riding in an elevator holding a spring scale with a 1-kg mass suspended from it. You look at the scale and see that it reads 9.3 N. What, if anything, can you conclude about the elevator's motion at that time?

If the elevator is stationary or moving at a constant velocity, the scale should read 9.80 N. Because the scale reads a lighter weight, the elevator must be accelerating downward. To find the exact acceleration: identify up as positive and the 1-kg mass as the system.

$$F_{\text{net}} = F_{\text{scale on 1 kg}} - F_{\text{Earth's mass on 1 kg}} = ma$$

$$a = \frac{F_{\text{scale on 1 kg}} - F_{\text{Earth's mass on 1 kg}}}{m}$$

$$= \frac{9.3\text{ N} - 9.80\text{ N}}{1\text{ kg}}$$

$$= -0.5\text{ m/s}^2$$

$$= 0.5\text{ m/s}^2\text{ downward}$$

25. Mass Marcos is playing tug-of-war with his cat using a stuffed toy. At one instant during the game, Marcos pulls on the toy with a force of 22 N, the cat pulls in the opposite direction with a force of 19.5 N, and the toy experiences an acceleration of 6.25 m/s^2. What is the mass of the toy?

Identify the toy as the system and the direction toward his cat as the positive direction.

$$F_{\text{net}} = F_{\text{Marcos on toy}} - F_{\text{cat on toy}} = ma$$

$$m = \frac{F_{\text{Marcos on toy}} - F_{\text{cat on toy}}}{a}$$

$$= \frac{22\text{ N} - 19.5\text{ N}}{6.25\text{ m/s}^2}$$

$$= 0.40\text{ kg}$$

26. Acceleration A sky diver falls at a constant speed in the spread-eagle position. After he opens his parachute, is the sky diver accelerating? If so, in which direction? Explain your answer using Newton's laws.

Yes, for a while the diver is accelerating upward because there is an additional upward force due to air resistance on the parachute. The upward acceleration causes the driver's downward velocity to decrease. Newton's second law says that a net force in a certain direction will result in an acceleration in that direction ($F_{\text{net}} = ma$).

27. Critical Thinking You have a job at a meat warehouse loading inventory onto trucks for shipment to grocery stores. Each truck has a weight limit of 10,000 N of cargo. You push each crate of meat along a low-resistance roller belt to a scale and weigh it before moving it onto the truck. However, right after you weigh a 1000-N crate, the scale breaks. Describe a way in which you could apply Newton's laws to figure out the approximate masses of the remaining crates.

Answers may vary. One possible answer is the following: You can neglect resistance if you do all your maneuvering on the roller belt. Because you know the weight of the 1000 N crate, you can use it as your standard. Pull on the 1000 N crate with a particular force for 1 s, estimate its velocity, and calculate the acceleration that your force gave to it. Next, pull on a crate of unknown mass with as close to the same force as you can for 1 s. Estimate the crate's velocity and calculate the acceleration your force gave to it. The force you pulled with on each crate will be the net force in each case.

$$F_{\text{net 1000-N crate}} = F_{\text{net unknown crate}}$$

$$(1000\text{ N})(a_{\text{1000-N crate}}) = (m_{\text{unk}})(a_{\text{unk}})$$

$$m_{\text{unk}} = \frac{(1000\text{ N})(a_{\text{1000-N crate}})}{a_{\text{unk}}}$$

Practice Problems

4.3 Interaction Forces pages 102–107

page 104

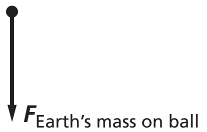
28. You lift a relatively light bowling ball with your hand, accelerating it upward. What are the forces on the ball? What forces does the ball exert? What objects are these forces exerted on?

The forces on the ball are the force of your hand and the gravitational force of Earth's mass. The ball exerts a force on your hand and a gravitational force on Earth. All these forces are exerted on your hand, on the ball, or on Earth.

29. A brick falls from a construction scaffold. Identify any forces acting on the brick. Also identify any forces that the brick exerts and the objects on which these forces are exerted. (Air resistance may be ignored.)

The only force acting on the brick is the gravitational attraction of Earth's mass. The brick exerts an equal and opposite force on Earth.

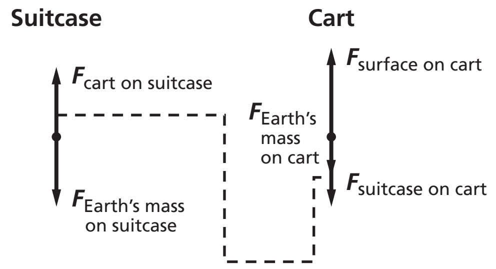
30. You toss a ball up in the air. Draw a free-body diagram for the ball while it is still moving upward. Identify any forces acting on the ball. Also identify any forces that the ball exerts and the objects on which these forces are exerted.



The only force acting on the ball is the force of Earth's mass on the ball, when ignoring air resistance. The ball exerts an equal and opposite force on Earth.

31. A suitcase sits on a stationary airport luggage cart, as in **Figure 4-13.** Draw a free-body diagram for each object and specifically indicate any interaction pairs between the two.

■ **Figure 4-13**



page 106

32. You are helping to repair a roof by loading equipment into a bucket that workers hoist to the rooftop. If the rope is guaranteed not to break as long as the tension does not exceed 450 N and you fill the bucket until it has a mass of 42 kg, what is the greatest acceleration that the workers can give the bucket as they pull it to the roof?

Identify the bucket as the system and up as positive.

$$F_{\text{net}} = F_{\text{rope on bucket}} - F_{\text{Earth's mass on bucket}} = ma$$

$$a = \frac{F_{\text{rope on bucket}} - F_{\text{Earth's mass on bucket}}}{m}$$

$$= \frac{F_{\text{rope on bucket}} - mg}{m}$$

$$= \frac{450\ \text{N} - (42\ \text{kg})(9.80\ \text{m/s}^2)}{42\ \text{kg}}$$

$$= 0.91\ \text{m/s}^2$$

33. Diego and Mika are trying to fix a tire on Diego's car, but they are having trouble getting the tire loose. When they pull together, Mika with a force of 23 N and Diego with a force of 31 N, they just barely get the tire to budge. What is the magnitude of the strength of the force between the tire and the wheel?

Identify the tire as the system and the direction of pulling as positive.

$F_{\text{net}} = F_{\text{wheel on tire}} - F_{\text{Mika on tire}} - F_{\text{Diego on tire}}$

$= ma = 0$

$F_{\text{wheel on tire}} = F_{\text{Mika on tire}} + F_{\text{Diego on tire}}$

$= 23\text{ N} + 31\text{ N}$

$= 54\text{ N}$

Section Review

4.3 Interaction Forces pages 102–107

page 107

34. Force Hold a book motionless in your hand in the air. Identify each force and its interaction pair on the book.

The forces on the book are downward force of gravity due to the mass of Earth and the upward force of the hand. The force of the book on Earth and the force of the book on the hand are the other halves of the interaction pairs.

35. Force Lower the book from problem 34 at increasing speed. Do any of the forces or their interaction-pair partners change? Explain.

Yes, the force of the hand on the book becomes smaller so there is a downward acceleration. The force of the book also becomes smaller; you can feel that. The interaction pair partners remain the same.

36. Tension A block hangs from the ceiling by a massless rope. A second block is attached to the first block and hangs below it on another piece of massless rope. If each of the two blocks has a mass of 5.0 kg, what is the tension in each rope?

For the bottom rope with the positive direction upward:

$F_{\text{net}} = F_{\text{bottom rope on bottom block}} - F_{\text{Earth's mass on bottom block}}$

$= ma = 0$

$F_{\text{bottom rope on bottom block}}$

$= F_{\text{Earth's mass on bottom block}}$

$= mg$

$= (5.0\text{ kg})(9.80\text{ m/s}^2)$

$= 49\text{ N}$

For the top rope, with the positive direction upward:

$F_{\text{net}} = F_{\text{top rope on top block}} - F_{\text{bottom rope on top block}} - F_{\text{Earth's mass on top block}}$

$= ma = 0$

$F_{\text{top rope on top block}}$

$= F_{\text{Earth's mass on top block}} + F_{\text{bottom rope on top block}}$

$= mg + F_{\text{bottom rope on top block}}$

$= (5.0\text{ kg})(9.80\text{ m/s}^2) + 49\text{ N}$

$= 98\text{ N}$

37. Tension If the bottom block in problem 36 has a mass of 3.0 kg and the tension in the top rope is 63.0 N, calculate the tension in the bottom rope and the mass of the top block.

For the bottom rope with the positive direction upward:

$F_{\text{net}} = F_{\text{bottom rope on bottom block}} - F_{\text{Earth's mass on bottom block}}$

$= ma = 0$

$F_{\text{bottom rope on bottom block}}$

$= F_{\text{Earth's mass on bottom block}}$

$= (3.0\text{ kg})(9.80\text{ m/s}^2)$

$= 29\text{ N}$

For the top mass with the positive direction upward:

$$F_{net} = F_{top\ rope\ on\ top\ block} - F_{bottom\ rope\ on\ top\ block} - F_{Earth's\ mass\ on\ top\ block} = ma = 0$$

$$F_{Earth's\ mass\ on\ top\ block} = mg = F_{top\ rope\ on\ top\ block} - F_{bottom\ rope\ on\ top\ block}$$

$$m = \frac{F_{top\ rope\ on\ top\ block} - F_{bottom\ rope\ on\ top\ block}}{g}$$

$$= \frac{63.0\ N - 29\ N}{9.80\ m/s^2}$$

$$= 3.5\ kg$$

38. Normal Force Poloma hands a 13-kg box to 61-kg Stephanie, who stands on a platform. What is the normal force exerted by the platform on Stephanie?

Identify Stephanie as the system and positive to be upward.

$$F_{net} = F_{platform\ on\ Stephanie} - F_{box\ on\ Stephanie} - F_{Earth's\ mass\ on\ Stephanie}$$

$$F_{platform\ on\ Stephanie} = F_{box\ on\ Stephanie} + F_{Earth's\ mass\ on\ Stephanie}$$

$$= m_{box}g + m_{Stephanie}g$$

$$= (13\ kg)(9.80\ m/s^2) + (61\ kg)(9.80\ m/s^2)$$

$$= 7.3\times10^2\ N$$

39. Critical Thinking A curtain prevents two tug-of-war teams from seeing each other. One team ties its end of the rope to a tree. If the other team pulls with a 500-N force, what is the tension? Explain.

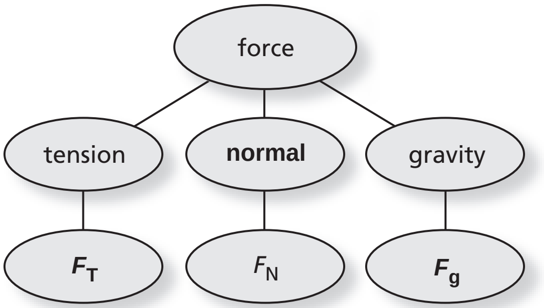
The tension would be 500 N. The rope is in equilibrium, so the net force on it is zero. The team and the tree exert equal forces in opposite directions.

Chapter Assessment

Concept Mapping

page 112

40. Complete the following concept map using the following term and symbols: *normal*, F_T, F_g.



Mastering Concepts

page 112

41. A physics book is motionless on the top of a table. If you give it a hard push with your hand, it slides across the table and slowly comes to a stop. Use Newton's laws to answer the following questions. (4.1)

a. Why does the book remain motionless before the force of your hand is applied?

An object at rest tends to stay at rest if no outside force acts on it.

b. Why does the book begin to move when your hand pushes hard enough on it?

The force from your hand is greater than any opposing force such as friction. With a net force on it, the book slides in the direction of the net force.

c. Under what conditions would the book remain in motion at a constant speed?

The book would remain in motion if the net force acting on it is zero.

42. Cycling Why do you have to push harder on the pedals of a single-speed bicycle to start it moving than to keep it moving at a constant velocity? (4.1)

A large force is required to accelerate the mass of the bicycle and rider. Once the desired constant velocity is reached, a much smaller force is sufficient to overcome the ever-present frictional forces.

43. Suppose that the acceleration of an object is zero. Does this mean that there are no forces acting on it? Give an example supporting your answer. (4.2)

No, it only means the forces acting on it are balanced and the net force is zero. For example, a book on a table is not moving but the force of gravity pulls down on it and the normal force of the table pushes up on it and these forces are balanced.

44. **Basketball** When a basketball player dribbles a ball, it falls to the floor and bounces up. Is a force required to make it bounce? Why? If a force is needed, what is the agent involved? (4.2)

Yes, its velocity changed direction; thus, it was accelerated and a force is required to accelerate the basketball. The agent is the floor.

45. Before a sky diver opens her parachute, she may be falling at a velocity higher than the terminal velocity that she will have after the parachute opens. (4.2)

a. Describe what happens to her velocity as she opens the parachute.

Because the force of air resistance suddenly becomes larger, the velocity of the diver drops suddenly.

b. Describe the sky diver's velocity from when her parachute has been open for a time until she is about to land.

The force of air resistance and the gravitational force are equal. Their sum is zero, so there is no longer any acceleration. The sky diver continues downward at a constant velocity.

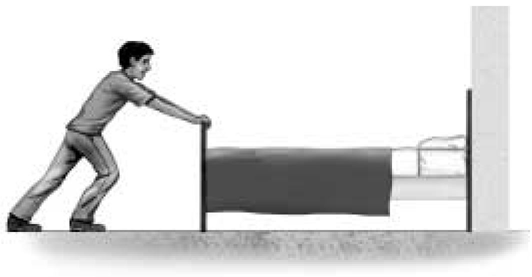
46. If your textbook is in equilibrium, what can you say about the forces acting on it? (4.2)

If the book is in equilibrium, the net force is zero. The forces acting on the book are balanced.

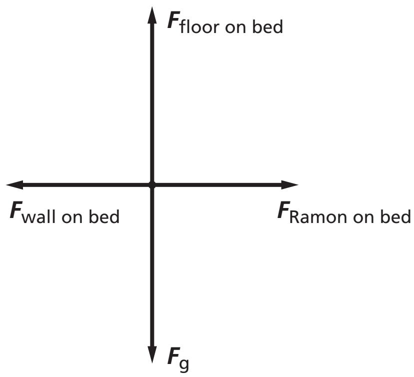
47. A rock is dropped from a bridge into a valley. Earth pulls on the rock and accelerates it downward. According to Newton's third law, the rock must also be pulling on Earth, yet Earth does not seem to accelerate. Explain. (4.3)

The rock does pull on Earth, but Earth's enormous mass would undergo only a minute acceleration as a result of such a small force. This acceleration would go undetected.

48. Ramon pushes on a bed that has been pushed against a wall, as in **Figure 4-17.** Draw a free-body diagram for the bed and identify all the forces acting on it. Make a separate list of all the forces that the bed applies to other objects. (4.3)



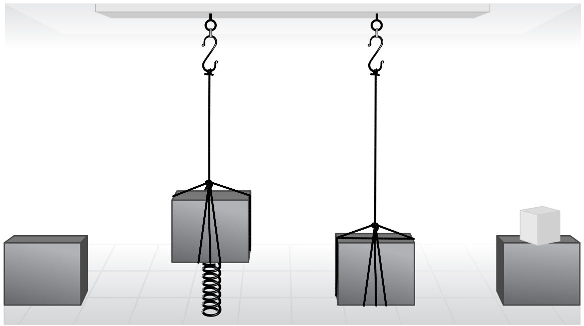
■ **Figure 4-17**



Forces that bed applies to other objects:

$F_{\text{bed on Ramon}}$, $F_{\text{bed on Earth}}$, $F_{\text{bed on floor}}$, $F_{\text{bed on wall}}$

49. **Figure 4-18** shows a block in four different situations. Rank them according to the magnitude of the normal force between the block and the surface, greatest to least. Specifically indicate any ties. (4.3)



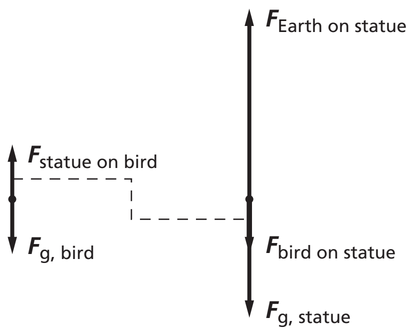
■ **Figure 4-18**

from left to right: second > fourth > third > first

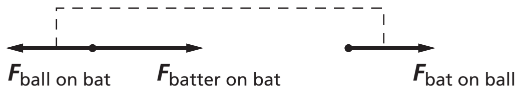
50. Explain why the tension in a massless rope is constant throughout it. (4.3)

If you draw a free-body diagram for any point on the rope, there will be two tension forces acting in opposite directions. $F_{net} = F_{up} - F_{down} = ma = 0$ (because it is massless). Therefore, $F_{up} = F_{down}$. According to Newton's third law, the force that the adjoining piece of rope exerts on this point is equal and opposite to the force that this point exerts on it, so the force must be constant throughout.

51. A bird sits on top of a statue of Einstein. Draw free-body diagrams for the bird and the statue. Specifically indicate any interaction pairs between the two diagrams. (4.3)



52. **Baseball** A slugger swings his bat and hits a baseball pitched to him. Draw free-body diagrams for the baseball and the bat at the moment of contact. Specifically indicate any interaction pairs between the two diagrams. (4.3)



Applying Concepts

pages 112–113

53. **Whiplash** If you are in a car that is struck from behind, you can receive a serious neck injury called whiplash.

a. Using Newton's laws, explain what happens to cause such an injury.

The car is suddenly accelerated forward. The seat accelerates your body, but your neck has to accelerate your head. This can hurt your neck muscles.

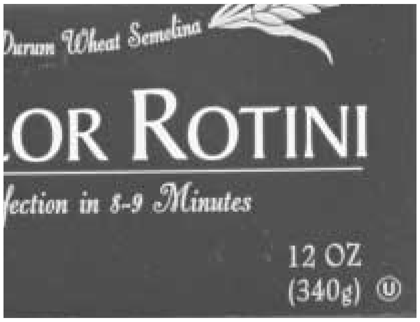
b. How does a headrest reduce whiplash?

The headrest pushes on your head, accelerating it in the same direction as the car.

54. **Space** Should astronauts choose pencils with hard or soft lead for making notes in space? Explain.

A soft lead pencil would work better because it would require less force to make a mark on the paper. The magnitude of the interaction force pair could push the astronaut away from the paper.

55. When you look at the label of the product in **Figure 4-19** to get an idea of how much the box contains, does it tell you its mass, weight, or both? Would you need to make any changes to this label to make it correct for consumption on the Moon?



■ **Figure 4-19**

The ounces tell you the weight in English units. The grams tell you the mass in metric units. The label would need to read "2 oz" to be correct on the Moon. The grams would remain unchanged.

56. From the top of a tall building, you drop two table-tennis balls, one filled with air and the other with water. Both experience air resistance as they fall. Which ball reaches terminal velocity first? Do both hit the ground at the same time?

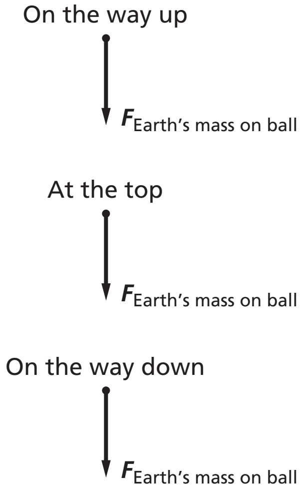
The lighter, air-filled table tennis ball reaches terminal velocity first. Its mass is less for the same shape and size, so the friction force of upward air resistance becomes equal to the downward force of *mg* sooner. Because the force of gravity on the water-filled table-tennis ball (more mass) is larger, its terminal velocity is larger, and it strikes the ground first.

57. It can be said that 1 kg equals 2.2 lb. What does this statement mean? What would be the proper way of making the comparison?

It means that on Earth's surface, the weight of 1 kg is equivalent to 2.2 lb. You should compare masses to masses and weights to weights. Thus 9.8 N equals 2.2 lb.

58. You toss a ball straight up into the air.

a. Draw a free-body diagram for the ball at three points during its motion: on the way up, at the very top, and on the way down. Specifically identify the forces acting on the ball and their agents.



b. What is the velocity of the ball at the very top of the motion?

0 m/s

c. What is the acceleration of the ball at this same point?

Because the only force acting on it is the gravitational attraction of Earth, $a = 9.80\ \text{m/s}^2$.

Mastering Problems

4.1 Force and Motion

page 113

Level 1

59. What is the net force acting on a 1.0-kg ball in free-fall?

$$F_{net} = F_g = mg$$
$$= (1.0\ \text{kg})(9.80\ \text{m/s}^2)$$
$$= 9.8\ \text{N}$$

60. Skating Joyce and Efua are skating. Joyce pushes Efua, whose mass is 40.0-kg, with a force of 5.0 N. What is Efua's resulting acceleration?

$F = ma$

$a = \frac{F}{m}$

$= \frac{5.0\text{ N}}{40.0\text{ kg}}$

$= 0.12\text{ m/s}^2$

61. A car of mass 2300 kg slows down at a rate of 3.0 m/s^2 when approaching a stop sign. What is the magnitude of the net force causing it to slow down?

$F = ma$

$= (2300\text{ kg})(3.0\text{ m/s}^2)$

$= 6.9\times10^3\text{ N}$

62. Breaking the Wishbone After Thanksgiving, Kevin and Gamal use the turkey's wishbone to make a wish. If Kevin pulls on it with a force 0.17 N larger than the force Gamal pulls with in the opposite direction, and the wishbone has a mass of 13 g, what is the wishbone's initial acceleration?

$a = \frac{F}{m}$

$= \frac{0.17\text{ N}}{0.013\text{ kg}}$

$= 13\text{ m/s}^2$

4.2 Using Newton's Laws

pages 113–114

Level 1

63. What is your weight in newtons?

$F_g = mg = (9.80\text{ m/s}^2)(m)$

Answers will vary.

64. Motorcycle Your new motorcycle weighs 2450 N. What is its mass in kilograms?

$F_g = mg$

$m = \frac{F_g}{g} = \frac{2450\text{ N}}{9.80\text{ m/s}^2}$

$= 2.50\times10^2\text{ N}$

65. Three objects are dropped simultaneously from the top of a tall building: a shot put, an air-filled balloon, and a basketball.

a. Rank the objects in the order in which they will reach terminal velocity, from first to last.

balloon, basketball, shot put

b. Rank the objects according to the order in which they will reach the ground, from first to last.

shot put, basketball, balloon

c. What is the relationship between your answers to parts a and b?

They are inverses of each other.

66. What is the weight in pounds of a 100.0-N wooden shipping case?

$(100.0\text{ N})\left(\frac{1\text{ kg}}{9.80\text{ N}}\right)\left(\frac{2.2\text{ lb}}{1\text{ kg}}\right) = 22\text{ lb}$

67. You place a 7.50-kg television on a spring scale. If the scale reads 78.4 N, what is the acceleration due to gravity at that location?

$F_g = mg$

$g = \frac{F_g}{m}$

$= \frac{78.4\text{ N}}{7.50\text{ kg}}$

$= 10.5\text{ m/s}^2$

Level 2

68. Drag Racing A 873-kg (1930-lb) dragster, starting from rest, attains a speed of 26.3 m/s (58.9 mph) in 0.59 s.

a. Find the average acceleration of the dragster during this time interval.

$a = \frac{\Delta v}{\Delta t}$

$= \frac{(26.3\text{ m/s} - 0.0\text{ m/s})}{0.59\text{ s}}$

$= 45\text{ m/s}^2$

b. What is the magnitude of the average net force on the dragster during this time?

$F = ma$

$= (873\text{ kg})(45\text{ m/s}^2)$

$= 3.9\times10^4\text{ N}$

c. Assume that the driver has a mass of 68 kg. What horizontal force does the seat exert on the driver?

$F = ma = (68 \text{ kg})(45 \text{ m/s}^2)$

$= 3.1\times10^3 \text{ N}$

69. Assume that a scale is in an elevator on Earth. What force would the scale exert on a 53-kg person standing on it during the following situations?

a. The elevator moves up at a constant speed.

$F_{scale} = F_g$

$= mg$

$= (53 \text{ kg})(9.80 \text{ m/s}^2)$

$= 5.2\times10^2 \text{ N}$

b. It slows at 2.0 m/s^2 while moving upward.

Slows while moving up or speeds up while moving down,

$F_{scale} = F_g + F_{slowing}$

$= mg + ma$

$= m(g + a)$

$= (53 \text{ kg})(9.80 \text{ m/s}^2 - 2.0 \text{ m/s}^2)$

$= 4.1\times10^2 \text{ N}$

c. It speeds up at 2.0 m/s^2 while moving downward.

Slows while moving up or speeds up while moving down,

$F_{scale} = F_g + F_{speeding}$

$= mg + ma$

$= m(g + a)$

$= (53 \text{ kg})(9.80 \text{ m/s}^2 - 2.0 \text{ m/s}^2)$

$= 4.1\times10^2 \text{ N}$

d. It moves downward at a constant speed.

$F_{scale} = F_g$

$= mg$

$= (53 \text{ kg})(9.80 \text{ m/s}^2)$

$= 5.2\times10^2 \text{ N}$

e. It slows to a stop while moving downward with a constant acceleration.

Depends on the magnitude of the acceleration.

$F_{scale} = F_g + F_{slowing}$

$= mg + ma$

$= m(g + a)$

$= (53 \text{ kg})(9.80 \text{ m/s}^2 + a)$

70. A grocery sack can withstand a maximum of 230 N before it rips. Will a bag holding 15 kg of groceries that is lifted from the checkout counter at an acceleration of 7.0 m/s^2 hold?

Use Newton's second law $F_{net} = ma$.

If $F_{groceries} > 230$, then the bag rips.

$F_{groceries} = m_{groceries}a_{groceries} + m_{groceries}g$

$= m_{groceries}(a_{groceries} + g)$

$= (15 \text{ kg})(7.0 \text{ m/s}^2 + 9.80 \text{ m/s}^2)$

$= 250 \text{ N}$

The bag does not hold.

71. A 0.50-kg guinea pig is lifted up from the ground. What is the smallest force needed to lift it? Describe its resulting motion.

$F_{lift} = F_g$

$= mg$

$= (0.50 \text{ kg})(9.80 \text{ m/s}^2)$

$= 4.9 \text{ N}$

It would move at a constant speed.

Level 3

72. Astronomy On the surface of Mercury, the gravitational acceleration is 0.38 times its value on Earth.

a. What would a 6.0-kg mass weigh on Mercury?

$F_g = mg(0.38)$

$= (6.0 \text{ kg})(9.80 \text{ m/s}^2)(0.38)$

$= 22 \text{ N}$

b. If the gravitational acceleration on the surface of Pluto is 0.08 times that of Mercury, what would a 7.0-kg mass weigh on Pluto?

$F_g = mg(0.38)(0.08)$

$= (7.0\text{ kg})(9.80\text{ m/s}^2)(0.38)(0.08)$

$= 2.1\text{ N}$

73. A 65-kg diver jumps off of a 10.0-m tower.

a. Find the diver's velocity when he hits the water.

$v_f^2 = v_i^2 + 2gd$

$v_i = 0\text{ m/s}$

so $v_f = \sqrt{2gd}$

$= \sqrt{2(9.80\text{ m/s}^2)(10.0\text{ m})}$

$= 14.0\text{ m/s}$

b. The diver comes to a stop 2.0 m below the surface. Find the net force exerted by the water.

$v_f^2 = v_i^2 + 2ad$

$v_f = 0$, so $a = \frac{-v_i^2}{2d}$

and $F = ma$

$= \frac{-mv_i^2}{2d}$

$= \frac{-(65\text{ kg})(14.0\text{ m/s})^2}{2(2.0\text{ m})}$

$= -3.2\times10^3\text{ N}$

74. Car Racing A race car has a mass of 710 kg. It starts from rest and travels 40.0 m in 3.0 s. The car is uniformly accelerated during the entire time. What net force is exerted on it?

$d = v_0t + \left(\frac{1}{2}\right)at^2$

Since $v_0 = 0$,

$a = \frac{2d}{t^2}$ and $F = ma$, so

$F = \frac{2md}{t^2}$

$= \frac{(2)(710\text{ kg})(40.0\text{ m})}{(3.0\text{ s})^2}$

$= 6.3\times10^3\text{ N}$

4.3 Interaction Forces

page 114

Level 1

75. A 6.0-kg block rests on top of a 7.0-kg block, which rests on a horizontal table.

a. What is the force (magnitude and direction) exerted by the 7.0-kg block on the 6.0-kg block?

$F_{net} = N - mg$

$F_N = F_{\text{7-kg block on 6-kg block}}$

$= mg$

$= (6.0\text{ kg})(9.80\text{ m/s}^2)$

= 59 N; the direction is upward.

b. What is the force (magnitude and direction) exerted by the 6.0-kg block on the 7.0-kg block?

equal and opposite to that in part a; therefore, 59 N downward

76. Rain A raindrop, with mass 2.45 mg, falls to the ground. As it is falling, what magnitude of force does it exert on Earth?

$F_{\text{raindrop on Earth}} = F_g$

$= mg$

$= (0.00245\text{ kg})(9.80\text{ m/s}^2)$

$= 2.40\times10^{-2}\text{ N}$

77. A 90.0-kg man and a 55-kg man have a tug-of-war. The 90.0-kg man pulls on the rope such that the 55-kg man accelerates at 0.025 m/s^2. What force does the rope exert on the 90.0-kg man?

same in magnitude as the force the rope exerts on the 55-kg man:

$F = ma = (55\text{ kg})(0.025\text{ m/s}^2) = 1.4\text{ N}$

Level 2

78. Male lions and human sprinters can both accelerate at about 10.0 m/s^2. If a typical lion weighs 170 kg and a typical sprinter weighs 75 kg, what is the difference in the force exerted on the ground during a race between these two species?

Use Newton's second law, $F_{net} = ma$.

The difference between F_{lion} and F_{human} is

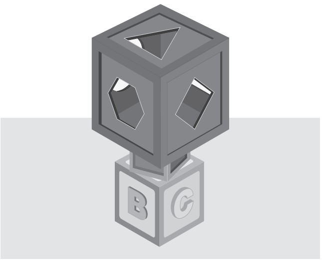
$$F_{lion} - F_{human} = m_{lion}a_{lion} - m_{human}a_{human}$$
$$= (170\text{ kg})(10.0\text{ m/s}^2) - (75\text{ kg})(10.0\text{ m/s}^2)$$
$$= 9.5\times10^2\text{ N}$$

79. A 4500-kg helicopter accelerates upward at 2.0 m/s^2. What lift force is exerted by the air on the propellers?

$$ma = F_{net} = F_{appl} + F_g = F_{appl} + mg$$
$$\text{so } F_{appl} = ma - mg = m(a - g)$$
$$= (4500\text{ kg})((2.0\text{m/s}^2) - (-9.8\text{ m/s}^2))$$
$$= 5.3\times10^4\text{ N}$$

Level 3

80. Three blocks are stacked on top of one another, as in **Figure 4-20.** The top block has a mass of 4.6 kg, the middle one has a mass of 1.2 kg, and the bottom one has a mass of 3.7 kg. Identify and calculate any normal forces between the objects.



■ **Figure 4-20**

The normal force is between the top and middle blocks; the top block is the system; upward is positive.

$$F_{net} = F_{middle\ block\ on\ top\ block} - F_{Earth's\ mass\ on\ top\ block} = ma = 0$$

$$F_{middle\ block\ on\ top\ block} = F_{Earth's\ mass\ on\ top\ block} = m_{top\ block}g$$
$$= (4.6\text{ kg})(9.80\text{ m/s}^2)$$
$$= 45\text{ N}$$

The normal force is between the bottom and middle block; the middle block is the system; upward is positive.

$$F_{net} = F_{bottom\ block\ on\ middle\ block} - F_{top\ block\ on\ middle\ block} - F_{Earth's\ mass\ on\ middle\ block} = ma = 0$$

$$F_{top\ block\ on\ middle\ block} = F_{middle\ block\ on\ top\ block}$$

$$F_{bottom\ block\ on\ middle\ block} = F_{middle\ block\ on\ top\ block} + F_{Earth's\ mass\ on\ middle\ block}$$
$$= F_{middle\ block\ on\ top\ block} + m_{middle\ block}g$$
$$= 45\text{ N} + (1.2\text{ kg})(9.80\text{ m/s}^2)$$
$$= 57\text{ N}$$

The normal force is between the bottom block and the surface; the bottom block is the system; upward is positive.

$$F_{net} = F_{surface\ on\ bottom\ block} - F_{middle\ block\ on\ bottom\ block} - F_{Earth's\ mass\ on\ bottom\ block} = ma = 0$$

$F_{\text{surface on bottom block}}$

$= F_{\text{middle block on bottom block}} + F_{\text{Earth's mass on bottom block}}$

$= F_{\text{middle block on bottom block}} + m_{\text{bottom block}}g$

$= 57\text{ N} + (3.7\text{ kg})(9.80\text{ m/s}^2)$

$= 93\text{ N}$

Mixed Review

pages 114–115

Level 1

81. The dragster in problem 68 completed a 402.3-m (0.2500-mi) run in 4.936 s. If the car had a constant acceleration, what was its acceleration and final velocity?

$$d_f = d_i + v_i t + \frac{1}{2}at^2$$

$d_i = v_i = 0$, so

$$a = \frac{2d_f}{t^2} = \frac{(2)(402.3\text{ m})}{(4.936\text{ s})^2} = 33.02\text{ m/s}^2$$

$$d_f = d_i + \frac{1}{2}(v_f - v_i)t$$

$d_i = v_i = 0$, so

$$v_f = \frac{2d_f}{t} = \frac{(2)(402.3\text{ m})}{4.936\text{ s}} = 163.0\text{ m/s}$$

Level 2

82. Jet A 2.75×10^6-N catapult jet plane is ready for takeoff. If the jet's engines supply a constant thrust of 6.35×10^6 N, how much runway will it need to reach its minimum takeoff speed of 285 km/h?

$$v_f = (285\text{ km/h})(1000\text{ m/km})\left(\frac{1\text{ h}}{3600\text{s}}\right) = 79.2\text{ m/s}$$

$F_{\text{thrust}} = ma$, so $a = \frac{F_{\text{thrust}}}{m}$

$$F_g = mg$$

$$m = \frac{F_g}{g}$$

$v_f = v_i + at$ and $v_i = 0$, so

$$t = \frac{v_f}{a} = \frac{v_f}{\left(\frac{F_{\text{thrust}}}{m}\right)} = \frac{v_f m}{F_{\text{thrust}}}$$

$$d_f = d_i + v_i t + \frac{1}{2}at^2$$

$d_i = v_i = 0$, so

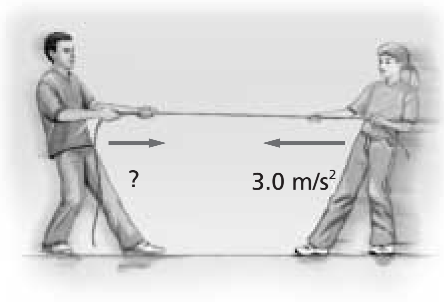
$$d_f = \frac{1}{2}at^2 = \left(\frac{1}{2}\right)\left(\frac{F_{\text{thrust}}}{m}\right)\left(\frac{v_f m}{F_{\text{thrust}}}\right)^2 = \left(\frac{1}{2}\right)\frac{v_f^2 m}{F_{\text{thrust}}} = \left(\frac{1}{2}\right)\frac{v_f^2\left(\frac{F_g}{g}\right)}{F_{\text{thrust}}}$$

$$= \left(\frac{1}{2}\right)\frac{(79.2\text{ m/s})^2\left(\frac{2.75\times10^6\text{ N}}{9.80\text{ m/s}^2}\right)}{6.35\times10^6\text{ N}} = 139\text{ m}$$

83. The dragster in problem 68 crossed the finish line going 126.6 m/s. Does the assumption of constant acceleration hold true? What other piece of evidence could you use to determine if the acceleration was constant?

126.6 m/s is slower than found in problem 81, so the acceleration cannot be constant. Further, the acceleration in the first 0.59 s was 45 m/s^2, not 33.02 m/s^2.

84. Suppose a 65-kg boy and a 45-kg girl use a massless rope in a tug-of-war on an icy, resistance-free surface as in **Figure 4-21.** If the acceleration of the girl toward the boy is 3.0 m/s^2, find the magnitude of the acceleration of the boy toward the girl.



■ **Figure 4-21**

$F_{1,2} = -F_{1,2}$, **so** $m_1a_1 = -m_2a_2$

and $a_1 = \dfrac{-m_2a_2}{m_1}$

$= \dfrac{-(45\ \text{kg})(3.0\ \text{m/s}^2)}{(65\ \text{kg})}$

$= -2.1\ \text{m/s}^2$

85. **Space Station** Pratish weighs 588 N and is weightless in a space station. If she pushes off the wall with a vertical acceleration of 3.00 m/s^2, determine the force exerted by the wall during her push off.

Use Newton's second law to obtain Pratish's mass, m_{Pratish}**. Use Newton's third law** $F_A = -F_B = m_Aa_A = -m_Ba_B$.

$m_{\text{Pratish}} = \dfrac{F_g}{g}$

$F_{\text{wall on Pratish}} = -F_{\text{Pratish on wall}}$

$= m_{\text{Pratish}}a_{\text{Pratish}}$

$= \dfrac{F_g a_{\text{Pratish}}}{g}$

$= \dfrac{(588\ \text{N})(3.00\ \text{m/s}^2)}{9.80\ \text{m/s}^2}$

$= 1.80\times10^2\ \text{N}$

86. **Baseball** As a baseball is being caught, its speed goes from 30.0 m/s to 0.0 m/s in about 0.0050 s. The mass of the baseball is 0.145 kg.

a. What is the baseball's acceleration?

$a = \dfrac{v_f - v_i}{t_f - t_i}$

$= \dfrac{0.0\ \text{m/s} - 30.0\ \text{m/s}}{0.0050\ \text{s} - 0.0\ \text{s}}$

$= -6.0\times10^3\ \text{m/s}^2$

b. What are the magnitude and direction of the force acting on it?

$F = ma$

$= (0.145\ \text{kg})(-6.0\times10^3\ \text{m/s}^2)$

$= -8.7\times10^2\ \text{N}$

(opposite direction of the velocity of the ball)

c. What are the magnitude and direction of the force acting on the player who caught it?

Same magnitude, opposite direction (in direction of velocity of ball)

Level 3

87. **Air Hockey** An air-hockey table works by pumping air through thousands of tiny holes in a table to support light pucks. This allows the pucks to move around on cushions of air with very little resistance. One of these pucks has a mass of 0.25 kg and is pushed along by a 12.0-N force for 9.0 s.

a. What is the puck's acceleration?

$F = ma$

$a = \dfrac{F}{m}$

$= \dfrac{12.0\ \text{N}}{0.25\ \text{kg}}$

$= 48\ \text{m/s}^2$

b. What is the puck's final velocity?

$v_f = v_i + at$

$v_i = 0$, **so** $v_f = at$

$= (48\ \text{m/s}^2)(9.0\ \text{s})$

$= 4.3\times10^2\ \text{m/s}$

88. A student stands on a bathroom scale in an elevator at rest on the 64th floor of a building. The scale reads 836 N.

a. As the elevator moves up, the scale reading increases to 936 N. Find the acceleration of the elevator.

$$F_{net} = F_g + F_{elevator}$$

$$F_{elevator} = F_{net} - F_g = ma$$

$$m = \frac{F_g}{g}\text{, so}$$

$$a = \frac{F_{net} - F_g}{\frac{F_g}{g}}$$

$$= \frac{g(F_{net} - F_g)}{F_g}$$

$$= \frac{(9.80\text{ m/s}^2)(963\text{ N} - 836\text{ N})}{836\text{ N}}$$

$$= 1.17\text{ m/s}^2$$

b. As the elevator approaches the 74th floor, the scale reading drops to 782 N. What is the acceleration of the elevator?

$$F_{net} = F_g + F_{elevator}$$

$$F_{elevator} = F_{net} - F_g = ma$$

$$m = \frac{F_g}{g}\text{, so}$$

$$a = \frac{F_{net} - F_g}{\frac{F_g}{g}}$$

$$= \frac{g(F_{net} - F_g)}{F_g}$$

$$= \frac{(9.80\text{ m/s}^2)(782\text{ N} - 836\text{ N})}{836\text{ N}}$$

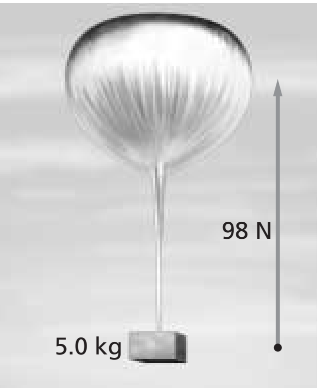
$$= -0.633\text{ m/s}^2$$

c. Using your results from parts **a** and **b,** explain which change in velocity, starting or stopping, takes the longer time.

Stopping, because the magnitude of the acceleration is less and

$$t = \frac{-v}{a}$$

89. Weather Balloon The instruments attached to a weather balloon in **Figure 4-22** have a mass of 5.0 kg. The balloon is released and exerts an upward force of 98 N on the instruments.



■ **Figure 4-22**

a. What is the acceleration of the balloon and instruments?

$$F_{net} = F_{appl} + F_g$$

$$= F_{appl} + mg$$

$$= 98\text{ N} + (5.0\text{ kg})(-9.80\text{ m/s}^2)$$

$$= +49\text{ N (up)}$$

$$a = \frac{F_{net}}{m}$$

$$= \frac{+49\text{ N}}{5.0\text{ kg}}$$

$$= +9.8\text{ m/s}^2$$

b. After the balloon has accelerated for 10.0 s, the instruments are released. What is the velocity of the instruments at the moment of their release?

$$v = at$$

$$= (+9.8\text{ m/s}^2)(10.0\text{ s})$$

$$= +98\text{ m/s (up)}$$

c. What net force acts on the instruments after their release?

just the instrument weight, −49 N (down)

d. When does the direction of the instruments' velocity first become downward?

The velocity becomes negative after it passes through zero. Thus, use

$v_f = v_i + gt$, **where** $v_f = 0$, **or**

$$t = \frac{-v_i}{g}$$

$$= \frac{-(+98 \text{ m/s})}{(-9.80 \text{ m/s}^2)}$$

$$= 1.0\times10^1 \text{ s after release}$$

90. When a horizontal force of 4.5 N acts on a block on a resistance-free surface, it produces an acceleration of 2.5 m/s². Suppose a second 4.0-kg block is dropped onto the first. What is the magnitude of the acceleration of the combination if the same force continues to act? Assume that the second block does not slide on the first block.

$$F = m_{\text{first block}}a_{\text{initial}}$$

$$m_{\text{first block}} = \frac{F}{a_{\text{initial}}}$$

$$F = m_{\text{both blocks}}a_{\text{final}}$$

$$= (m_{\text{first block}} + m_{\text{second block}})a_{\text{final}}$$

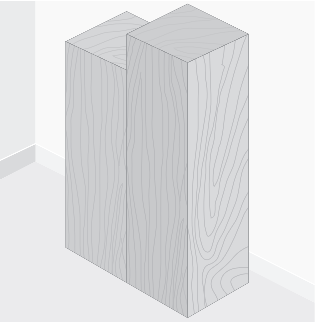
so, $$a_{\text{final}} = \frac{F}{m_{\text{first block}} + m_{\text{second block}}}$$

$$= \frac{F}{\frac{F}{a_{\text{initial}}} + m_{\text{second block}}}$$

$$= \frac{4.5 \text{ N}}{\frac{4.5 \text{ N}}{2.5 \text{ m/s}^2} + 4.0 \text{ kg}}$$

$$= 0.78 \text{ m/s}^2$$

91. Two blocks, masses 4.3 kg and 5.4 kg, are pushed across a frictionless surface by a horizontal force of 22.5 N, as shown in **Figure 4-23.**



■ **Figure 4-23**

a. What is the acceleration of the blocks?

Identify the two blocks together as the system, and right as positive.

$F_{net} = ma$, **and** $m = m_1 + m_2$

$$a = \frac{F}{m_1 + m_2}$$

$$= \frac{22.5 \text{ N}}{4.3 \text{ kg} + 5.4 \text{ kg}}$$

$$= 2.3 \text{ m/s}^2 \text{ to the right}$$

b. What is the force of the 4.3-kg block on the 5.4-kg block?

Identify the 5.4-kg block as the system and right as positive.

$$F_{net} = F_{\text{4.3-kg block on 5.4-kg block}}$$

$$= ma$$

$$= (5.4 \text{ kg})(2.3 \text{ m/s}^2)$$

$$= 12 \text{ N to the right}$$

c. What is the force of the 5.4-kg block on the 4.3-kg block?

According to Newton's third law, this should be equal and opposite to the force found in part b, so the force is 12 N to the left.

92. Two blocks, one of mass 5.0 kg and the other of mass 3.0 kg, are tied together with a massless rope as in **Figure 4-24.** This rope is strung over a massless, resistance-free pulley. The blocks are released from rest. Find the following.

a. the tension in the rope

b. the acceleration of the blocks

Hint: you will need to solve two simultaneous equations.

■ **Figure 4-24**

Equation 1 comes from a free-body diagram for the 5.0-kg block. Down is positive.

$F_{\text{net}} = F_{\text{Earth's mass on 5.0-kg block}} - F_{\text{rope on 5.0-kg block}} = m_{\text{5.0-kg block}}a$ **(1)**

Equation 2 comes from a free-body diagram for the 3.0-kg block. Up is positive.

$F_{\text{net}} = F_{\text{rope on 3.0-kg block}} - F_{\text{Earth's mass on 3.0-kg block}} = m_{\text{3.0-kg block}}a$ **(2)**

The forces of the rope on each block will have the same magnitude, because the tension is constant throughout the rope. Call this force *T*.

$F_{\text{Earth's mass on 5.0-kg block}} - T = m_{\text{5.0-kg block}}a$ **(1)**

$T - F_{\text{Earth's mass on 3.0-kg block}} = m_{\text{3.0-kg block}}a$ **(2)**

Solve equation 2 for *T* and plug into equation 1:

$$m_{\text{5.0-kg block}}a = F_{\text{Earth's mass on 5.0-kg block}} - F_{\text{Earth's mass on 3.0-kg block}} - m_{\text{3.0-kg block}}a$$

$$a = \frac{F_{\text{Earth's mass on 5.0-kg block}} - F_{\text{Earth's mass on 3.0-kg block}}}{m_{\text{5.0-kg block}} + m_{\text{3.0-kg block}}}$$

$$= \frac{(m_{\text{5.0-kg block}} - m_{\text{3.0-kg block}})g}{m_{\text{3.0-kg block}} + m_{\text{5.0-kg block}}}$$

$$= \frac{(5.0\text{ kg} - 3.0\text{ kg})(9.80\text{ m/s}^2)}{3.0\text{ kg} + 5.0\text{ kg}}$$

$$= 2.4\text{ m/s}^2$$

Solve equation 2 for T:

$T = F_{\text{Earth's mass on 3.0-kg block}} + m_{\text{3.0-kg block}}a$

$= m_{\text{3.0-kg block}}g + m_{\text{3.0-kg block}}a$

$= m_{\text{3.0-kg block}}(g + a)$

$= (3.0\text{ kg})(9.80\text{ m/s}^2 + 2.4\text{ m/s}^2)$

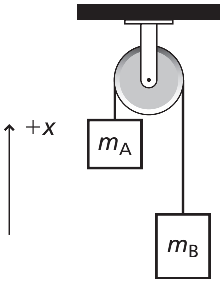
$= 37\text{ N}$

Thinking Critically

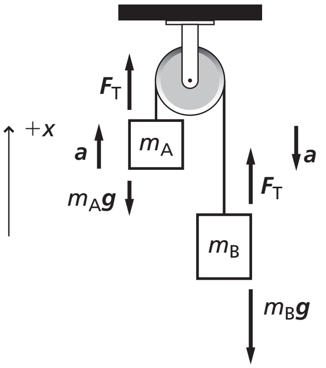
pages 115–116

93. Formulate Models A 2.0-kg mass, m_A, and a 3.0-kg mass, m_B, are connected to a lightweight cord that passes over a frictionless pulley. The pulley only changes the direction of the force exerted by the rope. The hanging masses are free to move. Choose coordinate systems for the two masses with the positive direction being up for m_A and down for m_B.

a. Create a pictorial model.



b. Create a physical model with motion and free-body diagrams.



c. What is the acceleration of the smaller mass?

$ma = F_{net}$ where m is the total mass being accelerated.

For m_A, $m_Aa = F_T - m_Ag$

For m_B, $m_Ba = -F_T + m_Bg$

$F_T = m_Bg - m_Ba = m_B(g - a)$

Substituting into the equation for m_A gives

$m_Aa = m_Bg - m_Ba - m_Ag$

or $(m_A + m_B)a = (m_B - m_A)g$

Therefore $a = \left(\dfrac{m_B - m_A}{m_A + m_B}\right)g$

$= \left(\dfrac{3.0\text{ kg} - 2.0\text{ kg}}{2.0\text{ kg} + 3.0\text{ kg}}\right)(9.80\text{ m/s}^2)$

$= 2.0\text{ m/s}^2$ **upward**

94. Use Models Suppose that the masses in problem 93 are now 1.00 kg and 4.00 kg. Find the acceleration of the larger mass.

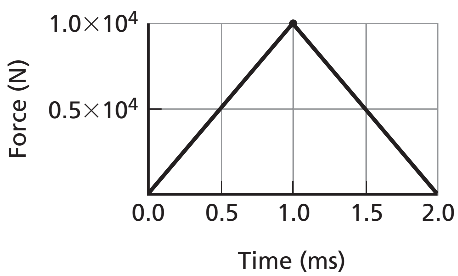
$a = \left(\dfrac{m_B - m_A}{m_A + m_B}\right)g$

$= \left(\dfrac{4.00\text{ kg} - 1.00\text{ kg}}{1.00\text{ kg} + 4.00\text{ kg}}\right)(9.80\text{ m/s}^2)$

$= 5.88\text{ m/s}^2$ **downward**

95. Infer The force exerted on a 0.145-kg baseball by a bat changes from 0.0 N to 1.0×10^4 N in 0.0010 s, then drops back to zero in the same amount of time. The baseball was going toward the bat at 25 m/s.

a. Draw a graph of force versus time. What is the average force exerted on the ball by the bat?



$F_{ave} = \dfrac{1}{2}F_{peak}$

$= \left(\dfrac{1}{2}\right)(1.0\times10^4\text{ N})$

$= 5.0\times10^3\text{ N}$

b. What is the acceleration of the ball?

$$a = \frac{F_{net}}{m} = \frac{5.0\times10^3\ N}{0.145\ kg}$$

$$= 3.4\times10^4\ m/s^2$$

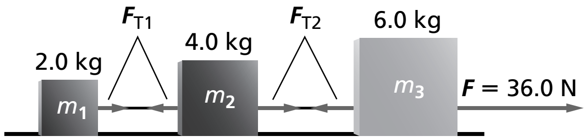
c. What is the final velocity of the ball, assuming that it reverses direction?

$$v_f = v_i + at$$

$$= -25\ m/s + (3.4\times10^4\ m/s^2)(0.0020\ s)$$

$$= 43\ m/s$$

96. Observe and Infer Three blocks that are connected by massless strings are pulled along a frictionless surface by a horizontal force, as shown in **Figure 4-25.**



■ **Figure 4-25**

a. What is the acceleration of each block?

Since they all move together, the acceleration is the same for all 3 blocks.

$$F = ma$$

$$= (m_1 + m_2 + m_3)a$$

$$a = \frac{F}{m_1 + m_2 + m_3}$$

$$= \frac{36\ N}{2.0\ kg + 4.0\ kg + 6.0\ kg}$$

$$= 3.0\ m/s^2$$

b. What are the tension forces in each of the strings?

Hint: Draw a separate free-body diagram for each block.

$$F_{net} = ma$$

$$F - F_{T2} = m_3a$$

$$F_{T2} - F_{T1} = m_2a$$

$$F_{T1} = m_1a$$

$$= (2.0\ kg)(3.0\ m/s^2)$$

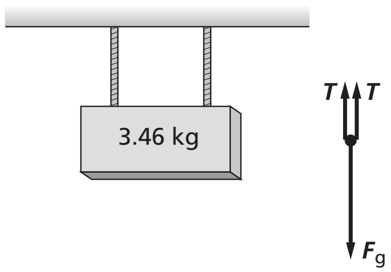
$$= 6.0\ N$$

$$F_{T2} = m_2a + F_{T1}$$

$$= (4.0\ kg)(3.0\ m/s^2) + 6.0\ N$$

$$= 18\ N$$

97. Critique Using the Example Problems in this chapter as models, write a solution to the following problem. A block of mass 3.46 kg is suspended from two vertical ropes attached to the ceiling. What is the tension in each rope?



1 Analyze and Sketch the Problem

Draw free-body diagrams for the block and choose upward to be positive

Solve for the Unknown

Known:

$m_{block} = 3.46\ kg$

Unknown:

$F_{rope1\ on\ block} = F_{rope2\ on\ block} = ?$

2 Solve for the Unknown

Use Newton's second law to find the tension in the ropes

$$F_{net} = 2F_{rope1\ on\ block} - F_{Earth's\ mass\ on\ block}$$

$$= ma = 0$$

$$F_{rope1\ on\ block} = \frac{F_{Earth's\ mass\ on\ block}}{2}$$

$$F_{rope1\ on\ block} = \frac{mg}{2}$$

$$= \frac{(3.46\ kg)(9.80\ m/s^2)}{2}$$

$$= 17.0\ N$$

3 Evaluate the Answer

- **Are the units correct? N is the correct unit for a tension, since it is a force.**
- **Does the sign make sense? The positive sign indicates that the tension is pulling upwards.**
- **Is the magnitude realistic? We would expect the magnitude to be on the same order as the block's weight.**

98. **Think Critically** Because of your physics knowledge, you are serving as a scientific consultant for a new science-fiction TV series about space exploration. In episode 3, the heroine, Misty Moonglow, has been asked to be the first person to ride in a new interplanetary transport for use in our solar system. She wants to be sure that the transport actually takes her to the planet she is supposed to be going to, so she needs to take a testing device along with her to measure the force of gravity when she arrives. The script writers don't want her to just drop an object, because it will be hard to depict different accelerations of falling objects on TV. They think they'd like something involving a scale. It is your job to design a quick experiment Misty can conduct involving a scale to determine which planet in our solar system she has arrived on. Describe the experiment and include what the results would be for Pluto ($g = 0.30$ m/s^2), which is where she is supposed to go, and Mercury ($g = 3.70$ m/s^2), which is where she actually ends up.

Answers will vary. Here is one possible answer: She should take a known mass, say 5.00-kg, with her and place it on the scale. Since the gravitational force depends upon the local acceleration due to gravity, the scale will read a different number of newtons, depending on which planet she is on. The following analysis shows how to figure out what the scale would read on a given planet:

Identify the mass as the system and upward as positive.

$F_{net} = F_{scale\ on\ mass} - F_g = ma = 0$

$F_{scale\ on\ mass} = F_g$

$F_{scale\ on\ mass} = mg$

Pluto: $F_{scale\ on\ mass}$

$= (5.00\ \text{kg})(0.30\ \text{m/s}^2)$

$= 1.5\ \text{N}$

Mercury: $F_{scale\ on\ mass}$

$= (5.00\ \text{kg})(3.7\ \text{m/s}^2)$

$= 19\ \text{N}$

99. **Apply Concepts** Develop a CBL lab, using a motion detector, that graphs the distance a free-falling object moves over equal intervals of time. Also graph velocity versus time. Compare and contrast your graphs. Using your velocity graph, determine the acceleration. Does it equal *g*?

Student labs will vary with equipment available and designs. *p-t* graphs and *v-t* graphs should reflect uniform acceleration. The acceleration should be close to *g*.

Writing in Physics

page 116

100. Research Newton's contributions to physics and write a one-page summary. Do you think his three laws of motion were his greatest accomplishments? Explain why or why not.

Answers will vary. Newton's contributions should include his work on light and color, telescopes, astronomy, laws of motion, gravity, and perhaps calculus. One argument in favor of his three laws of motion being his greatest accomplishments is that mechanics is based on the foundation of these laws. His advances in the understanding of the concept of gravity may be suggested as his greatest accomplishment instead of his three laws of motion.

101. Review, analyze, and critique Newton's first law. Can we prove this law? Explain. Be sure to consider the role of resistance.

Answers will vary. Newton's first law of motion involves an object whose net forces are zero. If the object is at rest, it remains at rest; if it is in motion, it will continue to move in the same direction at a constant velocity. Only a force acting on an object at rest can cause it to move. Likewise, only a force acting on an object in motion can cause it to change its direction or speed. The two cases (object at rest, object in motion) could be viewed as two different frames of reference. This law can be demonstrated, but it cannot be proven.

102. Physicists classify all forces into four fundamental categories: gravitational, electromagnetic, strong nuclear, and weak nuclear. Investigate these four forces and describe the situations in which they are found.

Answers will vary. The strong nuclear force has a very short range and is what holds protons and neutrons together in the nucleus of an atom. The weak nuclear force is much less strong than the strong nuclear force and is involved in radioactive decay. The electromagnetic force is involved in holding atoms and molecules together and is based on the attraction of opposite charges. Gravity is a long-range force between two or more masses.

Cumulative Review

page 116

103. **Cross-Country Skiing** Your friend is training for a cross-country skiing race, and you and some other friends have agreed to provide him with food and water along his training route. It is a bitterly cold day, so none of you wants to wait outside longer than you have to. Taro, whose house is the stop before yours, calls you at 8:25 A.M. to tell you that the skier just passed his house and is planning to move at an average speed of 8.0 km/h. If it is 5.2 km from Taro's house to yours, when should you expect the skier to pass your house? (Chapter 2)

$\boldsymbol{d = vt, \text{ or } t = \frac{d}{v}}$

$\boldsymbol{d = 5.2 \text{ km} = 5.2\times10^3 \text{ m}}$

$\boldsymbol{v = (8.0 \text{ km/h})\left(\frac{1000 \text{ m}}{1 \text{ km}}\right)\left(\frac{1\text{h}}{3600 \text{ s}}\right)}$

$\boldsymbol{= 2.2 \text{ m/s}}$

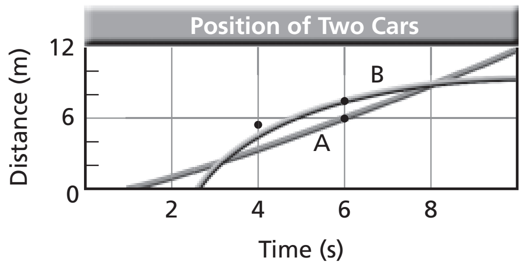
$\boldsymbol{t = \frac{5.2\times10^3 \text{ m}}{2.2 \text{ m/s}}}$

$\boldsymbol{= 2.4\times10^3 \text{ s}}$

$\boldsymbol{= 39 \text{ min}}$

The skier should pass your house at 8:25 + 0:39 = 9:04 A.M.

104. **Figure 4-26** is a position-time graph of the motion of two cars on a road. (Chapter 3)



■ **Figure 4-26**

a. At what time(s) does one car pass the other?

3 s, 8 s

b. Which car is moving faster at 7.0 s?

car A

c. At what time(s) do the cars have the same velocity?

5 s

d. Over what time interval is car B speeding up all the time?

none

e. Over what time interval is car B slowing down all the time?

~ 3 s to 10 s

105. Refer to Figure 4-26 to find the instantaneous speed for the following: (Chapter 3)

a. car B at 2.0 s

0 m/s

b. car B at 9.0 s

~ 0 m/s

c. car A at 2.0 s

~ 1 m/s

Challenge Problem

page 100

An air-track glider passes through a photoelectric gate at an initial speed of 0.25 m/s. As it passes through the gate, a constant force of 0.40 N is applied to the glider in the same direction as its motion. The glider has a mass of 0.50 kg.

1. What is the acceleration of the glider?

$F = ma$

$a = \frac{F}{m}$

$= \frac{0.40\ \text{N}}{0.50\ \text{kg}}$

$= 0.80\ \text{m/s}^2$

2. It takes the glider 1.3 s to pass through a second gate. What is the distance between the two gates?

$d_f = d_i + v_i t + \frac{1}{2}at^2$

Let d_i = position of first gate = 0.0 m

$d = 0.0\ \text{m} + (0.25\ \text{m/s})(1.3\ \text{s}) + \left(\frac{1}{2}\right)(0.80\ \text{m/s}^2)(1.3\ \text{s})^2$

$= 1.0\ \text{m}$

3. The 0.40-N force is applied by means of a string attached to the glider. The other end of the string passes over a resistance-free pulley and is attached to a hanging mass, *m*. How big is *m*?

$F_g = m_{mass}g$

$m_{mass} = \frac{F_g}{g}$

$= \frac{0.40\ \text{N}}{9.80\ \text{m/s}^2}$

$= 4.1\times10^{-2}\ \text{kg}$

4. Derive an expression for the tension, *T*, in the string as a function of the mass, *M*, of the glider, the mass, *m*, of the hanging mass, and *g*.

$T = mg = Ma$

CHAPTER

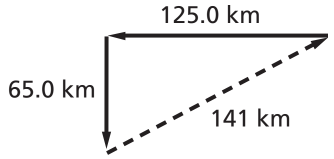
5 Forces in Two Dimensions

Practice Problems

5.1 Vectors pages 119–125

page 121

1. A car is driven 125.0 km due west, then 65.0 km due south. What is the magnitude of its displacement? Solve this problem both graphically and mathematically, and check your answers against each other.



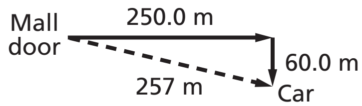
$$R^2 = A^2 + B^2$$

$$R = \sqrt{A^2 + B^2}$$

$$= \sqrt{(65.0 \text{ km})^2 + (125.0 \text{ km})^2}$$

$$= 141 \text{ km}$$

2. Two shoppers walk from the door of the mall to their car, which is 250.0 m down a lane of cars, and then turn 90° to the right and walk an additional 60.0 m. What is the magnitude of the displacement of the shoppers' car from the mall door? Solve this problem both graphically and mathematically, and check your answers against each other.



$$R^2 = A^2 + B^2$$

$$R = \sqrt{A^2 + B^2}$$

$$= \sqrt{(250.0 \text{ m})^2 + (60.0 \text{ m})^2}$$

$$= 257 \text{ m}$$

3. A hiker walks 4.5 km in one direction, then makes a 45° turn to the right and walks another 6.4 km. What is the magnitude of her displacement?

$$R^2 = A^2 + B^2 - 2AB \cos \theta$$

$$R = \sqrt{A^2 + B^2 - 2AB \cos \theta}$$

$$= \sqrt{(4.5 \text{ km})^2 + (6.4 \text{ km})^2 - 2(4.5 \text{ km})(6.4 \text{ km})(\cos 135°)}$$

$$= 1.0\times10^1 \text{ km}$$

4. An ant is crawling on the sidewalk. At one moment, it is moving south a distance of 5.0 mm. It then turns southwest and crawls 4.0 mm. What is the magnitude of the ant's displacement?

$$R^2 = A^2 + B^2 - 2AB \cos \theta$$

$$R = \sqrt{A^2 + B^2 - 2AB \cos \theta}$$

$$= \sqrt{(5.0 \text{ mm})^2 + (4.0 \text{ mm})^2 - 2(5.0 \text{ mm})(4.0 \text{ mm})(\cos 135°)}$$

$$= 8.3 \text{ mm}$$

page 125

Solve problems 5–10 algebraically. You may also choose to solve some of them graphically to check your answers.

5. Sudhir walks 0.40 km in a direction 60.0° west of north, then goes 0.50 km due west. What is his displacement?

Identify north and west as the positive directions.

$d_{1W} = d_1 \sin\theta = (0.40\text{ km})(\sin 60.0°) = 0.35\text{ km}$

$d_{1N} = d_1 \cos\theta = (0.40\text{ km})(\cos 60.0°) = 0.20\text{ km}$

$d_{2W} = 0.50\text{ km} \quad d_{2N} = 0.00\text{ km}$

$R_W = d_{1W} + d_{2W} = 0.35\text{ km} + 0.50\text{ km} = 0.85\text{ km}$

$R_N = d_{1N} + d_{2N} = 0.20\text{ km} + 0.00\text{ km} = 0.20\text{ km}$

$$R = \sqrt{R_W{}^2 + R_N{}^2}$$

$$= \sqrt{(0.85\text{ km})^2 + (0.20\text{ km})^2}$$

$$= 0.87\text{ km}$$

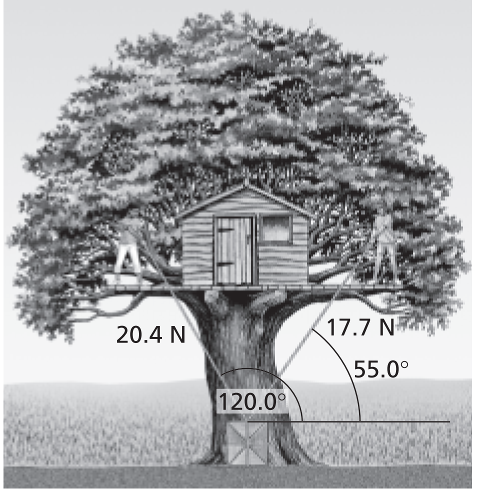
$$\theta = \tan^{-1}\left(\frac{R_W}{R_N}\right)$$

$$= \tan^{-1}\left(\frac{0.85\text{ km}}{0.20\text{ km}}\right)$$

$$= 77°$$

$R = 0.87$ **km at 77° west of north**

6. Afua and Chrissy are going to sleep overnight in their tree house and are using some ropes to pull up a box containing their pillows and blankets, which have a total mass of 3.20 kg. The girls stand on different branches, as shown in **Figure 5-6,** and pull at the angles and with the forces indicated. Find the *x*- and *y*-components of the net force on the box. *Hint: Draw a free-body diagram so that you do not leave out a force.*



■ **Figure 5-6**

Identify up and right as positive.

$$F_{A\text{ on box},x} = F_{A\text{ on box}} \cos\theta_A$$

$$= (20.4\text{ N})(\cos 120°)$$

$$= -10.2\text{ N}$$

$$F_{A\text{ on box},y} = F_{A\text{ on box}} \sin\theta_A$$

$$= (20.4\text{ N})(\sin 120°)$$

$$= 17.7\text{ N}$$

$$F_{C\text{ on box},x} = F_{C\text{ on box}} \cos\theta_A$$

$$= (17.7\text{ N})(\cos 55°)$$

$= 10.2\ \text{N}$

$F_{\text{C on box},y} = F_{\text{C on box}} \sin \theta_A$

$= (17.7\ \text{N})(\sin 55°)$

$= 14.5\ \text{N}$

$F_{g,x} = 0.0\ \text{N}$

$F_{g,y} = -mg$

$= -(3.20\ \text{kg})(9.80\ \text{m/s}^2)$

$= -31.4\ \text{N}$

$F_{\text{net on box},x} = F_{\text{A on box},x} + F_{\text{C on box},x} + F_{g,x}$

$= -10.2\ \text{N} + 10.2\ \text{N} + 0.0\ \text{N}$

$= 0.0\ \text{N}$

$F_{\text{net on box},y} = F_{\text{A on box},y} + F_{\text{C on box},y} + F_{g,y}$

$= 17.7\ \text{N} + 14.5\ \text{N} - 31.4\ \text{N}$

$= 0.8\ \text{N}$

The net force is 0.8 N in the upward direction.

7. You first walk 8.0 km north from home, then walk east until your displacement from home is 10.0 km. How far east did you walk?

The resultant is 10.0 km. Using the Pythagorean Theorem, the distance east is

$R^2 = A^2 + B^2$, so

$B = \sqrt{R^2 - A^2}$

$= \sqrt{(10.0\ \text{km})^2 - (8.0\ \text{km})^2}$

$= 6.0\ \text{km}$

8. A child's swing is held up by two ropes tied to a tree branch that hangs 13.0° from the vertical. If the tension in each rope is 2.28 N, what is the combined force (magnitude and direction) of the two ropes on the swing?

The force will be straight up. Because the angles are equal, the horizontal forces will be equal and opposite and cancel out. The magnitude of this vertical force is

$F_{\text{combined}} = F_{\text{rope1 on swing}} \cos \theta + F_{\text{rope2 on swing}} \cos \theta$

$= 2F_{\text{rope2 on swing}} \cos \theta$

$= (2)(2.28\ \text{N})(\cos 13.0°)$

$= 4.44$ **N upward**

9. Could a vector ever be shorter than one of its components? Equal in length to one of its components? Explain.

It could never be shorter than one of its components, but if it lies along either the *x*- or *y*-axis, then one of its components equals its length.

10. In a coordinate system in which the *x*-axis is east, for what range of angles is the *x*-component positive? For what range is it negative?

The *x*-component is positive for angles less than 90° and for angles greater than 270°. It's negative for angles greater than 90° but less than 270°.

Section Review

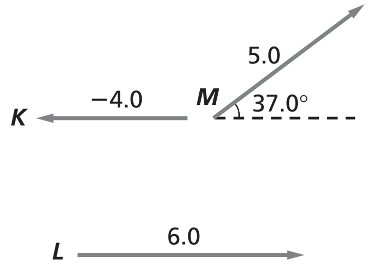
5.1 Vectors pages 119–125

page 125

11. Distance v. Displacement Is the distance that you walk equal to the magnitude of your displacement? Give an example that supports your conclusion.

Not necessarily. For example, you could walk around the block (one km per side). Your displacement would be zero, but the distance that you walk would be 4 kilometers.

12. Vector Difference Subtract vector ***K*** from vector ***L***, shown in **Figure 5-7.**



■ **Figure 5-7**

6.0 − (−4.0) = 10.0 to the right

13. Components Find the components of vector ***M***, shown in Figure 5-7.

$M_x = m \cos \theta$

$= (5.0)(\cos 37.0°)$

= 4.0 to the right

$M_y = m \sin \theta$

$= (5.0)(\sin 37.0°)$

= 3.0 upward

14. Vector Sum Find the sum of the three vectors shown in Figure 5-7.

$R_x = K_x + L_x + M_x$

$= -4.0 + 6.0 + 4.0$

$= 6.0$

$R_y = K_y + L_y + M_y$

$= 0.0 + 0.0 + 3.0$

$= 3.0$

$R = \sqrt{R_x^2 + R_y^2}$

$= \sqrt{6.0^2 + 3.0^2}$

$= 6.7$

$\theta = \tan^{-1}\left(\frac{R_y}{R_x}\right)$

$= \tan^{-1}\left(\frac{3}{6}\right)$

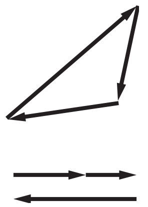
$= 27°$

$R = 6.7$ at 27°

15. Commutative Operations The order in which vectors are added does not matter. Mathematicians say that vector addition is commutative. Which ordinary arithmetic operations are commutative? Which are not?

Addition and multiplication are commutative. Subtraction and division are not.

16. Critical Thinking A box is moved through one displacement and then through a second displacement. The magnitudes of the two displacements are unequal. Could the displacements have directions such that the resultant displacement is zero? Suppose the box was moved through three displacements of unequal magnitude. Could the resultant displacement be zero? Support your conclusion with a diagram.



No, but if there are three displacements, the sum can be zero if the three vectors form a triangle when they are placed tip-to-tail. Also, the sum of three displacements can be zero without forming a triangle if the sum of two displacements in one direction equals the third in the opposite direction.

Practice Problems

5.2 Friction pages 126–130

page 128

17. A girl exerts a 36-N horizontal force as she pulls a 52-N sled across a cement sidewalk at constant speed. What is the coefficient of kinetic friction between the sidewalk and the metal sled runners? Ignore air resistance.

$F_N = mg = 52$ N

Since the speed is constant, the friction force equals the force exerted by the girl, 36 N.

$F_f = \mu_k F_N$

so $\mu_k = \frac{F_f}{F_N}$

$= \frac{36 \text{ N}}{52 \text{ N}}$

$= 0.69$

18. You need to move a 105-kg sofa to a different location in the room. It takes a force of 102 N to start it moving. What is the coefficient of static friction between the sofa and the carpet?

$F_f = \mu_s F_N$

$\mu_s = \frac{F_f}{F_N}$

$= \frac{F_f}{mg}$

$= \frac{102\ N}{(105\ kg)(9.80\ m/s^2)}$

$= 0.0991$

19. Mr. Ames is dragging a box full of books from his office to his car. The box and books together have a combined weight of 134 N. If the coefficient of static friction between the pavement and the box is 0.55, how hard must Mr. Ames push the box in order to start it moving?

$F_{Ames\ on\ box} = F_{friction}$

$= \mu_s F_N$

$= \mu_s mg$

$= (0.55)(134\ N)$

$= 74\ N$

20. Suppose that the sled in problem 17 is resting on packed snow. The coefficient of kinetic friction is now only 0.12. If a person weighing 650 N sits on the sled, what force is needed to pull the sled across the snow at constant speed?

At constant speed, applied force equals friction force, so

$F_f = \mu_k F_N$

$= (0.12)(52\ N + 650\ N)$

$= 84\ N$

21. Suppose that a particular machine in a factory has two steel pieces that must rub against each other at a constant speed. Before either piece of steel has been treated to reduce friction, the force necessary to get them to perform properly is 5.8 N. After the pieces have been treated with oil, what will be the required force?

$F_{f,\ before} = \mu_{k,\ before} F_N$

so $F_N = \frac{F_{f,\ before}}{\mu_{k,\ before}}$

$= \frac{5.8\ N}{0.58}$

$= 1.0\times10^1\ N$

$F_{f,\ after} = \mu_{k,\ after} F_N$

$= (0.06)(1.0\times10^1\ N)$

$= 0.6\ N$

page 130

22. A 1.4-kg block slides across a rough surface such that it slows down with an acceleration of 1.25 m/s^2. What is the coefficient of kinetic friction between the block and the surface?

$F_{net} = \mu_k F_N$

$ma = \mu_k mg$

$\mu_k = \frac{a}{g}$

$= \frac{1.25\ m/s^2}{9.80\ m/s^2}$

$= 0.128$

23. You help your mom move a 41-kg bookcase to a different place in the living room. If you push with a force of 65 N and the bookcase accelerates at 0.12 m/s^2, what is the coefficient of kinetic friction between the bookcase and the carpet?

$F_{net} = F - \mu_k F_N = F - \mu_k mg = ma$

$\mu_k = \frac{F - ma}{mg}$

$= \frac{65\ N - (41\ kg)(0.12\ m/s^2)}{(41\ kg)(9.80\ m/s^2)}$

$= 0.15$

24. A shuffleboard disk is accelerated to a speed of 5.8 m/s and released. If the coefficient of kinetic friction between the disk and the concrete court is 0.31, how far does the disk go before it comes to a stop? The courts are 15.8 m long.

Identify the direction of the disk's motion as positive. Find the acceleration of the disk due to the force of friction.

$F_{net} = -\mu_k F_N = -\mu_k mg = ma$

$a = -\mu_k g$

Then use the equation $v_f^2 = v_i^2 + 2a(d_f - d_i)$ to find the distance.

Let $d_i = 0$ and solve for d_f.

$$d_f = \frac{v_f^2 - v_i^2}{2a}$$

$$= \frac{v_f^2 - v_i^2}{(2)(-\mu_k g)}$$

$$= \frac{(0.0\ \text{m/s})^2 - (5.8\ \text{m/s})^2}{(2)(-0.31)(9.80\ \text{m/s}^2)}$$

$$= 5.5\ \text{m}$$

25. Consider the force pushing the box in Example Problem 4. How long would it take for the velocity of the box to double to 2.0 m/s?

The initial velocity is 1.0 m/s, the final velocity is 2.0 m/s, and the acceleration is 2.0 m/s^2, so

$a = \frac{v_f - v_i}{t_f - t_i}$; **let $t_i = 0$ and solve for t_f.**

$$t_f = \frac{v_f - v_i}{a}$$

$$= \frac{2.0\ \text{m/s} - 1.0\ \text{m/s}}{2.0\ \text{m/s}^2}$$

$$= 0.50\ \text{s}$$

26. Ke Min is driving along on a rainy night at 23 m/s when he sees a tree branch lying across the road and slams on the brakes when the branch is 60.0 m in front of him. If the coefficient of kinetic friction between the car's locked tires and the road is 0.41, will the car stop before hitting the branch? The car has a mass of 2400 kg.

Choose positive direction as direction of car's movement.

$$F_{net} = -\mu_k F_N = -\mu_k mg = ma$$

$$a = -\mu_k g$$

Then use the equation $v_f^2 = v_i^2 + 2a(d_f - d_i)$ to find the distance.

Let $d_i = 0$ and solve for d_f.

$$d_f = \frac{v_f^2 - v_i^2}{2a}$$

$$= \frac{v_f^2 - v_i^2}{(2)(-\mu_k g)}$$

$$= \frac{(0.0\ \text{m/s}) - (23\ \text{m/s})^2}{(2)(-0.41)(9.80\ \text{m/s}^2)}$$

= 66 m, so he hits the branch before he can stop.

Section Review

5.2 Friction pages 126–130

page 130

27. Friction In this section, you learned about static and kinetic friction. How are these two types of friction similar? What are the differences between static and kinetic friction?

They are similar in that they both act in a direction opposite to the motion (or intended motion) and they both result from two surfaces rubbing against each other. Both are dependent on the normal force between these two surfaces. Static friction applies when there is no relative motion between the two surfaces. Kinetic friction is the type of friction when there is relative motion. The coefficient of static friction between two surfaces is greater than the coefficient of kinetic friction between those same two surfaces.

28. Friction At a wedding reception, you notice a small boy who looks like his mass is about 25 kg, running part way across the dance floor, then sliding on his knees until he stops. If the kinetic coefficient of friction between the boy's pants and the floor is 0.15, what is the frictional force acting on him as he slides?

$$F_{friction} = \mu_k F_N$$

$$= \mu_k mg$$

$$= (0.15)(25\ \text{kg})(9.80\ \text{m/s}^2)$$

$$= 37\ \text{N}$$

29. Velocity Derek is playing cards with his friends, and it is his turn to deal. A card has a mass of 2.3 g, and it slides 0.35 m along the table before it stops. If the coefficient of kinetic friction between the card and the table is 0.24, what was the initial speed of the card as it left Derek's hand?

Identify the direction of the card's movement as positive

$F_{net} = -\mu_k F_N = -\mu_k mg = ma$

$a = -\mu_k g$

$v_f = d_i = 0$ **so**

$v_i = \sqrt{-2ad_f}$

$= \sqrt{-2(-\mu_k g)d_f}$

$= \sqrt{-2(-0.24)(9.80\ m/s^2)(0.35\ m)}$

$= 1.3\ m/s$

30. Force The coefficient of static friction between a 40.0-kg picnic table and the ground below it is 0.43 m. What is the greatest horizontal force that could be exerted on the table while it remains stationary?

$F_f = \mu_s F_N$

$= \mu_s mg$

$= (0.43)(40.0\ kg)(9.80\ m/s^2)$

$= 1.7\times10^2\ N$

31. Acceleration Ryan is moving to a new apartment and puts a dresser in the back of his pickup truck. When the truck accelerates forward, what force accelerates the dresser? Under what circumstances could the dresser slide? In which direction?

Friction between the dresser and the truck accelerates the dresser forward. The dresser will slide backward if the force accelerating it is greater than $\mu_s mg$.

32. Critical Thinking You push a 13-kg table in the cafeteria with a horizontal force of 20 N, but it does not move. You then push it with a horizontal force of 25 N, and it accelerates at 0.26 m/s^2. What, if anything, can you conclude about the coefficients of static and kinetic friction?

From the sliding portion of your experiment you can determine that the coefficient of kinetic friction between the table and the floor is

$F_f = F_{on\ table} - F_2$

$\mu_k F_N = F_{on\ table} - ma$

$\mu_k = \frac{F_{on\ table} - ma}{mg}$

$= \frac{25\ N - (13\ kg)(0.26\ m/s)}{(13\ kg)(9.80\ m/s^2)}$

$= 0.17$

All you can conclude about the coefficient of static friction is that it is between

$\mu_s = \frac{F_{on\ table}}{mg}$

$= \frac{20\ N}{(13\ kg)(9.80\ m/s^2)}$

$= 0.16$

and $\mu_s = \frac{F_{on\ table}}{mg}$

$= \frac{25\ N}{(13\ kg)(9.80\ m/s^2)}$

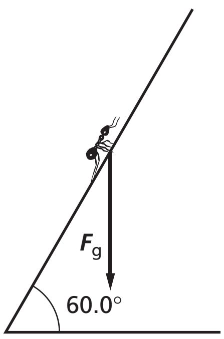
$= 0.20$

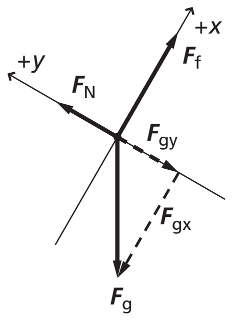
Practice Problems

5.3 Force and Motion in Two Dimensions pages 131–135

page 133

33. An ant climbs at a steady speed up the side of its anthill, which is inclined 30.0° from the vertical. Sketch a free-body diagram for the ant.



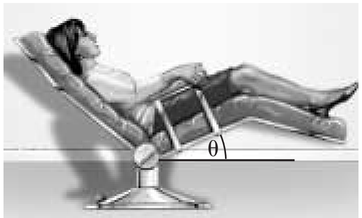


34. Scott and Becca are moving a folding table out of the sunlight. A cup of lemonade, with a mass of 0.44 kg, is on the table. Scott lifts his end of the table before Becca does, and as a result, the table makes an angle of 15.0° with the horizontal. Find the components of the cup's weight that are parallel and perpendicular to the plane of the table.

$$F_{g,\text{ parallel}} = F_g \sin\theta$$
$$= (0.44\text{ kg})(9.80\text{ m/s}^2)(\sin 15.0°)$$
$$= 1.1\text{ N}$$

$$F_{g,\text{ perpendicular}} = F_g \cos\theta$$
$$= (0.44\text{ kg})(9.80\text{ m/s}^2)(\cos 15.0°)$$
$$= 4.2\text{ N}$$

35. Kohana, who has a mass of 50.0 kg, is at the dentist's office having her teeth cleaned, as shown in **Figure 5-14.** If the component of her weight perpendicular to the plane of the seat of the chair is 449 N, at what angle is the chair tilted?



■ **Figure 5-14**

$$F_{g,\text{ perpendicular}} = F_g \cos\theta = mg\cos\theta$$

$$\theta = \cos^{-1}\left(\frac{F_{g,\text{ perpendicular}}}{mg}\right)$$
$$= \cos^{-1}\left(\frac{449\text{ N}}{(50.0\text{ kg})(9.80\text{ m/s}^2)}\right)$$
$$= 23.6°$$

36. Fernando, who has a mass of 43.0 kg, slides down the banister at his grandparents' house. If the banister makes an angle of 35.0° with the horizontal, what is the normal force between Fernando and the banister?

$$F_N = mg\cos\theta$$
$$= (43.0\text{ kg})(9.80\text{ m/s}^2)(\cos 35.0°)$$
$$= 345\text{ N}$$

37. A suitcase is on an inclined plane. At what angle, relative to the vertical, will the component of the suitcase's weight parallel to the plane be equal to half the perpendicular component of its weight?

$F_{g,\text{ parallel}} = F_g \sin\theta$, when the angle is with respect to the horizontal

$F_{g,\text{ perpendicular}} = F_g \cos\theta$, when the angle is with respect to the horizontal

$$F_{g,\text{ perpendicular}} = 2F_{g,\text{ parallel}}$$

$$2 = \frac{F_{g,\text{ perpendicular}}}{F_{g,\text{ parallel}}}$$
$$= \frac{F_g\cos\theta}{F_g\sin\theta}$$
$$= \frac{1}{\tan\theta}$$

$$\theta = \tan^{-1}\left(\frac{1}{2}\right)$$

= 26.6° relative to the horizontal, or 63.4° relative to the vertical

page 135

38. Consider the crate on the incline in Example Problem 5.

a. Calculate the magnitude of the acceleration.

$$a = \frac{F}{m}$$
$$= \frac{F_g\sin\theta}{m}$$
$$= \frac{mg\sin\theta}{m}$$
$$= g\sin\theta$$
$$= (9.80\text{ m/s}^2)(\sin 30.0°)$$
$$= 4.90\text{ m/s}^2$$

b. After 4.00 s, how fast will the crate be moving?

$$a = \frac{v_f - v_i}{t_f - t_i};\text{ let } v_i = t_i = 0.$$

Solve for v_f.

$$v_f = at_f$$
$$= (4.90\text{ m/s}^2)(4.00\text{ s})$$
$$= 19.6\text{ m/s}$$

39. If the skier in Example Problem 6 were on a 31° downhill slope, what would be the magnitude of the acceleration?

Since $a = g(\sin\theta - \mu\cos\theta)$,

$$a = (9.80\ \text{m/s}^2)(\sin 31° - (0.15)(\cos 31°))$$
$$= 3.8\ \text{m/s}^2$$

40. Stacie, who has a mass of 45 kg, starts down a slide that is inclined at an angle of 45° with the horizontal. If the coefficient of kinetic friction between Stacie's shorts and the slide is 0.25, what is her acceleration?

$$F_{\text{Stacie's weight parallel with slide}} - F_f = ma$$

$$a = \frac{F_{\text{Stacie's weight parallel with slide}} - F_f}{m}$$
$$= \frac{mg\sin\theta - \mu_k F_N}{m}$$
$$= \frac{mg\sin\theta - \mu_k mg\cos\theta}{m}$$
$$= g(\sin\theta - \mu_k\cos\theta)$$
$$= (9.80\ \text{m/s}^2)[\sin 45° - (0.25)(\cos 45°)]$$
$$= 5.2\ \text{m/s}^2$$

41. After the skier on the 37° hill in Example Problem 6 had been moving for 5.0 s, the friction of the snow suddenly increased and made the net force on the skier zero. What is the new coefficient of friction?

$$a = g(\sin\theta - \mu_k\cos\theta)$$
$$a = g\sin\theta - g\mu_k\cos\theta$$

If $a = 0$,

$$0 = g\sin\theta - g\mu_k\cos\theta$$
$$\mu_k\cos\theta = \sin\theta$$
$$\mu_k = \frac{\sin\theta}{\cos\theta}$$
$$\mu_k = \frac{\sin 37°}{\cos 37°}$$
$$= 0.75$$

Section Review

5.3 Force and Motion in Two Dimensions pages 131–135

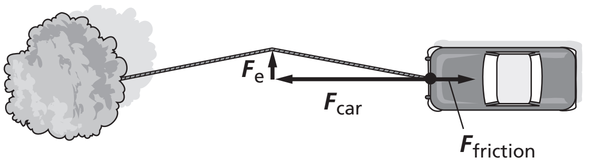
page 135

42. Forces One way to get a car unstuck is to tie one end of a strong rope to the car and the other end to a tree, then push the rope at its midpoint at right angles to the rope. Draw a free-body diagram and explain why even a small force on the rope can exert a large force on the car.

The vectors shown in the free body diagram indicate that even a small force perpendicular to the rope can increase the tension in the rope enough to overcome the friction force. Since $F = 2T\sin\theta$ (where θ is the angle between the rope's original position and its displaced position),

$$T = \frac{F}{2\sin\theta}$$

For smaller values of θ, the tension, T, will increase greatly.



43. Mass A large scoreboard is suspended from the ceiling of a sports arena by 10 strong cables. Six of the cables make an angle of 8.0° with the vertical while the other four make an angle of 10.0°. If the tension in each cable is 1300.0 N, what is the scoreboard's mass?

$F_{net,y} = ma_y = 0$

$F_{net,y} = F_{cables\ on\ board} - F_g$

$= 6F_{cable} \cos \theta_6 + 4F_{cable} \cos \theta_4 - mg = 0$

$$m = \frac{6F_{cable} \cos \theta_6 + 4F_{cable} \cos \theta_4}{g}$$

$$= \frac{6(1300.0\ N)(\cos 8.0°) + 4(1300.0\ N)(\cos 10.0°)}{9.80\ m/s^2}$$

$= 1.31 \times 10^3$ kg

44. Acceleration A 63-kg water skier is pulled up a 14.0° incline by a rope parallel to the incline with a tension of 512 N. The coefficient of kinetic friction is 0.27. What are the magnitude and direction of the skier's acceleration?

$F_N = mg \cos \theta$

$F_{rope\ on\ skier} - F_g - F_f = ma$

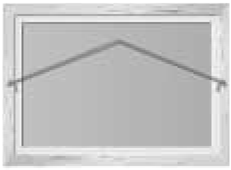
$F_{rope\ on\ skier} - mg \sin \theta - \mu_k mg \cos \theta = ma$

$$a = \frac{F_{rope\ on\ skier} - mg \sin \theta - \mu_k mg \cos \theta}{m}$$

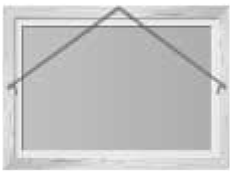
$$= \frac{512\ N - (63\ kg)(9.80\ m/s^2)(\sin 14.0°) - (0.27)(63\ kg)(9.80\ m/s^2)(\cos 14.0°)}{63\ kg}$$

$= 3.2$ m/s^2, up the incline

45. Equilibrium You are hanging a painting using two lengths of wire. The wires will break if the force is too great. Should you hang the painting as shown in **Figures 5-15a** or **5-15b?** Explain.



■ Figure 5-15a



■ Figure 5-15b

Figure 5-15b; $F_T = \frac{F_g}{2 \sin \theta}$, so F_T gets smaller as θ gets larger, and θ is larger in 5-15b.

46. Critical Thinking Can the coefficient of friction ever have a value such that a skier would be able to slide uphill at a constant velocity? Explain why or why not. Assume there are no other forces acting on the skier.

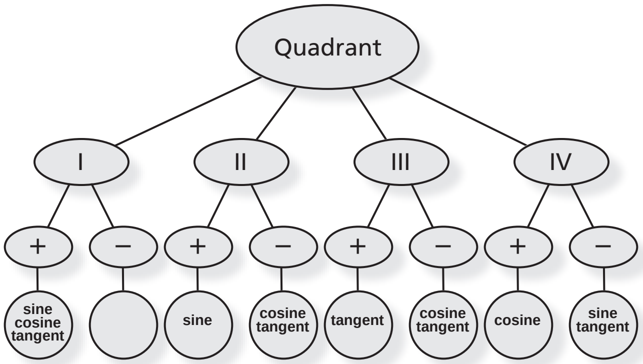
No, because both the frictional force opposing the motion of the skier and the component of Earth's gravity parallel to the slope point downhill, not uphill.

Chapter Assessment

Concept Mapping

page 140

47. Complete the concept map below by labeling the circles with *sine, cosine,* or *tangent* to indicate whether each function is positive or negative in each quadrant.



Mastering Concepts

page 140

48. Describe how you would add two vectors graphically. (5.1)

Make scale drawings of arrows representing the vector quantities. Place the arrows for the quantities to be added tip-to-tail. Draw an arrow from the tail of the first to the tip of the last. Measure the length of that arrow and find its direction.

49. Which of the following actions is permissible when you graphically add one vector to another: moving the vector, rotating the vector, or changing the vector's length? (5.1)

allowed: moving the vector without changing length or direction

50. In your own words, write a clear definition of the resultant of two or more vectors. Do not explain how to find it; explain what it represents. (5.1)

The resultant is the vector sum of two or more vectors. It represents the quantity that results from adding the vectors.

51. How is the resultant displacement affected when two displacement vectors are added in a different order? (5.1)

It is not affected.

52. Explain the method that you would use to subtract two vectors graphically. (5.1)

Reverse the direction of the second vector and then add them.

53. Explain the difference between these two symbols: **A** and *A*. (5.1)

A **is the symbol for the vector quantity. *A* is the signed magnitude (length) of the vector.**

54. The Pythagorean theorem usually is written $c^2 = a^2 + b^2$. If this relationship is used in vector addition, what do *a*, *b*, and *c* represent? (5.1)

a **and *b* represent the lengths of two vectors that are at the right angles to one another. *c* represents the length of the sum of the two vectors.**

55. When using a coordinate system, how is the angle or direction of a vector determined with respect to the axes of the coordinate system? (5.1)

The angle is measured counterclockwise from the *x*-axis.

56. What is the meaning of a coefficient of friction that is greater than 1.0? How would you measure it? (5.2)

The frictional force is greater than the normal force. You can pull the object along the surface, measuring the force needed to move it at constant speed. Also measure the weight of the object.

57. **Cars** Using the model of friction described in this textbook, would the friction between a tire and the road be increased by a wide rather than a narrow tire? Explain. (5.2)

It would make no difference. Friction does not depend upon surface area.

58. Describe a coordinate system that would be suitable for dealing with a problem in which a ball is thrown up into the air. (5.3)

One axis is vertical, with the positive direction either up or down.

59. If a coordinate system is set up such that the positive *x*-axis points in a direction 30° above the horizontal, what should be the angle between the *x*-axis and the *y*-axis? What should be the direction of the positive *y*-axis? (5.3)

The two axes must be at right angles. The positive *y*-axis points 30° away from the vertical so that it is at right angles to the *x*-axis.

60. Explain how you would set up a coordinate system for motion on a hill. (5.3)

For motion on a hill, the vertical (*y*) axis is usually set up perpendicular, or normal, to the surface of the hill.

61. If your textbook is in equilibrium, what can you say about the forces acting on it? (5.3)

The net force acting on the book is zero.

62. Can an object that is in equilibrium be moving? Explain. (5.3)

Yes, Newton's first law permits motion as long as the object's velocity is constant. It cannot accelerate.

63. What is the sum of three vectors that, when placed tip to tail, form a triangle? If these vectors represent forces on an object, what does this imply about the object? (5.3)

The vector sum of forces forming a closed triangle is zero. If these are the only forces acting on the object, the net force on the object is zero and the object is in equilibrium.

64. You are asked to analyze the motion of a book placed on a sloping table. (5.3)

a. Describe the best coordinate system for analyzing the motion.
Set up the *y*-axis perpendicular to the surface of the table and the *x*-axis pointing uphill and parallel to the surface.

b. How are the components of the weight of the book related to the angle of the table?
One component is parallel to the inclined surface and the other is perpendicular to it.

65. For a book on a sloping table, describe what happens to the component of the weight force parallel to the table and the force of friction on the book as you increase the angle that the table makes with the horizontal. (5.3)

a. Which components of force(s) increase when the angle increases?
As you increase the angle the table makes with the horizontal, the component of the book's weight force along the table increases.

b. Which components of force(s) decrease?
When the angle increases, the component of the weight force normal to the table decreases and the friction force decreases.

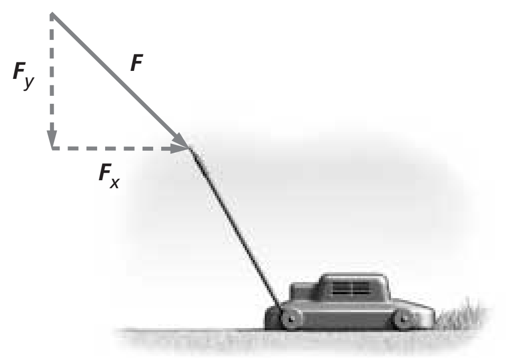
Applying Concepts

pages 140–141

66. A vector that is 1 cm long represents a displacement of 5 km. How many kilometers are represented by a 3-cm vector drawn to the same scale?

$$(3\ \text{cm})\left(\frac{5\ \text{km}}{1\ \text{cm}}\right) = 15\ \text{km}$$

67. Mowing the Lawn If you are pushing a lawn mower across the grass, as shown in **Figure 5-16,** can you increase the horizontal component of the force that you exert on the mower without increasing the magnitude of the force? Explain.



■ **Figure 5-16**

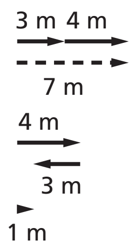
Yes, lower the handle to make the angle between the handle and the horizontal smaller.

68. A vector drawn 15 mm long represents a velocity of 30 m/s. How long should you draw a vector to represent a velocity of 20 m/s?

$$\mathbf{(20\ m/s)\left(\frac{15\ mm}{30\ m/s}\right) = 10\ mm}$$

69. What is the largest possible displacement resulting from two displacements with magnitudes 3 m and 4 m? What is the smallest possible resultant? Draw sketches to demonstrate your answers.

The largest is 7 m; the smallest is 1 m.



70. How does the resultant displacement change as the angle between two vectors increases from 0° to 180°?

The resultant increases.

71. *A* and *B* are two sides of a right triangle, where $\tan \theta = A/B$.

a. Which side of the triangle is longer if $\tan \theta$ is greater than 1.0?

A is longer.

b. Which side is longer if $\tan \theta$ is less than 1.0?

B is longer.

c. What does it mean if $\tan \theta$ is equal to 1.0?

A and B are equal in length.

72. Traveling by Car A car has a velocity of 50 km/h in a direction 60° north of east. A coordinate system with the positive *x*-axis pointing east and a positive *y*-axis pointing north is chosen. Which component of the velocity vector is larger, *x* or *y*?

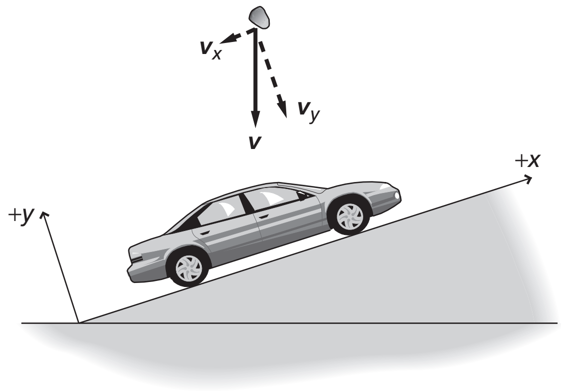
The northward component (*y*) is longer.

73. Under what conditions can the Pythagorean theorem, rather than the law of cosines, be used to find the magnitude of a resultant vector?

The Pythagorean theorem can be used only if the two vectors to be added are at right angles to one another.

74. A problem involves a car moving up a hill, so a coordinate system is chosen with the positive *x*-axis parallel to the surface of the hill. The problem also involves a stone that is dropped onto the car. Sketch the problem and show the components of the velocity vector of the stone.

One component is in the negative *x*-direction, the other in the negative *y*-direction, assuming that the positive direction points upward, perpendicular to the hill.



75. Pulling a Cart According to legend, a horse learned Newton's laws. When the horse was told to pull a cart, it refused, saying that if it pulled the cart forward, according to Newton's third law, there would be an equal force backwards; thus, there would be balanced forces, and, according to Newton's second law, the cart would not accelerate. How would you reason with this horse?

The equal and opposite forces referred to in Newton's third law are acting on different objects. The horse would pull on the cart, and the cart would pull on the horse. The cart would have an unbalanced net force on it (neglecting friction) and would thus accelerate.

76. **Tennis** When stretching a tennis net between two posts, it is relatively easy to pull one end of the net hard enough to remove most of the slack, but you need a winch to take the last bit of slack out of the net to make the top almost completely horizontal. Why is this true?

When stretching the net between the two posts, there is no perpendicular component upward to balance the weight of the net. All the force exerted on the net is horizontal. Stretching the net to remove the last bit of slack requires great force in order to reduce the flexibility of the net and to increase the internal forces that hold it together.

77. The weight of a book on an inclined plane can be resolved into two vector components, one along the plane, and the other perpendicular to it.

a. At what angle are the components equal?
45°

b. At what angle is the parallel component equal to zero?
0°

c. At what angle is the parallel component equal to the weight?
90°

78. **TV Towers** The transmitting tower of a TV station is held upright by guy wires that extend from the top of the tower to the ground. The force along the guy wires can be resolved into two perpendicular components. Which one is larger?

The component perpendicular to the ground is larger if the angle between the guy wire and horizontal is greater than 45°.

Mastering Problems

5.1 Vectors

pages 141–142

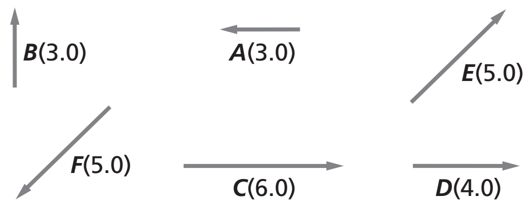
Level 1

79. **Cars** A car moves 65 km due east, then 45 km due west. What is its total displacement?

$65 \text{ km} + (-45 \text{ km}) = 2.0\times10^1 \text{ km}$

$\Delta d = 2.0\times10^1$ km, east

80. Find the horizontal and vertical components of the following vectors, as shown in **Figure 5-17.**



■ **Figure 5-17**

a. *E*

$E_x = E \cos\theta$
$= (5.0)(\cos 45°)$
$= 3.5$

$E_y = E \sin\theta$
$= (5.0)(\sin 45°)$
$= 3.5$

b. *F*

$F_x = F \cos\theta$
$= (5.0)(\cos 225°)$
$= -3.5$

$F_y = F \sin\theta$
$= (5.0)(\sin 225°)$
$= -3.5$

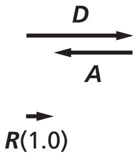
c. *A*

$A_x = A \cos\theta$
$= (3.0)(\cos 180°)$
$= -3.0$

$A_y = A \sin\theta$
$= (3.0)(\sin 180°)$
$= 0.0$

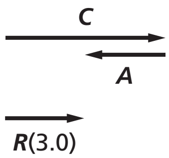
81. Graphically find the sum of the following pairs of vectors, whose lengths and directions are shown in Figure 5-17.

a. ***D*** and ***A***

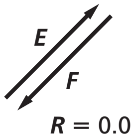


b. ***C*** and ***D***

c. ***C*** and ***A***



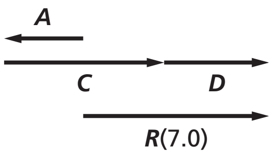
d. ***E*** and ***F***



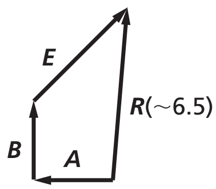
Level 2

82. Graphically add the following sets of vectors, as shown in Figure 5-17.

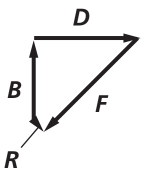
a. ***A, C,*** and ***D***



b. ***A, B,*** and ***E***



c. ***B, D,*** and ***F***



83. You walk 30 m south and 30 m east. Find the magnitude and direction of the resultant displacement both graphically and algebraically.

$$R^2 = A^2 + B^2$$

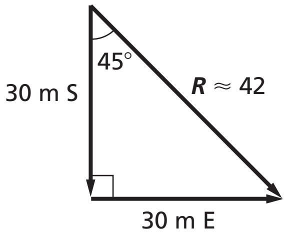
$$R = \sqrt{(30\text{ m})^2 + (30\text{ m})^2}$$

$$= 40\text{ m}$$

$$\tan\theta = \frac{30\text{ m}}{30\text{ m}} = 1$$

$$\theta = 45°$$

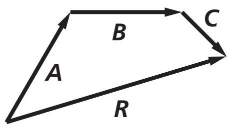
R = 40 m, 45° east of south



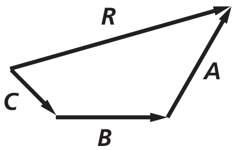
The difference in the answers is due to significant digits being considered in the calculation.

84. **Hiking** A hiker's trip consists of three segments. Path ***A*** is 8.0 km long heading 60.0° north of east. Path ***B*** is 7.0 km long in a direction due east. Path ***C*** is 4.0 km long heading 315° counterclockwise from east.

a. Graphically add the hiker's displacements in the order ***A, B, C.***



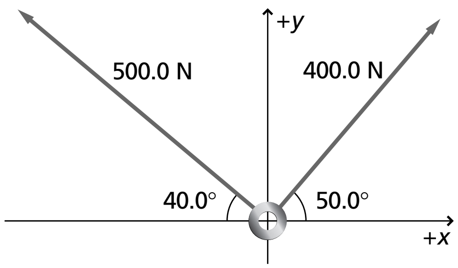
b. Graphically add the hiker's displacements in the order ***C, B, A.***



c. What can you conclude about the resulting displacements?

You can add vectors in any order. The result is always the same.

85. What is the net force acting on the ring in **Figure 5-18?**



■ **Figure 5-18**

$$R^2 = A^2 + B^2$$

$$R = \sqrt{A^2 + B^2}$$

$$= \sqrt{(500.0\ N)^2 + (400.0\ N)^2}$$

$$= 640.3\ N$$

$$\tan\theta = \frac{A}{B}$$

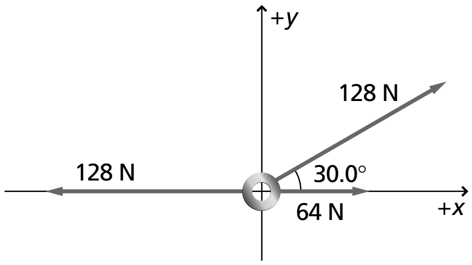
$$\theta = \tan^{-1}\left(\frac{A}{B}\right)$$

$$= \tan^{-1}\left(\frac{500.0}{400.0}\right)$$

$$= 51.34° \text{ from } B$$

The net force is 640.3 N at 51.34°

86. What is the net force acting on the ring in **Figure 5-19?**



■ **Figure 5-19**

$$A = -128\ N + 64\ N$$

$$= -64\ N$$

$$A_x = A\cos\theta_A$$

$$= (-64\ N)(\cos 180°)$$

$$= -64\ N$$

$$A_y = A\sin\theta_A$$

$$= (-64\ N)(\sin 180°)$$

$$= 0\ N$$

$$B_x = B\cos\theta_B$$

$$= (128\ N)(\cos 30.0°)$$

$$= 111\ N$$

$$B_y = B\sin\theta_B$$

$$= (128\ N)(\sin 30.0°)$$

$$= 64\ N$$

$$R_x = A_x + B_x$$

$$= -64\ N + 111\ N$$

$$= 47\ N$$

$$R_y = A_y + B_y$$

$$= 0\ N + 64\ N$$

$$= 64\ N$$

$$R = \sqrt{R_x^2 + R_y^2}$$

$$= \sqrt{(47\ N)^2 + (64\ N)^2}$$

$$= 79\ N$$

$$\theta = \tan^{-1}\left(\frac{R_y}{R_x}\right)$$

$$= \tan^{-1}\left(\frac{64}{47}\right)$$

$$= 54°$$

Level 3

87. A Ship at Sea A ship at sea is due into a port 500.0 km due south in two days. However, a severe storm comes in and blows it 100.0 km due east from its original position. How far is the ship from its destination? In what direction must it travel to reach its destination?

$$R^2 = A^2 + B^2$$

$$R = \sqrt{(100.0\ km)^2 + (500.0\ km)^2}$$

$$= 509.9\ km$$

$$\theta = \tan^{-1}\left(\frac{R_y}{R_x}\right)$$

$$= \tan^{-1}\left(\frac{500.0}{100.0}\right)$$

$$= 78.69°$$

R = 509.9 km, 78.69° south of west

88. **Space Exploration** A descent vehicle landing on Mars has a vertical velocity toward the surface of Mars of 5.5 m/s. At the same time, it has a horizontal velocity of 3.5 m/s.

a. At what speed does the vehicle move along its descent path?

$$R^2 = A^2 + B^2$$

$$R = \sqrt{(5.5\text{ m/s})^2 + (3.5\text{ m/s})^2}$$

$$v = R = 6.5\text{ m/s}$$

b. At what angle with the vertical is this path?

$$\theta = \tan^{-1}\left(\frac{R_y}{R_x}\right)$$

$$= \tan^{-1}\left(\frac{5.5}{3.5}\right)$$

$= 58°$ **from horizontal, which is 32° from vertical**

89. **Navigation** Alfredo leaves camp and, using a compass, walks 4 km E, then 6 km S, 3 km E, 5 km N, 10 km W, 8 km N, and, finally, 3 km S. At the end of three days, he is lost. By drawing a diagram, compute how far Alfredo is from camp and which direction he should take to get back to camp.

Take north and east to be positive directions. North: −6 km + 5 km + 8 km − 3 km = 4 km. East: 4 km + 3 km − 10 km = −3 km. The hiker is 4 km north and 3 km west of camp. To return to camp, the hiker must go 3 km east and 4 km south.

$$R^2 = A^2 + B^2$$

$$R = \sqrt{(3\text{ km})^2 + (4\text{ km})^2}$$

$$= 5\text{ km}$$

$$\theta = \tan^{-1}\left(\frac{R_y}{R_x}\right)$$

$$= \tan^{-1}\left(\frac{4\text{ km}}{3\text{ km}}\right)$$

$$= 53°$$

$R = 5$ **km, 53° south of east**

5.2 Friction

page 142

Level 1

90. If you use a horizontal force of 30.0 N to slide a 12.0-kg wooden crate across a floor at a constant velocity, what is the coefficient of kinetic friction between the crate and the floor?

$$F_f = \mu_k F_N = \mu_k mg = F_{horizontal}$$

$$\mu_k = \frac{F_{horizontal}}{mg}$$

$$= \frac{30.0\text{ N}}{(12.0\text{ kg})(9.80\text{ m/s}^2)}$$

$$= 0.255$$

91. A 225-kg crate is pushed horizontally with a force of 710 N. If the coefficient of friction is 0.20, calculate the acceleration of the crate.

$$ma = F_{net} = F_{appl} - F_f$$

where $F_f = \mu_k F_N = \mu_k mg$

Therefore

$$a = \frac{F_{appl} - \mu_k mg}{m}$$

$$= \frac{710\text{ N} - (0.20)(225\text{ kg})(9.80\text{ m/s}^2)}{225\text{ kg}}$$

$$= 1.2\text{ m/s}^2$$

Level 2

92. A force of 40.0 N accelerates a 5.0-kg block at 6.0 m/s^2 along a horizontal surface.

a. How large is the frictional force?

$$ma = F_{net} = F_{appl} - F_f$$

so $F_f = F_{appl} - ma$

$$= 40.0\text{ N} - (5.0\text{ kg})(6.0\text{ m/s}^2)$$

$$= 1.0\times10^1\text{ N}$$

b. What is the coefficient of friction?

$$F_f = \mu_k F_N = \mu_k mg$$

so $\mu_k = \frac{F_f}{mg}$

$$= \frac{1.0\times10^1\text{ N}}{(5.0\text{ kg})(9.80\text{ m/s}^2)}$$

$$= 0.20$$

93. Moving Appliances Your family just had a new refrigerator delivered. The delivery man has left and you realize that the refrigerator is not quite in the right position, so you plan to move it several centimeters. If the refrigerator has a mass of 180 kg, the coefficient of kinetic friction between the bottom of the refrigerator and the floor is 0.13, and the static coefficient of friction between these same surfaces is 0.21, how hard do you have to push horizontally to get the refrigerator to start moving?

$$F_{\text{on fridge}} = F_{\text{friction}}$$
$$= \mu_s F_N$$
$$= \mu_s mg$$
$$= (0.21)(180\ \text{kg})(9.80\ \text{m/s}^2)$$
$$= 370\ \text{N}$$

Level 3

94. Stopping at a Red Light You are driving a 2500.0-kg car at a constant speed of 14.0 m/s along a wet, but straight, level road. As you approach an intersection, the traffic light turns red. You slam on the brakes. The car's wheels lock, the tires begin skidding, and the car slides to a halt in a distance of 25.0 m. What is the coefficient of kinetic friction between your tires and the wet road?

$$F_f = \mu_k F_N = ma$$

$$-\mu_k mg = \frac{m(v_f^2 - v_i^2)}{2\Delta d} \text{ where } v_f = 0$$

(The minus sign indicates the force is acting opposite to the direction of motion.)

$$\mu_k = \frac{v_i^2}{2dg}$$
$$= \frac{(14.0\ \text{m/s})^2}{2(25.0\ \text{m})(9.80\ \text{m/s}^2)}$$
$$= 0.400$$

5.3 Force and Motion in Two Dimensions

pages 142–143

Level 1

95. An object in equilibrium has three forces exerted on it. A 33.0-N force acts at 90.0° from the x-axis and a 44.0-N force acts at 60.0° from the x-axis. What are the magnitude and direction of the third force?

First, find the magnitude of the sum of these two forces. The equilibrant will have the same magnitude but opposite direction.

$$F_1 = 33.0\ \text{N}, 90.0°$$
$$F_2 = 44.0\ \text{N}, 60.0°$$
$$F_3 = ?$$
$$F_{1x} = F_1 \cos \theta_1$$
$$= (33.0\ \text{N})(\cos 90.0°)$$
$$= 0.0\ \text{N}$$
$$F_{1y} = F_1 \sin \theta_1$$
$$= (33.0\ \text{N})(\sin 90.0°)$$
$$= 33.0\ \text{N}$$
$$F_{2x} = F_2 \cos \theta_2$$
$$= (44.0\ \text{N})(\cos 60.0°)$$
$$= 22.0\ \text{N}$$
$$F_{2y} = F_2 \sin \theta_2$$
$$= (44.0\ \text{N})(\sin 60.0°)$$
$$= 38.1\ \text{N}$$
$$F_{3x} = F_1x + F_2x$$
$$= 0.0\ \text{N} + 22.0\ \text{N}$$
$$= 22.0\ \text{N}$$
$$F_{3y} = F_1y + F_2y$$
$$= 33.0\ \text{N} + 38.1\ \text{N}$$
$$= 71.1\ \text{N}$$
$$F_3 = \sqrt{F_{3x}^2 + F_{3y}^2}$$
$$= \sqrt{(22.0\ \text{N})^2 + (71.1\ \text{N})^2}$$
$$= 74.4\ \text{N}$$

For equilibrium, the sum of the components must equal zero, so

$$\theta = \tan^{-1}\left(\frac{F_{3y}}{F_{3x}}\right) + 180.0°$$

$$= \tan^{-1}\left(\frac{71.1\text{ N}}{22.0\text{ N}}\right) + 180.0°$$

$$= 253°$$

F_3 = 74.4 N, 253°

Level 2

96. Five forces act on an object: (1) 60.0 N at 90.0°, (2) 40.0 N at 0.0°, (3) 80.0 N at 270.0°, (4) 40.0 N at 180.0°, and (5) 50.0 N at 60.0°. What are the magnitude and direction of a sixth force that would produce equilibrium?

Solutions by components

F_1 = 60.0 N, 90.0°

F_2 = 40.0 N, 0.0°

F_3 = 80.0 N, 270.0°

F_4 = 40.0 N, 180.0°

F_5 = 50.0 N, 60.0°

F_6 = ?

$$F_{1x} = F_1 \cos \theta_1$$
$$= (60.0\text{ N})(\cos 90.0°) = 0.0\text{ N}$$

$$F_{1y} = F_1 \sin \theta_1 = (60.0\text{ N})(\sin 90.0°)$$
$$= 60.0\text{ N}$$

$$F_{2x} = F_2 \cos \theta_2 = (40.0\text{ N})(\cos 0.0°)$$
$$= 40.0\text{ N}$$

$$F_{2y} = F_2 \sin \theta_2 = (40.0\text{ N})(\sin 0.0°)$$
$$= 0.0\text{ N}$$

$$F_{3x} = F_3 \cos \theta_3 = (80.0\text{ N})(\cos 270.0°)$$
$$= 0.0\text{ N}$$

$$F_{3y} = F_3 \sin \theta_3 = (80.0\text{ N})(\sin 270.0°)$$
$$= -80.0\text{ N}$$

$$F_{4x} = F_4 \cos \theta_4 = (40.0\text{ N})(\cos 180.0°)$$
$$= -40.0\text{ N}$$

$$F_{4y} = F_4 \sin \theta_4 = (40.0\text{ N})(\sin 180.0°)$$
$$= 0.0\text{ N}$$

$$F_{5x} = F_5 \cos \theta_5 = (50.0\text{ N})(\cos 60.0°)$$
$$= 25.0\text{ N}$$

$$F_{5y} = F_5 \sin \theta_5 = (50.0\text{ N})(\sin 60.0°)$$
$$= 43.3\text{ N}$$

$$F_{6x} = F_{1x} + F_{2x} + F_{3x} + F_{4x} + F_{5x}$$
$$= 0.0\text{ N} + 40.0\text{ N} + 0.0\text{ N} + (-40.0\text{ N}) + 25.0\text{ N}$$
$$= 25.0\text{ N}$$

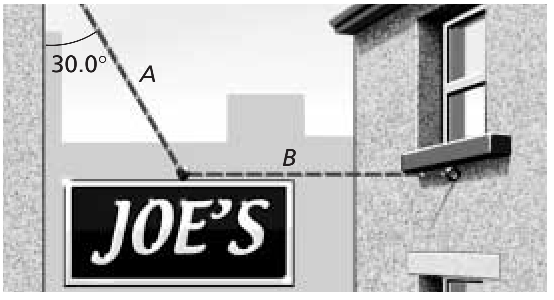
$$F_{6y} = F_{1y} + F_{2y} + F_{3y} + F_{4y} + F_{5y}$$
$$= 60.0\text{ N} + 0.0\text{ N} + (-80.0\text{ N}) + 0.0\text{ N} + 43.3\text{ N}$$
$$= 23.3\text{ N}$$

$$F_6 = \sqrt{{F_{6x}}^2 + {F_{6y}}^2}$$
$$= \sqrt{(25.0\text{ N})^2 + (23.3\text{ N})^2}$$
$$= 34.2\text{ N}$$

$$\theta_6 = \tan^{-1}\left(\frac{F_{6y}}{F_{6x}}\right) + 180.0°$$
$$= \tan^{-1}\left(\frac{23.3\text{ N}}{25.0\text{ N}}\right) + 180.0°$$
$$= 223°$$

F_6 = 34.2 N, 223°

97. **Advertising** Joe wishes to hang a sign weighing 7.50×10^2 N so that cable *A*, attached to the store, makes a 30.0° angle, as shown in **Figure 5-20.** Cable *B* is horizontal and attached to an adjoining building. What is the tension in cable *B*?



■ **Figure 5-20**

Solution by components. The sum of the components must equal zero, so

$F_{Ay} - F_g = 0$

so $F_{Ay} = F_g$

$= 7.50\times10^2$ N

$F_{Ay} = F_A \sin 60.0°$

so $F_A = \frac{F_{Ay}}{\sin 60.0°}$

$= \frac{7.50\times10^2 \text{ N}}{\sin 60.0°}$

$= 866$ N

Also, $F_B - F_A = 0$, so

$F_B = F_A$

$= F_A \cos 60.0°$

$= (866 \text{ N})(\cos 60.0°)$

$= 433$ N, right

98. A street lamp weighs 150 N. It is supported by two wires that form an angle of 120.0° with each other. The tensions in the wires are equal.

a. What is the tension in each wire supporting the street lamp?

$F_g = 2T \sin \theta$

so $T = \frac{F_g}{2 \sin \theta}$

$= \frac{150 \text{ N}}{(2)(\sin 30.0°)}$

$= 1.5\times10^2$ N

b. If the angle between the wires supporting the street lamp is reduced to 90.0°, what is the tension in each wire?

$T = \frac{F_g}{2 \sin \theta}$

$= \frac{150 \text{ N}}{(2)(\sin 45°)}$

$= 1.1\times10^2$ N

99. A 215-N box is placed on an inclined plane that makes a 35.0° angle with the horizontal. Find the component of the weight force parallel to the plane's surface.

$F_{parallel} = F_g \sin \theta$

$= (215 \text{ N})(\sin 35.0°)$

$= 123$ N

Level 3

100. Emergency Room You are shadowing a nurse in the emergency room of a local hospital. An orderly wheels in a patient who has been in a very serious accident and has had severe bleeding. The nurse quickly explains to you that in a case like this, the patient's bed will be tilted with the head downward to make sure the brain gets enough blood. She tells you that, for most patients, the largest angle that the bed can be tilted without the patient beginning to slide off is 32.0° from the horizontal.

a. On what factor or factors does this angle of tilting depend?

The coefficient of static friction between the patient and the bed's sheets.

b. Find the coefficient of static friction between a typical patient and the bed's sheets.

$F_{g \text{ parallel to bed}} = mg \sin \theta$

$= F_f$

$= \mu_s F_N$

$= \mu_s mg \cos \theta$

so $\mu_s = \frac{mg \sin \theta}{mg \cos \theta}$

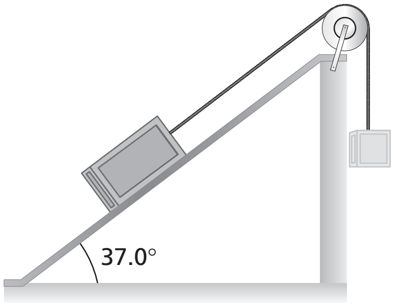
$= \frac{\sin \theta}{\cos \theta}$

$= \tan \theta$

$= \tan 32.0°$

$= 0.625$

101. Two blocks are connected by a string over a frictionless, massless pulley such that one is resting on an inclined plane and the other is hanging over the top edge of the plane, as shown in **Figure 5-21.** The hanging block has a mass of 16.0 kg, and the one on the plane has a mass of 8.0 kg. The coefficient of kinetic friction between the block and the inclined plane is 0.23. The blocks are released from rest.



■ **Figure 5-21**

a. What is the acceleration of the blocks?

$$F = m_{both}a = F_{g\ hanging} - F_{\parallel plane} - F_{f\ plane}$$

$$\text{so } a = \frac{m_{hanging}g - F_{g\ plane}\sin\theta - \mu_k F_{g\ plane}\cos\theta}{m_{both}}$$

$$= \frac{m_{hanging}g - m_{plane}g\sin\theta - \mu_k m_{plane}g\cos\theta}{m_{both}}$$

$$= \frac{g(m_{hanging} - m_{plane}\sin\theta - \mu_k m_{plane}\cos\theta)}{m_{hanging} + m_{plane}}$$

$$= \frac{(9.80\text{ m/s}^2)(16.0\text{ kg} - (8.0\text{ kg})(\sin 37.0°) - (0.23)(8.0\text{ kg})(\cos 37.0°))}{(16.0\text{ kg} + 80\text{ kg})}$$

$$= 4.0\text{ m/s}^2$$

b. What is the tension in the string connecting the blocks?

$$F_T = F_g - F_a$$

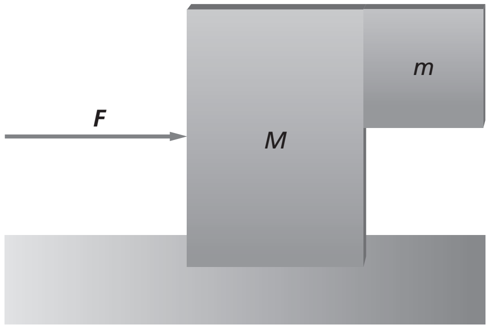
$$= mg - ma$$

$$= m(g - a)$$

$$= (16.0\text{ kg})(9.80\text{ m/s}^2 - 4.0\text{ m/s}^2)$$

$$= 93\text{ N}$$

102. In **Figure 5-22,** a block of mass *M* is pushed with such a force, *F,* that the smaller block of mass *m* does not slide down the front of it. There is no friction between the larger block and the surface below it, but the coefficient of static friction between the two blocks is μ_s. Find an expression for *F* in terms of *M, m,* μ_s, and *g.*



■ **Figure 5-22**

Smaller block:

$$F_{f,\ M\ on\ m} = \mu_s F_{N,\ M\ on\ m} = mg$$

$$F_{N,\ M\ on\ m} = \frac{mg}{\mu_s} = ma$$

$$a = \frac{g}{\mu_s}$$

Larger block:

$F - F_{\text{N, m on M}} = Ma$

$F - \frac{mg}{\mu_s} = \frac{Mg}{\mu_s}$

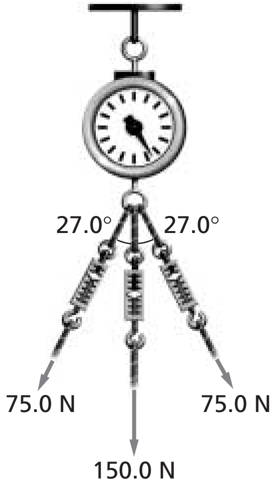
$F = \frac{g}{\mu_s}(m + M)$

Mixed Review

pages 143–144

Level 1

103. The scale in **Figure 5-23** is being pulled on by three ropes. What net force does the scale read?



■ **Figure 5-7**

Find the *y*-component of the two side ropes and then add them to the middle rope.

$F_y = F \cos \theta$

$= (75.0 \text{ N})(\cos 27.0°)$

$= 66.8 \text{ N}$

$F_{y,\text{ total}} = F_{y,\text{ left}} + F_{y,\text{ middle}} + F_{y,\text{ right}}$

$= 66.8 \text{ N} + 150.0 \text{ N} + 66.8 \text{ N}$

$= 283.6 \text{ N}$

104. Sledding A sled with a mass of 50.0 kg is pulled along flat, snow-covered ground. The static friction coefficient is 0.30, and the kinetic friction coefficient is 0.10.

a. What does the sled weigh?

$F_g = mg = (50.0 \text{ kg})(9.80 \text{ m/s}^2)$

$= 4.90\times10^2 \text{ N}$

b. What force will be needed to start the sled moving?

$F_f = \mu_s F_N$

$= \mu_s F_g$

$= (0.30)(4.90\times10^2 \text{ N})$

$= 1.5\times10^2 \text{ N}$

c. What force is needed to keep the sled moving at a constant velocity?

$F_f = \mu_s F_N$

$= \mu_s F_g$

$= (0.10)(4.90\times10^2 \text{ N})$

$= 49 \text{ N, kinetic friction}$

d. Once moving, what total force must be applied to the sled to accelerate it at 3.0 m/s^2?

$ma = F_{\text{net}} = F_{\text{appl}} - F_f$

so $F_{\text{appl}} = ma + F_f$

$= (50.0 \text{ kg})(3.0 \text{ m/s}^2) + 49 \text{ N}$

$= 2.0\times10^2 \text{ N}$

Level 2

105. Mythology Sisyphus was a character in Greek mythology who was doomed in Hades to push a boulder to the top of a steep mountain. When he reached the top, the boulder would slide back down the mountain and he would have to start all over again. Assume that Sisyphus slides the boulder up the mountain without being able to roll it, even though in most versions of the myth, he rolled it.

a. If the coefficient of kinetic friction between the boulder and the mountainside is 0.40, the mass of the boulder is 20.0 kg, and the slope of the mountain is a constant 30.0°, what is the force that Sisyphus must exert on the boulder to move it up the mountain at a constant velocity?

$F_{\text{S on rock}} - F_{\text{g}\|\text{to slope}} - F_f$

$= F_{\text{S on rock}} - mg \sin \theta -$

$\mu_k mg \cos \theta = ma = 0$

$F_{\text{S on rock}} = mg \sin \theta + \mu_k mg \cos \theta$

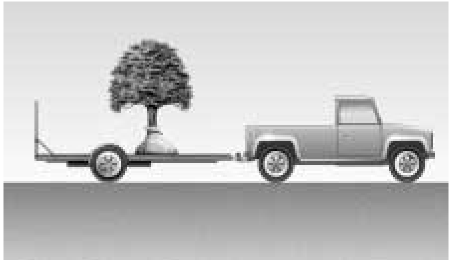
$$= mg(\sin \theta + \mu_k \cos \theta)$$
$$= (20.0\text{ kg})(9.80\text{ m/s}^2)(\sin 30.0° + (0.40)(\cos 30.0°))$$
$$= 166\text{ N}$$

b. If Sisyphus pushes the boulder at a velocity of 0.25 m/s and it takes him 8.0 h to reach the top of the mountain, what is the mythical mountain's vertical height?

$$h = d \sin \theta$$
$$= vt \sin \theta$$
$$= (0.25\text{ m/s})(8.0\text{ h})(3600\text{ s/h})(\sin 30.0°)$$
$$= 3.6\times10^3\text{ m} = 3.6\text{ km}$$

Level 3

106. Landscaping A tree is being transported on a flatbed trailer by a landscaper, as shown in **Figure 5-24.** If the base of the tree slides on the tree will the trailer, fall over and be damaged. If the coefficient of static friction between the tree and the trailer is 0.50, what is the minimum stopping distance of the truck, traveling at 55 km/h, if it is to accelerate uniformly and not have the tree slide forward and fall on the trailer?



■ **Figure 5-24**

$$F_{truck} = -F_f = -\mu_s F_N = -\mu_s mg = ma$$

$$a = \frac{-\mu_s mg}{m} = -\mu_s g$$
$$= -(0.50)(9.80\text{ m/s}^2)$$
$$= -4.9\text{ m/s}^2$$

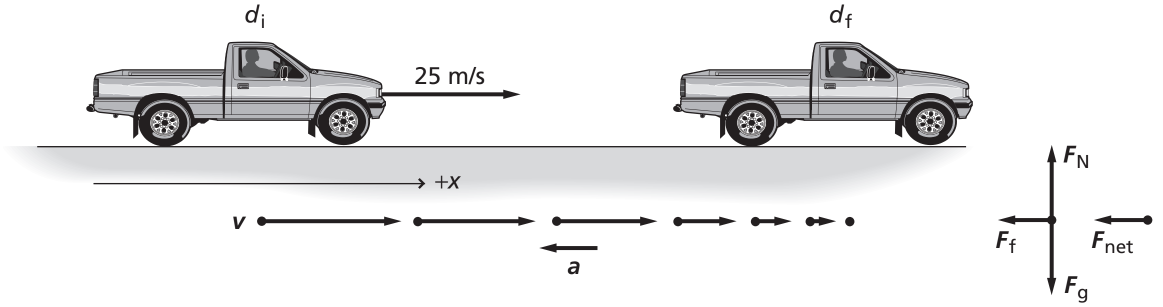
$v_f^2 = v_i^2 + 2a\Delta d$ with $v_f = 0$,

$$\text{so } \Delta d = -\frac{v_i^2}{2a}$$
$$= \frac{-\left((55\text{ km/h})\left(\frac{1000\text{ m}}{1\text{ km}}\right)\left(\frac{1\text{ h}}{3600\text{ s}}\right)\right)^2}{(2)(-4.9\text{ m/s}^2)}$$
$$= 24\text{ m}$$

Thinking Critically

page 144

107. Use Models Using the Example Problems in this chapter as models, write an example problem to solve the following problem. Include the following sections: Analyze and Sketch the Problem, Solve for the Unknown (with a complete strategy), and Evaluate the Answer. A driver of a 975-kg car traveling 25 m/s puts on the brakes. What is the shortest distance it will take for the car to stop? Assume that the road is concrete, the force of friction of the road on the tires is constant, and the tires do not slip.



Analyze and Sketch the Problem

- **Choose a coordinate system with a positive axis in the direction of motion.**
- **Draw a motion diagram.**
- **Label v and a.**
- **Draw the free-body diagram.**

Known:	**Unknown:**
$d_i = 0$	$d_f = ?$
$v_i = 25$ m/s	
$v_f = 0$	
$m = 975$ kg	
$\mu_s = 0.80$	

Solve for the Unknown

Solve Newton's second law for a.

$-F_{net} = ma$

$-F_f = ma$ **Substitute $-F_f = -F_{net}$**

$-\mu F_N = ma$ **Substitute $F_f = \mu F_N$**

$-\mu mg = ma$ **Substitute $F_N = mg$**

$a = -\mu g$

Use the expression for acceleration to solve for distance.

$v_f^2 = v_i^2 + 2a(d_f - d_i)$

$$d_f = d_i + \frac{v_f^2 - v_i^2}{2a}$$

$$= d_i + \frac{v_f^2 - v_i^2}{(2)(-\mu g)}$$ **Substitute $a = -\mu g$**

$= 0.0\text{ m} + \frac{(0.0\text{ m/s})^2 - (25\text{ m/s})^2}{(2)(-0.65)(9.80\text{ m/s})^2}$ **Substitute $d_i = 0.0$ m, $v_f = 0.0$ m/s, $v_i = 25$ m/s, $\mu = 0.65$, $g = 9.80$ m/s^2**

$= 49\text{ m}$

108. Analyze and Conclude Margaret Mary, Doug, and Kako are at a local amusement park and see an attraction called the Giant Slide, which is simply a very long and high inclined plane. Visitors at the amusement park climb a long flight of steps to the top of the 27° inclined plane and are given canvas sacks. They sit on the sacks and slide down the 70-m-long plane. At the time when the three friends walk past the slide, a 135-kg man and a 20-kg boy are each at the top preparing to slide down. "I wonder how much less time it will take the man to slide down than it will take the boy," says Margaret Mary. "I think the boy will take less time," says Doug. "You're both wrong," says Kako. "They will reach the bottom at the same time."

a. Perform the appropriate analysis to determine who is correct.

$F_{net} = F_g - F_f$

$= F_g \sin\theta - \mu_k F_N$

$= mg \sin\theta - \mu_k mg \cos\theta = ma$

$a = g(\sin\theta - \mu_k \cos\theta)$**, so the acceleration is independent of the mass. They will tie, so Kako is correct.**

b. If the man and the boy do not take the same amount of time to reach the of the slide, calculate how many seconds of difference there will be between the two times.

They will reach the bottom at the same time.

Writing in Physics

page 144

109. Investigate some of the techniques used in industry to reduce the friction between various parts of machines. Describe two or three of these techniques and explain the physics of how they work.

Answers will vary and may include lubricants and reduction of the normal force to reduce the force of friction.

110. Olympics In recent years, many Olympic athletes, such as sprinters, swimmers, skiers, and speed skaters, have used modified equipment to reduce the effects of friction and air or water drag. Research a piece of equipment used by one of these types of athletes and the way it has changed over the years. Explain how physics has impacted these changes.

Answers will vary.

Cumulative Review

page 144

111. Add or subtract as indicated and state the answer with the correct number of significant digits. (Chapter 1)

a. 85.26 g + 4.7 g

90.0 g

b. 1.07 km + 0.608 km

1.68 km

c. 186.4 kg − 57.83 kg

128.6 kg

d. 60.08 s − 12.2 s

47.9 s

112. You ride your bike for 1.5 h at an average velocity of 10 km/h, then for 30 min at 15 km/h. What is your average velocity? (Chapter 3)

Average velocity is the total displacement divided by the total time.

$$\bar{v} = \frac{d_f - d_i}{t_f - t_i}$$

$$= \frac{v_1t_1 + v_2t_2 - d_i}{t_1 + t_2 - t_i}$$

$d_i = t_i = 0$, so

$$\bar{v} = \frac{v_1t_1 + v_2t_2}{t_1 + t_2}$$

$$= \frac{(10\text{ km/h})(1.5\text{ h}) + (15\text{ km/h})(0.5\text{ h})}{1.5\text{ h} + 0.5\text{ h}}$$

$$= 10\text{ km/h}$$

113. A 45-N force is exerted in the upward direction on a 2.0-kg briefcase. What is the acceleration of the briefcase? (Chapter 4)

$$F_{net} = F_{applied} - F_g = F_{applied} - mg$$

$$= ma$$

so $a = \frac{F_{applied} - mg}{m}$

$$= \frac{45\text{ N} - (2.0\text{ kg})(9.80\text{ m/s}^2)}{2.0\text{ kg}}$$

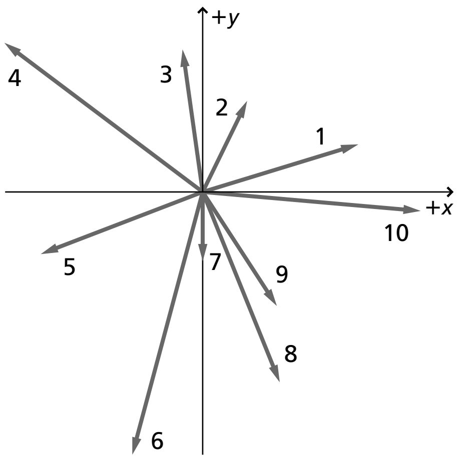
$$= 13\text{ m/s}^2$$

Challenge Problem

page 132

Find the equilibrant for the following forces.

F_1 = 61.0 N at 17.0° north of east
F_2 = 38.0 N at 64.0° north of east
F_3 = 54.0 N at 8.0° west of north
F_4 = 93.0 N at 53.0° west of north
F_5 = 65.0 N at 21.0° south of west
F_6 = 102.0 N at 15.0° west of south
F_7 = 26.0 N south
F_8 = 77.0 N at 22.0° east of south
F_9 = 51.0 N at 33.0° east of south
F_{10} = 82.0 N at 5.0° south of east



F_{1x} = (61.0 N)(cos 17.0°) = 58.3 N

F_{1y} = (61.0 N)(sin 17.0°) = 17.8 N

F_{2x} = (38.0 N)(cos 64.0°) = 16.7 N

F_{2y} = (38.0 N)(sin 64.0°) = 34.2 N

F_{3x} = −(54.0 N)(sin 8.0°) = −7.52 N

F_{3y} = (54.0 N)(cos 8.0°) = 53.5 N

F_{4x} = −(93.0 N)(sin 53.0°) = −74.3 N

F_{4y} = (93.0 N)(cos 53.0°) = 56.0 N

F_{5x} = −(65.0 N)(cos 21.0°) = −60.7 N

F_{5y} = −(65.0 N)(sin 21.0°) = −23.3 N

F_{6x} = −(102 N)(sin 15.0°) = −26.4 N

F_{6y} = −(102 N)(cos 15.0°) = −98.5 N

$F_{7x} = 0.0 \text{ N}$

$F_{7y} = -26.0 \text{ N}$

$F_{8x} = (77.0 \text{ N})(\sin 22.0°) = 28.8 \text{ N}$

$F_{8y} = -(77.0 \text{ N})(\cos 22.0°) = -71.4 \text{ N}$

$F_{9x} = (51.0 \text{ N})(\sin 33.0°) = 27.8 \text{ N}$

$F_{9y} = -(51.0 \text{ N})(\cos 33.0°) = -42.8 \text{ N}$

$F_{10x} = (82.0 \text{ N})(\cos 5.0°) = 81.7 \text{ N}$

$F_{10y} = -(82.0 \text{ N})(\sin 5.0°) = -7.15 \text{ N}$

$$F_x = \sum_{i=1}^{10} F_{ix}$$

$$= 44.38 \text{ N}$$

$$F_y = \sum_{i=1}^{10} F_{iy}$$

$$= -107.65 \text{ N}$$

$$F_R = \sqrt{(F_x)^2 + (F_y)^2}$$

$$= \sqrt{(44.38 \text{ N})^2 + (-107.65 \text{ N})^2}$$

$$= 116 \text{ N}$$

$$\theta_R = \tan^{-1}\left(\frac{F_y}{F_x}\right)$$

$$= \tan^{-1}\left(\frac{-107.65 \text{ N}}{44.38 \text{ N}}\right)$$

$$= -67.6°$$

$F_{\text{equilibrant}} = 116 \text{ N at } 112.4°$

$= 116 \text{ N at } 22.4° \text{ W of N}$

CHAPTER

6 Motion in Two Dimensions

Practice Problems

6.1 Projectile Motion pages 147–152

page 150

1. A stone is thrown horizontally at a speed of 5.0 m/s from the top of a cliff that is 78.4 m high.

a. How long does it take the stone to reach the bottom of the cliff?

Since $v_y = 0$, $y - v_y t = -\frac{1}{2}gt^2$

becomes $y = -\frac{1}{2}gt^2$

or $t = \sqrt{-\frac{2y}{g}}$

$= \sqrt{\frac{-(2)(-78.4\ \text{m})}{9.80\ \text{m/s}^2}}$

$= 4.00\ \text{s}$

b. How far from the base of the cliff does the stone hit the ground?

$x = v_x t$

$= (5.0\ \text{m/s})(4.00\ \text{s})$

$= 2.0\times10^1\ \text{m}$

c. What are the horizontal and vertical components of the stone's velocity just before it hits the ground?

$v_x = 5.0$ m/s. This is the same as the initial horizontal speed because the acceleration of gravity influences only the vertical motion. For the vertical component, use $v = v_i + gt$ with $v = v_y$ and v_i, the initial vertical component of velocity, zero.

At $t = 4.00$ s

$v_y = gt$

$= (9.80\ \text{m/s}^2)(4.0\ \text{s})$

$= 39.2\ \text{m/s}$

2. Lucy and her friend are working at an assembly plant making wooden toy giraffes. At the end of the line, the giraffes go horizontally off the edge of the conveyor belt and fall into a box below. If the box is 0.6 m below the level of the conveyor belt and 0.4 m away from it, what must be the horizontal velocity of giraffes as they leave the conveyor belt?

$x = v_x t = v_x\sqrt{\frac{-2y}{g}}$

so $v_x = \frac{x}{\sqrt{\frac{-2y}{g}}}$

$= \frac{0.4\ \text{m}}{\sqrt{\frac{(-2)(-0.6\ \text{m})}{9.80\ \text{m/s}^2}}}$

$= 1\ \text{m/s}$

3. You are visiting a friend from elementary school who now lives in a small town. One local amusement is the ice-cream parlor, where Stan, the short-order cook, slides his completed ice-cream sundaes down the counter at a constant speed of 2.0 m/s to the servers. (The counter is kept very well polished for this purpose.) If the servers catch the sundaes 7.0 cm from the edge of the counter, how far do they fall from the edge of the counter to the point at which the servers catch them?

$x = v_x t;$

$t = \frac{x}{v_x}$

$y = -\frac{1}{2}gt^2$

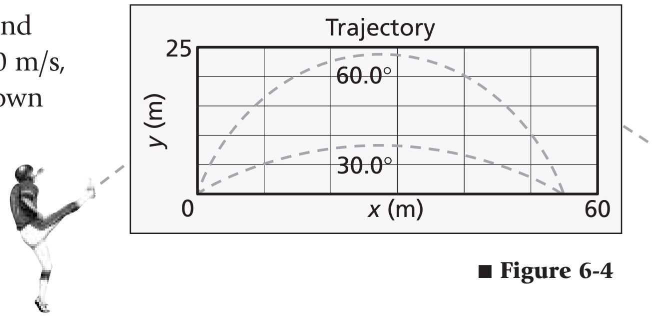
$= -\frac{1}{2}g\left(\frac{x}{v_x}\right)^2$

$= -\frac{1}{2}(9.80\ \text{m/s}^2)\left(\frac{0.070\ \text{m}}{2.0\ \text{m/s}}\right)^2$

$= 0.0060\ \text{m or } 0.60\ \text{cm}$

page 152

4. A player kicks a football from ground level with an initial velocity of 27.0 m/s, 30.0° above the horizontal, as shown in **Figure 6-4.** Find each of the following. Assume that air resistance is negligible.



■ **Figure 6-4**

a. the ball's hang time

$$v_y = v_i \sin\theta$$

When it lands, $y = v_y t - \frac{1}{2}gt^2 = 0$.

Therefore,

$$t^2 = \frac{2v_y t}{g}$$

$$t = \frac{2v_y}{g}$$

$$= \frac{2v_i \sin\theta}{g}$$

$$= \frac{(2)(27.0\text{ m/s})(\sin 30.0°)}{9.80\text{ m/s}^2}$$

$$= 2.76\text{ s}$$

b. the ball's maximum height

Maximum height occurs at half the "hang time," or 1.38 s. Thus,

$$y = v_y t - \frac{1}{2}gt^2$$

$$= v_i \sin\theta\, t - \frac{1}{2}gt^2$$

$$= (27.0\text{ m/s})(\sin 30.0°)(1.38\text{ s}) - \frac{1}{2}(+9.80\text{ m/s}^2)(1.38\text{ s})^2$$

$$= 9.30\text{ m}$$

c. the ball's range

Distance:

$$v_x = v_i \cos\theta$$

$$x = v_x t = (v_i \cos\theta)(t) = (27.0\text{ m/s})(\cos 30.0°)(2.76\text{ s}) = 64.5\text{ m}$$

5. The player in problem 4 then kicks the ball with the same speed, but at 60.0° from the horizontal. What is the ball's hang time, range, and maximum height?

Following the method of Practice Problem 4,

Hangtime:

$$t = \frac{2v_i \sin\theta}{g}$$

$$= \frac{(2)(27.0\text{ m/s})(\sin 60.0°)}{9.80\text{ m/s}^2}$$

$$= 4.77\text{ s}$$

Distance:

$x = v_i \cos \theta \, t$

$= (27.0 \text{ m/s})(\cos 60.0°)(4.77 \text{ s})$

$= 64.4 \text{ m}$

Maximum height:

at $t = \frac{1}{2}(4.77 \text{ s}) = 2.38 \text{ s}$

$y = v_i \sin \theta \, t - \frac{1}{2}gt^2$

$= (27.0 \text{ m/s})(\sin 60.0°)(2.38 \text{ s}) - \frac{1}{2}(+9.80 \text{ m/s}^2)(2.38 \text{ s})^2$

$= 27.9 \text{ m}$

6. A rock is thrown from a 50.0-m-high cliff with an initial velocity of 7.0 m/s at an angle of 53.0° above the horizontal. Find the velocity vector for when it hits the ground below.

$v_x = v_i \cos \theta$

$v_y = v_i \sin \theta + gt$

$= v_i \sin \theta + g\sqrt{\frac{2y}{g}}$

$= v_i \sin \theta + \sqrt{2yg}$

$v = \sqrt{v_x{}^2 + v_y{}^2}$

$= \sqrt{(v_i \cos \theta)^2 + (v_i \sin \theta + \sqrt{2yg})^2}$

$= \sqrt{((7.0 \text{ m/s}) \cos 53.0°)^2 + \left((7.0 \text{ m/s})(\sin 53.0°) + \sqrt{(2)(50.0 \text{ m})(9.80 \text{ m/s}^2)}\right)^2}$

$= 37 \text{ m/s}$

$\theta = \tan^{-1}\left(\frac{v_y}{v_x}\right)$

$= \tan^{-1}\left(\frac{v_i \sin \theta_i + \sqrt{2yg}}{v_i \cos \theta_i}\right)$

$= \tan^{-1}\left(\frac{(7.0 \text{ m/s})(\sin 53.0°) + \sqrt{(2)(50.0 \text{ m})(9.80 \text{ m/s}^2)}}{(7.0 \text{ m/s})(\cos 53.0°)}\right)$

$= 83°$ **from horizontal**

Section Review

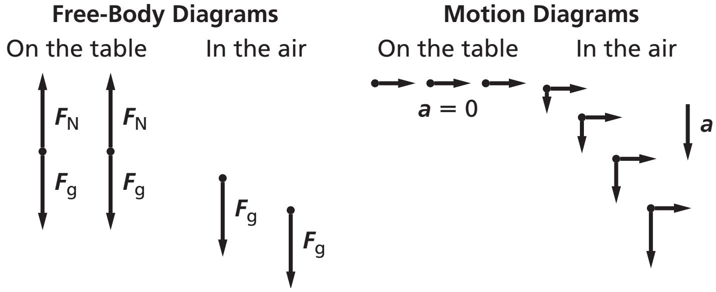
6.1 Projectile Motion pages 147–152

page 152

7. Projectile Motion Two baseballs are pitched horizontally from the same height, but at different speeds. The faster ball crosses home plate within the strike zone, but the slower ball is below the batter's knees. Why does the faster ball not fall as far as the slower one?

The faster ball is in the air a shorter time, and thus gains a smaller vertical velocity.

8. **Free-Body Diagram** An ice cube slides without friction across a table at a constant velocity. It slides off the table and lands on the floor. Draw free-body and motion diagrams of the ice cube at two points on the table and at two points in the air.



9. **Projectile Motion** A softball is tossed into the air at an angle of 50.0° with the vertical at an initial velocity of 11.0 m/s. What is its maximum height?

$v_f^2 = v_{iy}^2 + 2a(d_f - d_i)$; $a = -g$, $d_i = 0$

At maximum height $v_f = 0$**, so**

$$d_f = \frac{v_{iy}^2}{2g}$$

$$= \frac{(v_i \cos \theta)^2}{2g}$$

$$= \frac{((11.0 \text{ m/s})(\cos 50.0°))^2}{(2)(9.80 \text{ m/s}^2)}$$

$$= 2.55 \text{ m}$$

10. **Projectile Motion** A tennis ball is thrown out a window 28 m above the ground at an initial velocity of 15.0 m/s and 20.0° below the horizontal. How far does the ball move horizontally before it hits the ground?

$x = v_{0x}t$**, but need to find** t

First, determine v_{yf}**:**

$$v_{yf}^2 = v_{yi}^2 + 2gy$$

$$v_{yf} = \sqrt{v_{yi}^2 + 2gy}$$

$$= \sqrt{(v_i \sin \theta)^2 + 2gy}$$

$$= \sqrt{((15.0 \text{ m/s})(\sin 20.0°))^2 + (2)(9.80 \text{ m/s}^2)(28 \text{ m})}$$

$$= 24.0 \text{ m/s}$$

Now use $v_{yf} = v_{yi} + gt$ **to find** t**.**

$$t = \frac{v_{yf} - v_{yi}}{g}$$

$$= \frac{v_{yf} - v_i \sin \theta}{g}$$

$$= \frac{2.40\text{ m/s} - (15.0\text{ m/s})(\sin 20.0°)}{9.80\text{ m/s}^2}$$

= 1.92 s

$x = v_{x\text{i}}t$

$= (v_\text{i} \cos \theta)(t)$

= (15.0 m/s)(cos 20.0°)(1.92 s)

= 27.1 m

11. **Critical Thinking** Suppose that an object is thrown with the same initial velocity and direction on Earth and on the Moon, where *g* is one-sixth that on Earth. How will the following quantities change?

a. v_x

will not change

b. the object's time of flight

will be larger; $t = \frac{-2v_y}{g}$

c. y_{max}

will be larger

d. *R*

will be larger

Practice Problems

6.2 Circular Motion pages 153–156

page 156

12. A runner moving at a speed of 8.8 m/s rounds a bend with a radius of 25 m. What is the centripetal acceleration of the runner, and what agent exerts force on the runner?

$a_\text{c} = \frac{v^2}{r} = \frac{(8.8\text{ m/s})^2}{25\text{ m}} = 3.1\text{ m/s}^2$**, the frictional force of the track acting on the runner's shoes exerts the force on the runner.**

13. A car racing on a flat track travels at 22 m/s around a curve with a 56-m radius. Find the car's centripetal acceleration. What minimum coefficient of static friction between the tires and road is necessary for the car to round the curve without slipping?

$a_\text{c} = \frac{v^2}{r} = \frac{(22\text{ m/s})^2}{56\text{ m}} = 8.6\text{ m/s}^2$

Recall $F_\text{f} = \mu F_\text{N}$**. The friction force must supply the centripetal force so** $F_\text{f} = ma_\text{c}$**. The normal force is** $F_\text{N} = -mg$**. The coefficient of friction must be at least**

$$\mu = \frac{F_\text{f}}{F_\text{N}} = \frac{ma_\text{c}}{mg} = \frac{a_\text{c}}{g} = \frac{8.6\text{ m/s}^2}{9.80\text{ m/s}^2} = 0.88$$

14. An airplane traveling at 201 m/s makes a turn. What is the smallest radius of the circular path (in km) that the pilot can make and keep the centripetal acceleration under 5.0 m/s^2?

$$a_c = \frac{v^2}{r}, \text{ so } r = \frac{v^2}{a_c} = \frac{(201 \text{ m/s})^2}{5.0 \text{ m/s}^2} = 8.1 \text{ km}$$

15. A 45-kg merry-go-round worker stands on the ride's platform 6.3 m from the center. If her speed as she goes around the circle is 4.1 m/s, what is the force of friction necessary to keep her from falling off the platform?

$$F_f = F_c = \frac{mv^2}{r} = \frac{(45 \text{ kg})(4.1 \text{ m/s})^2}{6.3 \text{ m}} = 120 \text{ N}$$

Section Review

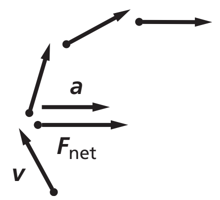
6.2 Circular Motion pages 153–156

page 156

16. Uniform Circular Motion What is the direction of the force that acts on the clothes in the spin cycle of a washing machine? What exerts the force?

The force is toward the center of the tub. The walls of the tub exert the force on the clothes. Of course, the whole point is that some of the water in the clothes goes out through holes in the wall of the tub rather than moving toward the center.

17. Free-Body Diagram You are sitting in the backseat of a car going around a curve to the right. Sketch motion and free-body diagrams to answer the following questions.



a. What is the direction of your acceleration?

Your body is accelerated to the right.

b. What is the direction of the net force that is acting on you?

The net force acting on your body is to the right

c. What exerts this force?

The force is exerted by the car's seat.

18. Centripetal Force If a 40.0-g stone is whirled horizontally on the end of a 0.60-m string at a speed of 2.2 m/s, what is the tension in the string?

$$F_T = ma_c$$

$$= \frac{mv^2}{r}$$

$$= \frac{(0.0400 \text{ kg})(22 \text{ m/s})^2}{0.60 \text{ m}}$$

$$= 0.32 \text{ N}$$

19. Centripetal Acceleration A newspaper article states that when turning a corner, a driver must be careful to balance the centripetal and centrifugal forces to keep from skidding. Write a letter to the editor that critiques this article.

The letter should state that there is an acceleration because the direction of the velocity is changing; therefore, there must be a net force in the direction of the center of the circle. The road supplies that force and the friction between the road and the tires allows the force to be exerted on the tires. The car's seat exerts the force on the driver that accelerates him or her toward the center of the circle. The note also should make it clear that centrifugal force is not a real force.

20. Centripetal Force A bowling ball has a mass of 7.3 kg. If you move it around a circle with a radius of 0.75 m at a speed of 2.5 m/s, what force would you have to exert on it?

$$F_{net} = ma_c$$

$$= \frac{mv^2}{r}$$

$$= \frac{(7.3\ \text{kg})(2.5\ \text{m/s})^2}{0.75\ \text{m}}$$

$$= 61\ \text{N}$$

21. **Critical Thinking** Because of Earth's daily rotation, you always move with uniform circular motion. What is the agent that supplies the force that accelerates you? How does this motion affect your apparent weight?

Earth's gravity supplies the force that accelerates you in circular motion. Your uniform circular motion decreases your apparent weight.

Practice Problems

6.3 Relative Velocity pages 157–159

page 159

22. You are riding in a bus moving slowly through heavy traffic at 2.0 m/s. You hurry to the front of the bus at 4.0 m/s relative to the bus. What is your speed relative to the street?

$$v_{y/g} = v_{b/g} + v_{y/b}$$

$$= 2.0\ \text{m/s} + 4.0\ \text{m/s}$$

$$= 6.0\ \text{m/s relative to street}$$

23. Rafi is pulling a toy wagon through the neighborhood at a speed of 0.75 m/s. A caterpillar in the wagon is crawling toward the rear of the wagon at a rate of 2.0 cm/s. What is the caterpillar's velocity relative to the ground?

$$v_{c/g} = v_{w/g} + v_{c/w}$$

$$= 0.75\ \text{m/s} - 0.02\ \text{m/s}$$

$$= 0.73\ \text{m/s}$$

24. A boat is rowed directly upriver at a speed of 2.5 m/s relative to the water. Viewers on the shore see that the boat is moving at only 0.5 m/s relative to the shore. What is the speed of the river? Is it moving with or against the boat?

$v_{b/g} = v_{b/w} + v_{w/g}$;

so, $v_{w/g} = v_{b/g} - v_{b/w}$

$$= 0.5\ \text{m/s} - 2.5\ \text{m/s}$$

$$= 2.0\ \text{m/s; against the boat}$$

25. An airplane flies due north at 150 km/h relative to the air. There is a wind blowing at 75 km/h to the east relative to the ground. What is the plane's speed relative to the ground?

$$v = \sqrt{v_p^{\,2} + v_w^{\,2}}$$

$$= \sqrt{(150\ \text{km/h})^2 + (75\ \text{km/h})^2}$$

$$= 1.7\times10^2\ \text{km/h}$$

Section Review

6.3 Relative Velocity pages 157–159

page 159

26. **Relative Velocity** A fishing boat with a maximum speed of 3 m/s relative to the water is in a river that is flowing at 2 m/s. What is the maximum speed the boat can obtain relative to the shore? The minimum speed? Give the direction of the boat, relative to the river's current, for the maximum speed and the minimum speed relative to the shore.

The maximum speed relative to the shore is when the boat moves at maximum speed in the same direction as the river's flow:

$$v_{b/s} = v_{b/w} + v_{w/s}$$

$$= 3\ \text{m/s} + 2\ \text{m/s}$$

$$= 5\ \text{m/s}$$

The minimum speed relative to the shore is when the boat moves in the opposite direction of the river's flow with the same speed as the river:

$$v_{b/s} = v_{b/w} + v_{w/s}$$

$$= 3\ \text{m/s} + (-2\ \text{m/s})$$

$$= 1\ \text{m/s}$$

27. **Relative Velocity of a Boat** A powerboat heads due northwest at 13 m/s relative to the water across a river that flows due north at 5.0 m/s. What is the velocity (both magnitude and direction) of the motorboat relative to the shore?

$$v_R = \sqrt{v_{RN}^2 + v_{RW}^2}$$

$$= \sqrt{(v_{bN} + v_{rN})^2 + (v_{bW} + v_{rW})^2}$$

$$= \sqrt{(v_b \sin \theta + v_r)^2 + (v_b \cos \theta)^2}$$

$$= \sqrt{((13\text{ m/s})(\sin 45°) + 5.0\text{ m/s})^2 + ((13\text{ m/s})(\cos 45°))^2} = 17\text{ m/s}$$

$$\theta = \tan^{-1}\left(\frac{v_{RW}}{v_{RN}}\right)$$

$$= \tan^{-1}\left(\frac{v_b \cos \theta}{v_b \sin \theta + v_r}\right)$$

$$= \tan^{-1}\left(\frac{(13\text{ m/s})(\cos 45°)}{(3\text{ m/s})(\sin 45°) + 5.0\text{ m/s}}\right)$$

$$= 33°$$

v_R = 17 m/s, 33° west of north

28. **Relative Velocity** An airplane flies due south at 175 km/h relative to the air. There is a wind blowing at 85 km/h to the east relative to the ground. What are the plane's speed and direction relative to the ground?

$$v_R = \sqrt{(175\text{ km/h})^2 + (85\text{ km/h})^2} = 190\text{ km/h}$$

$$\theta = \tan^{-1}\left(\frac{175\text{ km/h}}{85\text{ km/h}}\right) = 64°$$

v_R = 190 km/h, 64° south of east

29. **A Plane's Relative Velocity** An airplane flies due north at 235 km/h relative to the air. There is a wind blowing at 65 km/h to the northeast relative to the ground. What are the plane's speed and direction relative to the ground?

$$v_R = \sqrt{v_{RE}^2 + v_{RN}^2}$$

$$= \sqrt{(v_{pE} + v_{aE})^2 + (v_{pN} + v_{wN})^2}$$

$$= \sqrt{(v_w \cos \theta)^2 + (v_p + v_w \sin \theta)^2}$$

$$= \sqrt{((65\text{ km/h})(\cos 45°))^2 + (235\text{ km/h} + (65\text{ km/h})(\sin 45°))^2} = 280\text{ km/h}$$

$$\theta = \tan^{-1}\left(\frac{v_{RN}}{v_{RE}}\right)$$

$$= \tan^{-1}\left(\frac{v_p + v_a \sin \theta}{v_a \cos \theta}\right)$$

$$= \tan^{-1}\left(\frac{235\text{ km/h} + (65\text{ km/h})(\sin 45°)}{(65\text{ km/h})(\cos 45°)}\right)$$

= 72° north of east

280 km/h, 72° north of east

30. **Relative Velocity** An airplane has a speed of 285 km/h relative to the air. There is a wind blowing at 95 km/h at 30.0° north of east relative to Earth. In which direction should the plane head to land at an airport due north of its present location? What is the plane's speed relative to the ground?

To travel north, the east components must be equal and opposite.

$$\cos \theta_p = \frac{v_{pW}}{v_{pR}}, \text{ so}$$

$$\theta_p = \cos^{-1}\left(\frac{v_{pW}}{v_{pR}}\right)$$

$$= \cos^{-1}\left(\frac{v_{wE} \cos \theta_w}{v_{pR}}\right)$$

$$= \cos^{-1}\left(\frac{(95 \text{ km/h})(\cos 30.0°)}{285 \text{ km/h}}\right)$$

$$= 73° \text{ north of west}$$

$$v_{pR} = v_{pN} + v_{wN}$$

$$= v_p \sin \theta_p + v_w \sin \theta_w$$

$$= (285 \text{ km/h})(\sin 107°) + (95 \text{ km/h})(\sin 30.0°)$$

$$= 320 \text{ km/h}$$

31. **Critical Thinking** You are piloting a boat across a fast-moving river. You want to reach a pier directly opposite your starting point. Describe how you would navigate the boat in terms of the components of your velocity relative to the water.

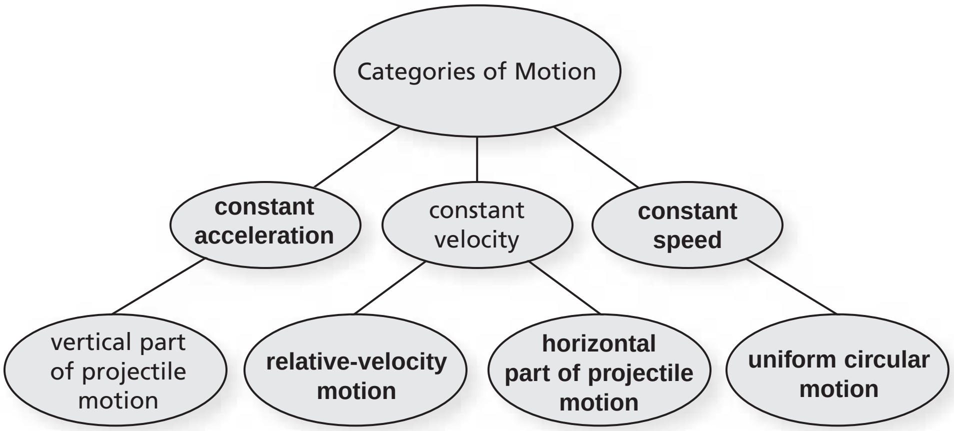
You should choose the component of your velocity along the direction of the river to be equal and opposite to the velocity of the river.

Chapter Assessment

Concept Mapping

page 164

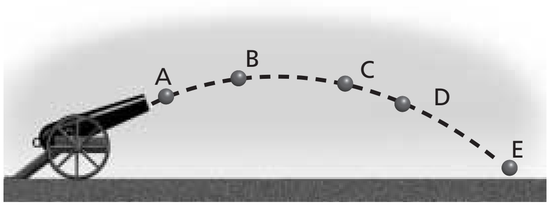
32. Use the following terms to complete the concept map below: *constant speed, horizontal part of projectile motion, constant acceleration, relative-velocity motion, uniform circular motion.*



Mastering Concepts

page 164

33. Consider the trajectory of the cannonball shown in **Figure 6-11.** (6.1)



■ **Figure 6-11**

Up is positive, down is negative.

a. Where is the magnitude of the vertical-velocity component largest?

The greatest vertical velocity occurs at point A.

b. Where is the magnitude of the horizontal-velocity component largest?

Neglecting air resistance, the horizontal velocity at all points is the same. Horizontal velocity is constant and independent of vertical velocity.

c. Where is the vertical-velocity smallest?

The least vertical velocity occurs at point E.

d. Where is the magnitude of the acceleration smallest?

The magnitude of the acceleration is the same everywhere.

34. A student is playing with a radio-controlled race car on the balcony of a sixth-floor apartment. An accidental turn sends the car through the railing and over the edge of the balcony. Does the time it takes the car to fall depend upon the speed it had when it left the balcony? (6.1)

No, the horizontal component of motion does not affect the vertical component.

35. An airplane pilot flying at constant velocity and altitude drops a heavy crate. Ignoring air resistance, where will the plane be relative to the crate when the crate hits the ground? Draw the path of the crate as seen by an observer on the ground. (6.1)

The plane will be directly over the crate when the crate hits the ground. Both have the same horizontal velocity. The crate will look like it is moving horizontally while falling vertically to an observer on the ground.

36. Can you go around a curve with the following accelerations? Explain.

a. zero acceleration

No, going around a curve causes a change in direction of velocity. Thus, the acceleration cannot be zero.

b. constant acceleration (6.2)

No, the magnitude of the acceleration may be constant, but the direction of the acceleration changes.

37. To obtain uniform circular motion, how must the net force depend on the speed of the moving object? (6.2)

Circular motion results when the direction of the force is constantly perpendicular to the instantaneous velocity of the object.

38. If you whirl a yo-yo about your head in a horizontal circle, in what direction must a force act on the yo-yo? What exerts the force? (6.2)

The force is along the string toward the center of the circle that the yo-yo follows. The string exerts the force.

39. Why is it that a car traveling in the opposite direction as the car in which you are riding on the freeway often looks like it is moving faster than the speed limit? (6.3)

The magnitude of the relative velocity of that car to your car can be found by adding the magnitudes of the two cars' velocities together. Since each car probably is moving at close to the speed limit, the resulting relative velocity will be larger than the posted speed limit.

Applying Concepts

pages 164–165

40. Projectile Motion Analyze how horizontal motion can be uniform while vertical motion is accelerated. How will projectile motion be affected when drag due to air resistance is taken into consideration?

The horizontal motion is uniform because there are no forces acting in that direction (ignoring friction). The vertical motion is accelerated due to the force of gravity. The projectile motion equations in this book do not hold when friction is taken into account. Projectile motion in both directions will be impacted when drag due to air resistance is taken into consideration. There will be a friction force opposing the motion.

41. Baseball A batter hits a pop-up straight up over home plate at an initial velocity of 20 m/s. The ball is caught by the catcher at the same height that it was hit. At what velocity does the ball land in the catcher's mitt? Neglect air resistance.

−20 m/s, where the negative sign indicates down

42. Fastball In baseball, a fastball takes about $\frac{1}{2}$ s to reach the plate. Assuming that such a pitch is thrown horizontally, compare the distance the ball falls in the first $\frac{1}{4}$ s with the distance it falls in the second $\frac{1}{4}$ s.

Because of the acceleration due to gravity, the baseball falls a greater distance during the second $\frac{1}{4}$ s than during the first $\frac{1}{4}$ s.

43. You throw a rock horizontally. In a second horizontal throw, you throw the rock harder and give it even more speed.

a. How will the time it takes the rock to hit the ground be affected? Ignore air resistance.

The time does not change—the time it takes to hit the ground depends only on vertical velocities and acceleration.

b. How will the increased speed affect the distance from where the rock left your hand to where the rock hits the ground?

A higher horizontal speed produces a longer horizontal distance.

44. Field Biology A zoologist standing on a cliff aims a tranquilizer gun at a monkey hanging from a distant tree branch. The barrel of the gun is horizontal. Just as the zoologist pulls the trigger, the monkey lets go and begins to fall. Will the dart hit the monkey? Ignore air resistance.

Yes, in fact, the monkey would be safe if it did not let go of the branch. The vertical acceleration of the dart is the same as that of the monkey. Therefore, the dart is at the same vertical height when

it reaches the monkey.

45. **Football** A quarterback throws a football at 24 m/s at a 45° angle. If it takes the ball 3.0 s to reach the top of its path and the ball is caught at the same height at which it is thrown, how long is it in the air? Ignore air resistance.

6.0 s: 3.0 s up and 3.0 s down

46. **Track and Field** You are working on improving your performance in the long jump and believe that the information in this chapter can help. Does the height that you reach make any difference to your jump? What influences the length of your jump?

Both speed and angle of launch matter, so height does make a difference. Maximum range is achieved when the resultant velocity has equal vertical and horizontal components—in other words, a launch angle of 45°. For this reason, height and speed affect the range.

47. Imagine that you are sitting in a car tossing a ball straight up into the air.

a. If the car is moving at a constant velocity, will the ball land in front of, behind, or in your hand?

The ball will land in your hand because you, the ball, and the car all are moving forward with the same speed.

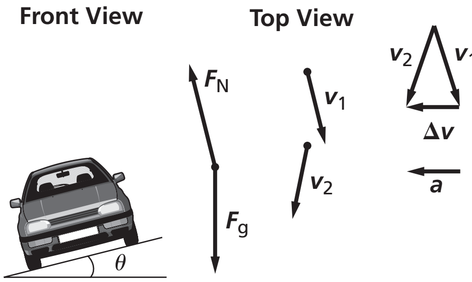
b. If the car rounds a curve at a constant speed, where will the ball land?

The ball will land beside you, toward the outside of the curve. A top view would show the ball moving straight while you and the car moved out from under the ball.

48. You swing one yo-yo around your head in a horizontal circle. Then you swing another yo-yo with twice the mass of the first one, but you don't change the length of the string or the period. How do the tensions in the strings differ?

The tension in the string is doubled since $F_T = ma_c$.

49. **Car Racing** The curves on a race track are banked to make it easier for cars to go around the curves at high speeds. Draw a free-body diagram of a car on a banked curve. From the motion diagram, find the direction of the acceleration.



The acceleration is directed toward the center of the track.

a. What exerts the force in the direction of the acceleration?

The component of the normal force acting toward the center of the curve, and depending on the car's speed, the component of the friction force acting toward the center, both contribute to the net force in the direction of acceleration.

b. Can you have such a force without friction?

Yes, the centripetal acceleration need only be due to the normal force.

50. **Driving on the Highway** Explain why it is that when you pass a car going in the same direction as you on the freeway, it takes a longer time than when you pass a car going in the opposite direction.

The relative speed of two cars going in the same direction is less than the relative speed of two cars going in the opposite direction. Passing with the lesser relative speed will take longer.

Mastering Problems

6.1 Projectile Motion

page 165

Level 1

51. You accidentally throw your car keys horizontally at 8.0 m/s from a cliff 64-m high. How far from the base of the cliff should you look for the keys?

$$y = v_y t - \frac{1}{2}gt^2$$

Since initial vertical velocity is zero,

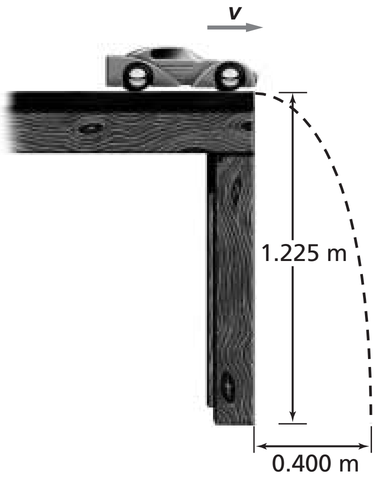
$$t = \sqrt{\frac{-2y}{g}} = \sqrt{\frac{(-2)(-64\text{ m})}{9.80\text{ m/s}^2}}$$

$$= 3.6\text{ s}$$

$$x = v_x t = (8.0\text{ m/s})(3.6) = 28.8\text{ m}$$

$$= 29\text{ m}$$

52. The toy car in **Figure 6-12** runs off the edge of a table that is 1.225-m high. The car lands 0.400 m from the base of the table.



■ **Figure 6-12**

a. How long did it take the car to fall?

$$y = v_{y0} t - \frac{1}{2}gt^2$$

Since initial vertical velocity is zero,

$$t = \sqrt{\frac{-2y}{g}} = \sqrt{\frac{(-2)(-1.225\text{ m})}{9.80\text{ m/s}^2}}$$

$$= 0.500\text{ s}$$

b. How fast was the car going on the table?

$$v_x = \frac{x}{t} = \frac{0.400\text{ m}}{0.500\text{ s}} = 0.800\text{ m/s}$$

53. A dart player throws a dart horizontally at 12.4 m/s. The dart hits the board 0.32 m below the height from which it was thrown. How far away is the player from the board?

$$y = v_{y0} t - \frac{1}{2}gt^2$$

and because initial velocity is zero,

$$t = \sqrt{\frac{-2y}{g}}$$

$= \sqrt{\frac{(-2)(-0.32\ \text{m})}{9.80\ \text{m/s}^2}}$

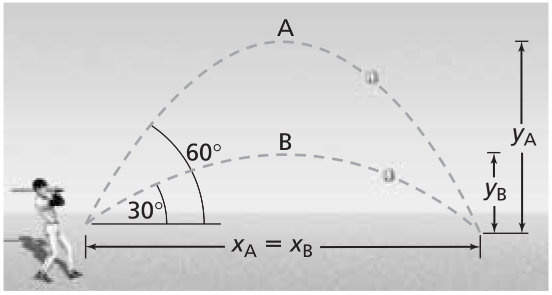
$= 0.26\ \text{s}$

Now $x = v_x t$

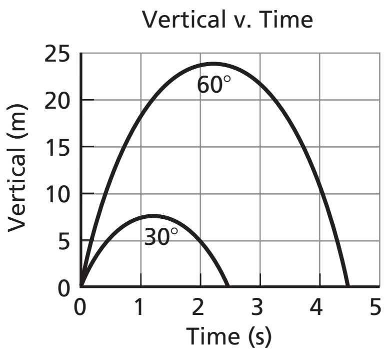
$= (12.4\ \text{m/s})(0.26\ \text{s})$

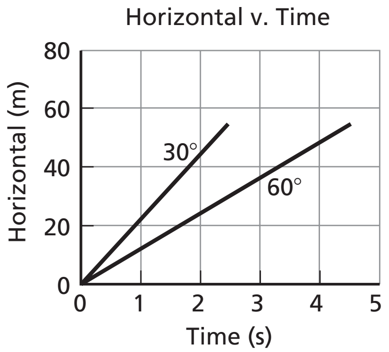
$= 3.2\ \text{m}$

54. The two baseballs in **Figure 6-13** were hit with the same speed, 25 m/s. Draw separate graphs of y versus t and x versus t for each ball.



■ **Figure 6-13**





55. **Swimming** You took a running leap off a high-diving platform. You were running at 2.8 m/s and hit the water 2.6 s later. How high was the platform, and how far from the edge of the platform did you hit the water? Ignore air resistance.

$y = v_{yi}t - \frac{1}{2}gt^2$

$= 0(2.6\ \text{s}) - \frac{1}{2}(9.80\ \text{m/s}^2)(2.6\ \text{s})^2$

$= -33$ **m, so the platform is 33 m high**

$x = v_x t = (2.8\ \text{m/s})(2.6\ \text{s}) = 7.3\ \text{m}$

Level 2

56. **Archery** An arrow is shot at 30.0° above the horizontal. Its velocity is 49 m/s, and it hits the target.

a. What is the maximum height the arrow will attain?

$v_y^2 = v_{yi}^2 - 2gd$

At the high point $v_y = 0$**, so**

$d = \frac{(v_{y0})^2}{2g}$

$= \frac{(v_i \sin\theta)^2}{2g}$

$= \frac{((49\ \text{m/s})(\sin 30.0°))^2}{(2)(9.80\ \text{m/s}^2)}$

$= 31\ \text{m}$

b. The target is at the height from which the arrow was shot. How far away is it?

$y = v_{y0}t - \frac{1}{2}gt^2$

but the arrow lands at the same height, so

$y = 0$ **and** $0 = v_{yi} - \frac{1}{2}gt$

so $t = 0$ **or**

$t = \frac{2vy_i}{g}$

$= \frac{2v_i \sin\theta}{g}$

$= \frac{(2)(49\ \text{m/s})(\sin 30.0°)}{9.80\ \text{m/s}^2}$

$= 5.0\ \text{s}$

and $x = v_x t$

$= (v_i \cos \theta)(t)$

$= (49\ \text{m/s})(\cos 30.0°)(5.0\ \text{s})$

$= 2.1\times10^2\ \text{m}$

57. Hitting a Home Run A pitched ball is hit by a batter at a 45° angle and just clears the outfield fence, 98 m away. If the fence is at the same height as the pitch, find the velocity of the ball when it left the bat. Ignore air resistance.

The components of the initial velocity are $v_x = v_i \cos \theta_i$ and $v_{yi} = v_i \sin \theta_i$

Now $x = v_x t = (v_i \cos \theta_i)t$, so

$$t = \frac{x}{v_i \cos \theta_i}$$

And $y = v_{yi}t - \frac{1}{2}gt^2$, but $y = 0$, so

$$0 = \left(v_{yi} - \frac{1}{2}gt\right)t$$

so $t = 0$ or $v_{yi} - \frac{1}{2}gt = 0$

From above

$$v_i \sin \theta_i - \frac{1}{2}g\left(\frac{x}{v_i \cos \theta_i}\right) = 0$$

Multiplying by $v_i \cos \theta_i$ gives

$$v_i^2 \sin \theta_i \cos \theta_i - \frac{1}{2}gx = 0$$

so $$v_i^2 = \frac{gx}{(2)(\sin \theta_i)(\cos \theta_i)}$$

thus, $$v_i = \sqrt{\frac{gx}{(2)(\sin \theta_i)(\cos \theta_i)}}$$

$$= \sqrt{\frac{(9.80\ \text{m/s}^2)(98\ \text{m})}{(2)(\sin 45°)(\cos 45°)}}$$

$= 31$ **m/s at 45°**

Level 3

58. At-Sea Rescue An airplane traveling 1001 m above the ocean at 125 km/h is going to drop a box of supplies to shipwrecked victims below.

a. How many seconds before the plane is directly overhead should the box be dropped?

$$y = v_{yi}t - \frac{1}{2}gt^2$$

but $v_{yi} = 0$, so

$$t = \sqrt{\frac{-2y}{g}}$$

$$= \sqrt{\frac{(-2)(-1001\ \text{m})}{9.80\ \text{m/s}^2}}$$

$= 14.3$ **s**

b. What is the horizontal distance between the plane and the victims when the box is dropped?

$x = v_x t$

$$= (125\ \text{km/h})\left(\frac{1\ \text{h}}{3600\ \text{s}}\right)\left(\frac{1000\ \text{m}}{1\ \text{km}}\right)(14.3\ \text{s})$$

$= 497$ **m**

59. Diving Divers in Acapulco dive from a cliff that is 61 m high. If the rocks below the cliff extend outward for 23 m, what is the minimum horizontal velocity a diver must have to clear the rocks?

$$y = v_{yi}t - \frac{1}{2}gt^2$$

and since $v_{yi} = 0$,

$$t = \sqrt{\frac{-2y}{g}}$$

$$= \sqrt{\frac{(-2)(-61\ \text{m})}{9.80\ \text{m/s}^2}}$$

$= 3.53$ **s**

$x = v_x t$

$$v_x = \frac{x}{t}$$

$$= \frac{23\ \text{m}}{3.53\ \text{s}}$$

$= 6.5$ **m/s**

60. Jump Shot A basketball player is trying to make a half-court jump shot and releases the ball at the height of the basket. Assuming that the ball is launched at 51.0°, 14.0 m from the basket, what speed must the player give the ball?

The components of the initial velocity are $v_{xi} = v_i \cos \theta_i$ and $v_{yi} = v_i \sin \theta_i$

Now $x = v_{xi}t = (v_i \cos \theta_i)t$, so

$t = \frac{x}{v_i \cos \theta_i}$

And $y = v_{yi}t - \frac{1}{2}gt^2$, but $y = 0$, so

$0 = \left(v_{yi} - \frac{1}{2}gt\right)t$

so $t = 0$ or $v_{yi} - \frac{1}{2}gt^2 = 0$

From above

$v_0 \sin \theta_i - \frac{1}{2}g\left(\frac{x}{v_i \cos \theta_i}\right) = 0$

Multiplying by $v_i \cos \theta_i$ gives

$v_i^2(\sin \theta_i)(\cos \theta_i) - \frac{1}{2}gx = 0$

so $v_i = \sqrt{\frac{gx}{(2)(\sin \theta_i)(\cos \theta_i)}}$

$= \sqrt{\frac{(9.80\text{ m/s}^2)(14.0\text{ m})}{(2)(\sin 51.0°)(\cos 51.0°)}}$

$= 11.8\text{ m/s}$

6.2 Circular Motion

page 166

Level 1

61. Car Racing A 615-kg racing car completes one lap in 14.3 s around a circular track with a radius of 50.0 m. The car moves at a constant speed.

a. What is the acceleration of the car?

$a_c = \frac{v^2}{r}$

$= \frac{4\pi^2 r}{T^2}$

$= \frac{4\pi^2(50.0\text{ m})}{(14.3\text{ s})^2}$

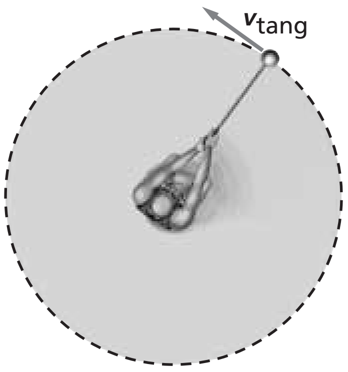
$= 9.59\text{ m/s}^2$

b. What force must the track exert on the tires to produce this acceleration?

$F_c = ma_c = (615\text{ kg})(9.59\text{ m/s}^2)$

$= 5.90\times10^3\text{ N}$

62. Hammer Throw An athlete whirls a 7.00-kg hammer 1.8 m from the axis of rotation in a horizontal circle, as shown in **Figure 6-14.** If the hammer makes one revolution in 1.0 s, what is the centripetal acceleration of the hammer? What is the tension in the chain?



■ **Figure 6-14**

$$a_c = \frac{4\pi^2 r}{T^2}$$

$$= \frac{(4\pi^2)(1.8 \text{ m})}{(1.0 \text{ s})^2}$$

$$= 71 \text{ m/s}^2$$

$$F_c = ma_c$$

$$= (7.00 \text{ kg})(71 \text{ m/s}^2)$$

$$= 5.0\times10^2 \text{ N}$$

Level 2

63. A coin is placed on a vinyl stereo record that is making $33\frac{1}{3}$ revolutions per minute on a turntable.

a. In what direction is the acceleration of the coin?

The acceleration is toward the center of the record.

b. Find the magnitude of the acceleration when the coin is placed 5.0, 10.0, and 15.0 cm from the center of the record.

$$T = \frac{1}{f} = \frac{1}{33\frac{1}{3} \text{ rev/min}}$$

$$= (0.0300 \text{ min})\left(\frac{60 \text{ s}}{1 \text{ min}}\right) = 1.80 \text{ s}$$

$r = 5.0$ **cm:**

$$a_c = \frac{4\pi^2 r}{T^2}$$

$$= \frac{(4\pi^2)(0.050 \text{ m})}{(1.80 \text{ s})^2} = 0.61 \text{ m/s}^2$$

$r = 10.0$ **cm:**

$$a_c = \frac{4\pi^2 r}{T^2} = \frac{(4\pi^2)(0.100 \text{ m})}{(1.80 \text{ s})^2}$$

$$= 1.22 \text{ m/s}^2$$

$r = 15.0$ **cm:**

$$a_c = \frac{4\pi^2 r}{T^2} = \frac{(4\pi^2)(0.150 \text{ m})}{(1.80 \text{ s})^2}$$

$$= 1.83 \text{ m/s}^2$$

c. What force accelerates the coin?

frictional force between coin and record

d. At which of the three radii in part **b** would the coin be most likely to fly off the turntable? Why?

15.0 cm, the largest radius; the friction force needed to hold it is the greatest.

64. A rotating rod that is 15.3 cm long is spun with its axis through one end of the rod so that the other end of the rod has a speed of 2010 m/s (4500 mph).

a. What is the centripetal acceleration of the end of the rod?

$$a_c = \frac{v^2}{r} = \frac{(2010 \text{ m/s})^2}{0.153 \text{ m}}$$

$$= 2.64\times10^7 \text{ m/s}^2$$

b. If you were to attach a 1.0-g object to the end of the rod, what force would be needed to hold it on the rod?

$$F_c = ma_c$$

$$= (0.0010 \text{ kg})(2.64\times10^7 \text{ m/s}^2)$$

$$= 2.6\times10^4 \text{ N}$$

65. Friction provides the force needed for a car to travel around a flat, circular race track. What is the maximum speed at which a car can safely travel if the radius of the track is 80.0 m and the coefficient of friction is 0.40?

$$F_c = F_f = \mu F_N = \mu mg$$

But $F_c = \frac{mv^2}{r}$, **thus** $\frac{mv^2}{r} = \mu mg$.

The mass of the car divides out to give $v^2 = \mu gr$, so

$v = \sqrt{\mu gr}$

$= \sqrt{(0.40)(9.80\ \text{m/s}^2)(80.0\ \text{m})}$

$= 18$ **m/s**

Level 3

66. A carnival clown rides a motorcycle down a ramp and around a vertical loop. If the loop has a radius of 18 m, what is the slowest speed the rider can have at the top of the loop to avoid falling? *Hint: At this slowest speed, the track exerts no force on the motorcycle at the top of the loop.*

$F_c = ma_c = F_g = mg$, **so**

$a_c = g$

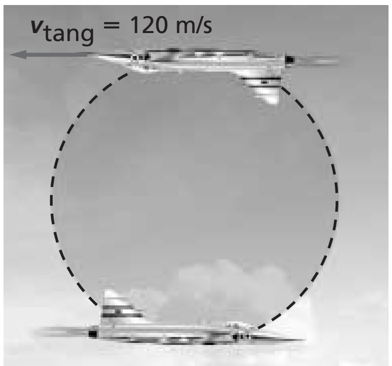
$\frac{v^2}{r} = g$, **so**

$v = \sqrt{gr}$

$= \sqrt{(9.80\ \text{m/s}^2)(18\ \text{m})}$

$= 13$ **m/s**

67. A 75-kg pilot flies a plane in a loop as shown in **Figure 6-15.** At the top of the loop, when the plane is completely upside-down for an instant, the pilot hangs freely in the seat and does not push against the seat belt. The airspeed indicator reads 120 m/s. What is the radius of the plane's loop?



■ **Figure 6-15**

Because the net force is equal to the weight of the pilot,

$F_c = ma_c = F_g = mg$, **so**

$a_c = g$ **or** $\frac{v^2}{r} = g$

so $r = \frac{v^2}{g}$

$= \frac{(120\ \text{m/s})^2}{9.80\ \text{m/s}^2}$

$= 1.5\times10^3$ **m**

6.3 Relative Velocity
pages 166–167
Level 1

68. Navigating an Airplane An airplane flies at 200.0 km/h relative to the air. What is the velocity of the plane relative to the ground if it flies during the following wind conditions?

a. a 50.0-km/h tailwind

Tailwind is in the same direction as the airplane

200.0 km/h + 50.0 km/h = 250.0 km/h

b. a 50.0-km/h headwind

Head wind is in the opposite direction of the airplane

200.0 km/h − 50.0 km/h = 150.0 km/h

69. Odina and LaToya are sitting by a river and decide to have a race. Odina will run down the shore to a dock, 1.5 km away, then turn around and run back. LaToya will also race to the dock and back, but she will row a boat in the river, which has a current of 2.0 m/s. If Odina's running speed is equal to LaToya's rowing speed in still water, which is 4.0 m/s, who will win the race? Assume that they both turn instantaneously.

$x = vt$, **so** $t = \frac{x}{v}$

for Odina,

$t = \frac{3.0\times10^3\ \text{m}}{4.0\ \text{m/s}}$

$= 7.5\times10^2$ **s**

For LaToya (assume against current on the way to the dock),

$t = \frac{x_1}{v_1} + \frac{x_2}{v_2}$

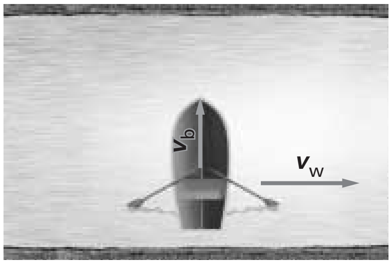
$$= \frac{1.5\times10^3 \text{ m}}{4.0 \text{ m/s} - 2.0 \text{ m/s}} + \frac{1.5\times10^3 \text{ m}}{4.0 \text{ m/s} + 2.0 \text{ m/s}}$$

$$= 1.0\times10^3 \text{ s}$$

Odina wins.

Level 2

70. Crossing a River You row a boat, such as the one in **Figure 6-16,** perpendicular to the shore of a river that flows at 3.0 m/s. The velocity of your boat is 4.0 m/s relative to the water.



■ **Figure 6-16**

a. What is the velocity of your boat relative to the shore?

$$v_{b/s} = \sqrt{(v_{b/w})^2 + (v_{w/s})^2}$$

$$= \sqrt{(4.0 \text{ m/s})^2 + (3.0 \text{ m/s})^2}$$

$$= 5.0 \text{ m/s}$$

$$\theta = \tan^{-1}\left(\frac{v_{b/w}}{v_{w/s}}\right)$$

$$= \tan^{-1}\left(\frac{4.0 \text{ m/s}}{3.0 \text{ m/s}}\right)$$

= 53° from shore

b. What is the component of your velocity parallel to the shore? Perpendicular to it?

3.0 m/s; 4.0 m/s

71. Studying the Weather A weather station releases a balloon to measure cloud conditions that rises at a constant 15 m/s relative to the air, but there is also a wind blowing at 6.5 m/s toward the west. What are the magnitude and direction of the velocity of the balloon?

$$v_b = \sqrt{(v_{b/air})^2 + (v_{air})^2}$$

$$= \sqrt{(15 \text{ m/s})^2 + (6.5 \text{ m/s})^2}$$

$$= 16 \text{ m/s}$$

$$\theta = \tan^{-1}\left(\frac{v_{b/air}}{v_{air}}\right)$$

$$= \tan^{-1}\left(\frac{15 \text{ m/s}}{6.5 \text{ m/s}}\right)$$

= 67° from the horizon toward the west

Level 3

72. Boating You are boating on a river that flows toward the east. Because of your knowledge of physics, you head your boat 53° west of north and have a velocity of 6.0 m/s due north relative to the shore.

a. What is the velocity of the current?

$$\tan\theta = \left(\frac{v_{w/s}}{v_{b/s}}\right), \text{ so}$$

$$v_{w/s} = (\tan\theta)(v_{b/s})$$

$$= (\tan 53°)(6.0 \text{ m/s})$$

= 8.0 m/s east

b. What is the speed of your boat relative to the water?

$$\cos\theta = \frac{v_{b/s}}{v_{b/w}}, \text{ so}$$

$$v_{b/w} = \frac{v_{b/s}}{\cos\theta}$$

$$= \frac{6.0 \text{ m/s}}{\cos 53°}$$

$$= 1.0\times10^1 \text{ m/s}$$

73. Air Travel You are piloting a small plane, and you want to reach an airport 450 km due south in 3.0 h. A wind is blowing from the west at 50.0 km/h. What heading and airspeed should you choose to reach your destination in time?

$$v_s = \frac{d_s}{t} = \frac{450 \text{ km}}{3.0 \text{ h}} = 150 \text{ km/h}$$

$$v_p = \sqrt{(150 \text{ km/h})^2 + (50.0 \text{ km/h})^2}$$

$$= 1.6\times10^2 \text{ km/h}$$

$$\theta = \tan^{-1}\left(\frac{v_{wind}}{v_s}\right)$$

$$= \tan^{-1}\left(\frac{50.0 \text{ km/h}}{150 \text{ km/h}}\right)$$

= 18° west of south

Mixed Review

page 167

Level 1

74. Early skeptics of the idea of a rotating Earth said that the fast spin of Earth would throw people at the equator into space. The radius of Earth is about 6.38×10^3 km. Show why this idea is wrong by calculating the following.

a. the speed of a 97-kg person at the equator

$$v = \frac{\Delta d}{\Delta t} = \frac{2\pi r}{T} = \frac{2\pi(6.38\times10^6\ \text{m})}{(24\ \text{h})\left(\frac{3600\ \text{s}}{1\ \text{h}}\right)}$$

$$= 464\ \text{m/s}$$

b. the force needed to accelerate the person in the circle

$$F_c = ma_c$$

$$= \frac{mv^2}{r}$$

$$= \frac{(97\ \text{kg})(464\ \text{m/s})^2}{6.38\times10^6\ \text{m}}$$

$$= 3.3\ \text{N}$$

c. the weight of the person

$$F_g = mg$$

$$= (97)(9.80\ \text{m/s}^2)$$

$$= 9.5\times10^2\ \text{N}$$

d. the normal force of Earth on the person, that is, the person's apparent weight

$$F_N = 9.5\times10^2\ \text{N} - 3.3\ \text{N}$$

$$= 9.5\times10^2\ \text{N}$$

75. **Firing a Missile** An airplane, moving at 375 m/s relative to the ground, fires a missile forward at a speed of 782 m/s relative to the plane. What is the speed of the missile relative to the ground?

$$v_{m/g} = v_{p/g} + v_{m/p}$$

$$= 375\ \text{m/s} + 782\ \text{m/s}$$

$$= 1157\ \text{m/s}$$

76. **Rocketry** A rocket in outer space that is moving at a speed of 1.25 km/s relative to an observer fires its motor. Hot gases are expelled out the back at 2.75 km/s relative to the rocket. What is the speed of the gases relative to the observer?

$$v_{g/o} = v_{r/o} + v_{g/r}$$

$$1.25\ \text{km/s} + (-2.75\ \text{km/s}) = -1.50\ \text{km/s}$$

Level 2

77. Two dogs, initially separated by 500.0 m, are running towards each other, each moving with a constant speed of 2.5 m/s. A dragonfly, moving with a constant speed of 3.0 m/s, flies from the nose of one dog to the other, then turns around instantaneously and flies back to the other dog. It continues to fly back and forth until the dogs run into each other. What distance does the dragonfly fly during this time?

The dogs will meet in

$$\frac{500.0\text{ m}}{5.0\text{ m/s}} = 1.0\times10^2\text{ s}$$

The dragonfly flies

$$(3.0\text{ m/s})(1.0\times10^2\text{ s}) = 3.0\times10^2\text{ m.}$$

78. A 1.13-kg ball is swung vertically from a 0.50-m cord in uniform circular motion at a speed of 2.4 m/s. What is the tension in the cord at the bottom of the ball's motion?

$$F_T = F_g + F_c$$

$$= mg + \frac{mv^2}{r}$$

$$= (1.13\text{ kg})(9.80\text{ m/s}^2) + \frac{(1.13\text{ kg})(2.4\text{ m/s})^2}{0.50\text{ m}}$$

$$= 24\text{ N}$$

79. Banked Roads Curves on roads often are banked to help prevent cars from slipping off the road. If the posted speed limit for a particular curve of radius 36.0 m is 15.7 m/s (35 mph), at what angle should the road be banked so that cars will stay on a circular path even if there were no friction between the road and the tires? If the speed limit was increased to 20.1 m/s (45 mph), at what angle should the road be banked?

For 35 mph:

$$F_c = F_g$$

$$\frac{mv^2}{r}\cos\theta = mg\sin\theta$$

$$\frac{v^2}{r} = g\left(\frac{\sin\theta}{\cos\theta}\right) = g\tan\theta$$

$$\theta = \tan^{-1}\left(\frac{v^2}{gr}\right)$$

$$= \tan^{-1}\left(\frac{(15.7\text{ m/s})^2}{(9.80\text{ m/s}^2)(56.0\text{ m})}\right)$$

$$= 34.9°$$

For 45 mph:

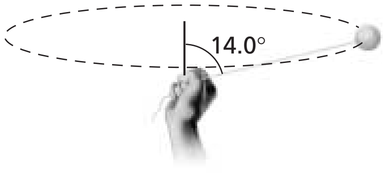
$$\theta = \tan^{-1}\left(\frac{v^2}{gr}\right)$$

$$= \tan^{-1}\left(\frac{(20.1\text{ m/s})^2}{(9.80\text{ m/s}^2)(36.0\text{ m})}\right)$$

$$= 48.9°$$

Level 3

80. The 1.45-kg ball in **Figure 6-17** is suspended from a 0.80-m string and swung in a horizontal circle at a constant speed such that the string makes an angle of 14.0° with the vertical.



■ **Figure 6-17**

a. What is the tension in the string?

$$F_T\cos\theta = mg$$

$$\text{so } F_T = \frac{mg}{\cos\theta}$$

$$= \frac{(1.45\text{ m/s})(9.80\text{ m/s}^2)}{\cos 14.0°}$$

$$= 14.6\text{ N}$$

b. What is the speed of the ball?

$$F_c = F_T\sin\theta = \frac{mv^2}{r} = F_g = F_T\cos\theta = mg$$

$$\text{so } \frac{F_T\sin\theta}{F_T\cos\theta} = \frac{mv^2}{rmg}$$

$$\text{or } \tan\theta = \frac{v^2}{rg}$$

so $v = \sqrt{rg \tan \theta}$

$= \sqrt{(0.80\ \text{m})(9.80\ \text{m/s}^2)(\tan 14.0°)}$

$= 1.4\ \text{m/s}$

81. A baseball is hit directly in line with an outfielder at an angle of 35.0° above the horizontal with an initial velocity of 22.0 m/s. The outfielder starts running as soon as the ball is hit at a constant velocity of 2.5 m/s and barely catches the ball. Assuming that the ball is caught at the same height at which it was hit, what was the initial separation between the hitter and outfielder? *Hint: There are two possible answers.*

$\Delta x = v_{xi}t \pm v_{p}t = t(v_{xi} \pm v_{p})$

To get t,

$y = v_{yi}t - \frac{1}{2}gt^2, y = 0$

so $v_{yi}t = \frac{1}{2}gt^2$, $t = 0$ or

$v_{yi} = \frac{1}{2}gt$

$t = \frac{2v_{yi}}{g}$

$= \frac{2v_{i} \sin \theta}{g}$

so $\Delta x = \frac{2v_{i} \sin \theta}{g}(v_{xi} \pm v_{p})$

$= \frac{2v_{i} \sin \theta}{g}(v_{i} \cos \theta \pm v_{p})$

$= \left(\frac{(2)(22.0\ \text{m/s})(\sin 35.0°)}{9.80\ \text{m/s}^2}\right)$

$((22.0\ \text{m/s})(\cos 35.0°) \pm$

$2.5\ \text{m/s})$

$= 53\ \text{m or } 4.0\times10^{1}\ \text{m}$

82. A Jewel Heist You are serving as a technical consultant for a locally produced cartoon. In one episode, two criminals, Shifty and Lefty, have stolen some jewels. Lefty has the jewels when the police start to chase him, and he runs to the top of a 60.0-m tall building in his attempt to escape. Meanwhile, Shifty runs to the convenient hot-air balloon 20.0 m from the base of the building and untethers it, so it begins to rise at a constant speed. Lefty tosses the bag of jewels horizontally with a speed of 7.3 m/s just as the balloon begins its ascent. What must the velocity of the balloon be for Shifty to easily catch the bag?

$$\Delta x = v_{xi}t, \text{ so } t = \frac{x}{v_{xi}}$$

$$\Delta y_{bag} = v_{yi}t - \frac{1}{2}gt^2, \text{ but } v_{yi} = 0$$

$$\text{so } \Delta y_{bag} = -\frac{1}{2}gt^2$$

$$v_{balloon} = \frac{\Delta y_{balloon}}{t}$$

$$= \frac{60.0\text{ m} - \Delta y_{bag}}{t}$$

$$= \frac{60.0\text{ m} + \frac{1}{2}gt^2}{t}$$

$$= \frac{60.0\text{ m}}{t} + \frac{1}{2}gt$$

$$= \frac{60.0\text{ m}}{\frac{x}{v_{xi}}} + \frac{1}{2}g\frac{x}{v_{xi}}$$

$$= \frac{(60.0\text{ m})v_{xi}}{x} + \frac{gx}{2v_{xi}}$$

$$= \frac{(60.0\text{ m})(7.3\text{ m/s})}{(20.0\text{ m})} + \frac{(-9.80\text{ m/s})(20.0\text{ m})}{2(7.3\text{ m/s})}$$

$$= 8.5\text{ m/s}$$

Thinking Critically

page 168

83. Apply Concepts Consider a roller-coaster loop like the one in **Figure 6-18.** Are the cars traveling through the loop in uniform circular motion? Explain.

■ **Figure 6-18**

The vertical gravitational force changes the speed of the cars, so the motion is not uniform circular motion.

84. Use Numbers A 3-point jump shot is released 2.2 m above the ground and 6.02 m from the basket. The basket is 3.05 m above the floor. For launch angles of 30.0° and 60.0°, find the speed the ball needs to be thrown to make the basket.

$$x = v_{ix}t, \text{ so } t = \frac{x}{v_{ix}} = \frac{x}{v_i \cos\theta}$$

$$\Delta y = v_{iy}t - \frac{1}{2}gt^2$$

$$= v_i \sin\theta\left(\frac{x}{v_i\cos\theta}\right) - \frac{1}{2}g\left(\frac{x}{v_i\cos\theta}\right)^2$$

$$= x\tan\theta - \frac{gx^2}{2v_i^2(\cos\theta)^2}$$

$$\text{so } v_i = \frac{x}{\cos\theta}\sqrt{\frac{g}{2((\tan\theta)x - \Delta y)}}$$

For $\theta = 30.0°$

$$v_i = \left(\frac{6.02\text{ m}}{\cos 30.0°}\right)\sqrt{\frac{9.80\text{ m/s}^2}{2((\tan 30.0°)(6.02\text{ m}) - (3.05\text{ m} - 2.2\text{ m}))}}$$

$= 9.5$ m/s

For $\theta = 60.0°$

$$v_i = \left(\frac{6.02\text{ m}}{\cos 60.0°}\right)\sqrt{\frac{-9.80\text{ m/s}^2}{2((\tan 60°(6.02\text{ m}) - (3.05\text{ m} - 2.2\text{ m}))}}$$

$= 8.6$ m/s

85. Analyze For which angle in problem 84 is it more important that the player get the speed right? To explore this question, vary the speed at each angle by 5 percent and find the change in the range of the attempted shot.

Varying speed by 5 percent at 30.0° changes *R* by about 0.90 m in either direction. At 60.0° it changes *R* by only about 0.65 m. Thus, the high launch angle is less sensitive to speed variations.

86. Apply Computers and Calculators A baseball player hits a belt-high (1.0 m) fastball down the left-field line. The ball is hit with an initial velocity of 42.0 m/s at 26°. The left-field wall is 96.0 m from home plate at the foul pole and is 14-m high. Write the equation for the height of the ball, *y*, as a function of its distance from home plate, *x*. Use a computer or graphing calculator to plot the path of the ball. Trace along the path to find how high above the ground the ball is when it is at the wall.

a. Is the hit a home run?

Yes, the hit is a home run; the ball clears the wall by 2.1 m.

b. What is the minimum speed at which the ball could be hit and clear the wall?

$$v_i = \frac{x}{\cos\theta}\sqrt{\frac{g}{2((\tan\theta)\,x - \Delta y)}}$$

$$= \left(\frac{96.0\text{ m}}{\cos 26°}\right)\sqrt{\frac{9.80\text{ m/s}^2}{(2)((\tan 26°)(96.0\text{ m}) - 13\text{ m})}}$$

$= 41$ m/s

c. If the initial velocity of the ball is 42.0 m/s, for what range of angles will the ball go over the wall?

For the ball to go over the wall, the range of angles needs to be 25°– 70°.

87. Analyze Albert Einstein showed that the rule you learned for the addition of velocities does not work for objects moving near the speed of light. For example, if a rocket moving at velocity v_A releases a missile that has velocity v_B relative to the rocket, then the velocity of the missile relative to an observer that is at rest is given by $v = (v_A + v_B)/(1 + v_A v_B/c^2)$, where c is the speed of light, 3.00×10^8 m/s. This formula gives the correct values for objects moving at slow speeds as well. Suppose a rocket moving at 11 km/s shoots a laser beam out in front of it. What speed would an unmoving observer find for the laser light? Suppose that a rocket moves at a speed $c/2$, half the speed of light, and shoots a missile forward at a speed of $c/2$ relative to the rocket. How fast would the missile be moving relative to a fixed observer?

$$v_{l/o} = \frac{(v_{r/o} + v_{l/r})}{\left(1 + \frac{v_{r/o} + v_{1/r}}{c^2}\right)}$$

$$= \frac{1.1\times10^4\text{ m/s} + 3.00\times10^8\text{ m/s}}{1 + \frac{(1.1\times10^4\text{ m/s})(3.00\times10^8\text{ m/s})}{(3.00\times10^8\text{ m/s})^2}}$$

$= 3.0\times10^8$ m/s

$$v_{m/o} = \frac{v_{r/o} + v_{m/r}}{1 + \frac{v_{r/o}v_{m/r}}{c^2}}$$

$$= \frac{\frac{c}{2} + \frac{c}{2}}{1 + \frac{\left(\frac{c}{2}\right)\left(\frac{c}{2}\right)}{c^2}}$$

$$= \frac{4}{5}c$$

88. Analyze and Conclude A ball on a light string moves in a vertical circle. Analyze and describe the motion of this system. Be sure to consider the effects of gravity and tension. Is this system in uniform circular motion? Explain your answer.

It is not uniform circular motion. Gravity increases the speed of the ball when it moves downward and reduces the speed when it is moving upward. Therefore, the centripetal acceleration needed to keep it moving in a circle will be larger at the bottom and smaller at the top of the circle. At the top, tension and gravity are in the same direction, so the tension needed will be even smaller. At the bottom, gravity is outward while the tension is inward. Thus, the tension exerted by the string must be even larger.

Writing in Physics

page 168

89. Roller Coasters If you take a look at vertical loops on roller coasters, you will notice that most of them are not circular in shape. Research why this is so and explain the physics behind this decision by the coaster engineers.

Answers will vary. Since $F_c = \frac{mv^2}{r}$, as v decreases due to gravity when going uphill, r is reduced to keep the force constant.

90. Many amusement-park rides utilize centripetal acceleration to create thrills for the park's customers. Choose two rides other than roller coasters that involve circular motion and explain how the physics of circular motion creates the sensations for the riders.

CHAPTER 7 Gravitation

Practice Problems

7.1 Planetary Motion and Gravitation pages 171–178

page 174

1. If Ganymede, one of Jupiter's moons, has a period of 32 days, how many units are there in its orbital radius? Use the information given in Example Problem 1.

$$\left(\frac{T_G}{T_I}\right)^2 = \left(\frac{r_G}{r_I}\right)^3$$

$$r_G = \sqrt[3]{(4.2\text{ units})^3\left(\frac{32\text{ days}}{1.8\text{ days}}\right)^2}$$

$$= \sqrt[3]{23.4\times10^3\text{ units}^3}$$

$$= 29\text{ units}$$

2. An asteroid revolves around the Sun with a mean orbital radius twice that of Earth's. Predict the period of the asteroid in Earth years.

$$\left(\frac{T_a}{T_E}\right)^2 = \left(\frac{r_a}{r_E}\right)^3 \text{ with } r_a = 2r_E$$

$$T_a = \sqrt{\left(\frac{r_a}{r_E}\right)^3 {T_E}^2}$$

$$= \sqrt{\left(\frac{2r_E}{r_E}\right)^3 (1.0\text{ y})^2}$$

$$= 2.8\text{ y}$$

3. From Table 7-1, on page 173, you can find that, on average, Mars is 1.52 times as far from the Sun as Earth is. Predict the time required for Mars to orbit the Sun in Earth days.

$$\left(\frac{T_M}{T_E}\right)^2 = \left(\frac{r_M}{r_E}\right)^3 \text{ with } r_M = 1.52r_E$$

$$\text{Thus, } T_M = \sqrt{\left(\frac{r_M}{r_E}\right)^3 {T_E}^2} = \sqrt{\left(\frac{1.52r_E}{r_E}\right)^3 (365\text{ days})^2}$$

$$= \sqrt{4.68\times10^5\text{ days}^2}$$

$$= 684\text{ days}$$

4. The Moon has a period of 27.3 days and a mean distance of 3.90×10^5 km from the center of Earth.

a. Use Kepler's laws to find the period of a satellite in orbit 6.70×10^3 km from the center of Earth.

$$\left(\frac{T_s}{T_M}\right)^2 = \left(\frac{r_s}{r_M}\right)^3$$

$$T_s = \sqrt{\left(\frac{r_s}{r_M}\right)^3 T_M{}^2}$$

$$= \sqrt{\left(\frac{6.70\times10^3\ \text{km}}{3.90\times10^5\ \text{km}}\right)^3 (27.3\ \text{days})^2}$$

$$= \sqrt{3.78\times10^{-3}\ \text{days}^2}$$

$$= 6.15\times10^{-2}\ \text{days} = 88.6\ \text{min}$$

b. How far above Earth's surface is this satellite?

$$h = r_s - r_E$$

$$= 6.70\times10^6\ \text{m} - 6.38\times10^6\ \text{m}$$

$$= 3.2\times10^5\ \text{m}$$

$$= 3.2\times10^2\ \text{km}$$

5. Using the data in the previous problem for the period and radius of revolution of the Moon, predict what the mean distance from Earth's center would be for an artificial satellite that has a period of exactly 1.00 day.

$$\left(\frac{T_s}{T_M}\right)^2 = \left(\frac{r_s}{r_M}\right)^3$$

$$r_s = \sqrt[3]{r_M{}^3\left(\frac{T_s}{T_M}\right)^2} = \sqrt[3]{(3.90\times10^5\ \text{km})^3\left(\frac{1.00\ \text{days}}{27.3\ \text{days}}\right)^2}$$

$$= \sqrt[3]{7.96\times10^{13}\ \text{km}^3}$$

$$= 4.30\times10^4\ \text{km}$$

Section Review

7.1 Planetary Motion and Gravitation pages 171–178

page 178

6. Neptune's Orbital Period Neptune orbits the Sun with an orbital radius of 4.495×10^{12} m, which allows gases, such as methane, to condense and form an atmosphere, as shown in **Figure 7-8.** If the mass of the Sun is 1.99×10^{30} kg, calculate the period of Neptune's orbit.

■ **Figure 7-8**

$$T = 2\pi\sqrt{\frac{r^3}{Gm_S}}$$

$$= 2\pi\sqrt{\frac{(4.495\times10^{12}\ \text{m})^3}{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(1.99\times10^{30}\ \text{kg})}}$$

$$= 5.20\times10^9\ \text{s} = 6.02\times10^5\ \text{days}$$

7. Gravity If Earth began to shrink, but its mass remained the same, what would happen to the value of g on Earth's surface?

The value of *g* would increase.

8. Gravitational Force What is the gravitational force between two 15-kg packages that are 35 cm apart? What fraction is this of the weight of one package?

$$F_g = G\frac{m_E m}{r^2}$$

$$= \frac{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(15\ \text{kg})^2}{(0.35\ \text{m})^2}$$

$$= 1.2\times10^{-7}\ \text{N}$$

Because the weight is mg = 147 N, the gravitational force is 8.2×10^{-10} or 0.82 parts per billion of the weight.

9. Universal Gravitational Constant Cavendish did his experiment using lead spheres. Suppose he had replaced the lead spheres with copper spheres of equal mass. Would his value of *G* be the same or different? Explain.

It would be the same, because the same value of *G* has been used successfully to describe the attraction of bodies having diverse chemical compositions: the Sun (a star), the planets, and satellites.

10. Laws or Theories? Kepler's three statements and Newton's equation for gravitational attraction are called "laws." Were they ever theories? Will they ever become theories?

No. A scientific law is a statement of what has been observed to happen many times. A theory explains scientific results. None of these statements offers explanations for why the motion of planets are as they are or for why gravitational attraction acts as it does.

11. Critical Thinking Picking up a rock requires less effort on the Moon than on Earth.

a. How will the weaker gravitational force on the Moon's surface affect the path of the rock if it is thrown horizontally?

Horizontal throwing requires the same effort because the inertial character, $F = ma$, of the rock is involved. The mass of the rock depends only on the amount of matter in the rock, not on its location in the universe. The path would still be a parabola, but it could be much wider because the rock would go farther before it hits the ground, given the smaller acceleration rate and longer time of flight.

b. If the thrower accidentally drops the rock on her toe, will it hurt more or less than it would on Earth? Explain.

Assume the rocks would be dropped from the same height on Earth and on the Moon. It will hurt less because the smaller value of *g* on the Moon means that the rock strikes the toe with a smaller velocity than on Earth.

Practice Problems

7.2 Using the Law of Universal of Gravitation pages 179–185

page 181

For the following problems, assume a circular orbit for all calculations.

12. Suppose that the satellite in Example Problem 2 is moved to an orbit that is 24 km larger in radius than its previous orbit. What would its speed be? Is this faster or slower than its previous speed?

$$r = (h + 2.40\times10^4\ \text{m}) + r_E$$
$$= (2.25\times10^5\ \text{m} + 2.40\times10^4\ \text{m}) + 6.38\times10^6\ \text{m} = 6.63\times10^6\ \text{m}$$
$$v = \sqrt{\frac{Gm_E}{r}}$$
$$= \sqrt{\frac{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(5.97\times10^{24}\ \text{kg})}{6.63\times10^6\ \text{m}}}$$
$$= 7.75\times10^3\ \text{m/s, slower}$$

13. Use Newton's thought experiment on the motion of satellites to solve the following.

a. Calculate the speed that a satellite shot from a cannon must have to orbit Earth 150 km above its surface.

$$v = \sqrt{\frac{Gm_E}{r}} = \sqrt{\frac{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(5.97\times10^{24}\ \text{kg})}{(6.38\times10^6\ \text{m} + 1.5\times10^5\ \text{m})}}$$
$$= 7.8\times10^3\ \text{m/s}$$

b. How long, in seconds and minutes, would it take for the satellite to complete one orbit and return to the cannon?

$$T = 2\pi\sqrt{\frac{r^3}{Gm_E}} = 2\pi\sqrt{\frac{(6.38\times10^6\ \text{m} + 1.5\times10^5\ \text{m})^3}{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(5.97\times10^{24}\ \text{kg})}}$$
$$= 5.3\times10^3\ \text{s} \approx 88\ \text{min}$$

14. Use the data for Mercury in Table 7-1 on page 173 to find the following.

a. the speed of a satellite that is in orbit 260 km above Mercury's surface

$$v = \sqrt{\frac{Gm_M}{r}}$$
$$r = r_M + 260\ \text{km}$$
$$= 2.44\times10^6\ \text{m} + 0.26\times10^6\ \text{m}$$
$$= 2.70\times10^6\ \text{m}$$
$$v = \sqrt{\frac{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(3.30\times10^{23}\ \text{kg})}{2.70\times10^6\ \text{m}}}$$
$$= 2.86\times10^3\ \text{m/s}$$

b. the period of the satellite

$$T = 2\pi\sqrt{\frac{r^3}{Gm_M}} = 2\pi\sqrt{\frac{(2.70\times10^6\ \text{m})^3}{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(3.30\times10^{23}\ \text{kg})}}$$
$$= 5.94\times10^3\ \text{s} = 1.65\ \text{h}$$

Section Review

7.2 Using the Law of Universal of Gravitation pages 179–185

page 185

15. Gravitational Fields The Moon is 3.9×10^5 km from Earth's center and 1.5×10^8 km from the Sun's center. The masses of Earth and the Sun are 6.0×10^{24} kg and 2.0×10^{30} kg, respectively.

a. Find the ratio of the gravitational fields due to Earth and the Sun at the center of the Moon.

Gravitational field due to the Sun: $g_S = G\frac{m_S}{r_S^2}$

Gravitational field due to Earth: $g_E = G\frac{m_E}{r_E^2}$

$$\frac{g_S}{g_E} = \left(\frac{m_S}{m_E}\right)\left(\frac{r_E^2}{r_S^2}\right)$$

$$= \frac{(2.0\times10^{30}\text{ kg})(3.9\times10^5\text{ km})^2}{(6.0\times10^{24}\text{ kg})(1.5\times10^8\text{ km})^2}$$

$$= 2.3$$

b. When the Moon is in its third quarter phase, as shown in **Figure 7-17,** its direction from Earth is at right angles to the Sun's direction. What is the net gravitational field due to the Sun and Earth at the center of the Moon?

■ **Figure 7-17**

Because the directions are at right angles, the net field is the square root of the sum of the squares of the two fields.

$$g_S = \frac{Gm_S}{r^2}$$

$$= \frac{(6.67\times10^{-11}\text{ N·m}^2/\text{kg}^2)(2.0\times10^{30}\text{ kg})}{(1.5\times10^{11}\text{ m})^2}$$

$$= 5.9\times10^{-3}\text{ N/kg}$$

Similarly, $g_E = 2.6\times10^{-3}$ **N/kg**

$$g_{net} = \sqrt{(5.9\times10^{-3}\text{ N/kg})^2 + (2.6\times10^{-3}\text{ N/kg})^2}$$

$$= 6.4\times10^{-3}\text{ N/kg}$$

16. Gravitational Field The mass of the Moon is 7.3×10^{22} kg and its radius is 1785 km. What is the strength of the gravitational field on the surface of the Moon?

$$g = \frac{GM}{r^2} = \frac{(6.67\times10^{-11}\text{ N·m}^2/\text{kg}^2)(7.3\times10^{22}\text{ kg})}{(1.785\times10^3\text{ m})^2}$$

= 1.5 N/kg, about one-sixth that on Earth

17. **A Satellite's Mass** When the first artificial satellite was launched into orbit by the former Soviet Union in 1957, U.S. president Dwight D. Eisenhower asked his scientific advisors to calculate the mass of the satellite. Would they have been able to make this calculation? Explain.

No. Because the speed and period of the orbit don't depend at all on the mass of the satellite, the scientific advisors would not have been able to calculate the mass of the satellite.

18. **Orbital Period and Speed** Two satellites are in circular orbits about Earth. One is 150 km above the surface, the other 160 km.

a. Which satellite has the larger orbital period?

When the orbital radius is large, the period also will be large. Thus, the one at 160 km will have the larger period.

b. Which one has the greater speed?

The one at 150 km, because the smaller the orbital radius, the greater the speed.

19. **Theories and Laws** Why is Einstein's description of gravity called a "theory," while Newton's is a "law?"

Newton's law describes how to calculate the force between two massive objects. Einstein's theory explains how an object, such as Earth, attracts the Moon.

20. **Weightlessness** Chairs in an orbiting spacecraft are weightless. If you were on board such a spacecraft and you were barefoot, would you stub your toe if you kicked a chair? Explain.

Yes. The chairs are weightless but not massless. They still have inertia and can exert contact forces on your toe.

21. **Critical Thinking** It is easier to launch a satellite from Earth into an orbit that circles eastward than it is to launch one that circles westward. Explain.

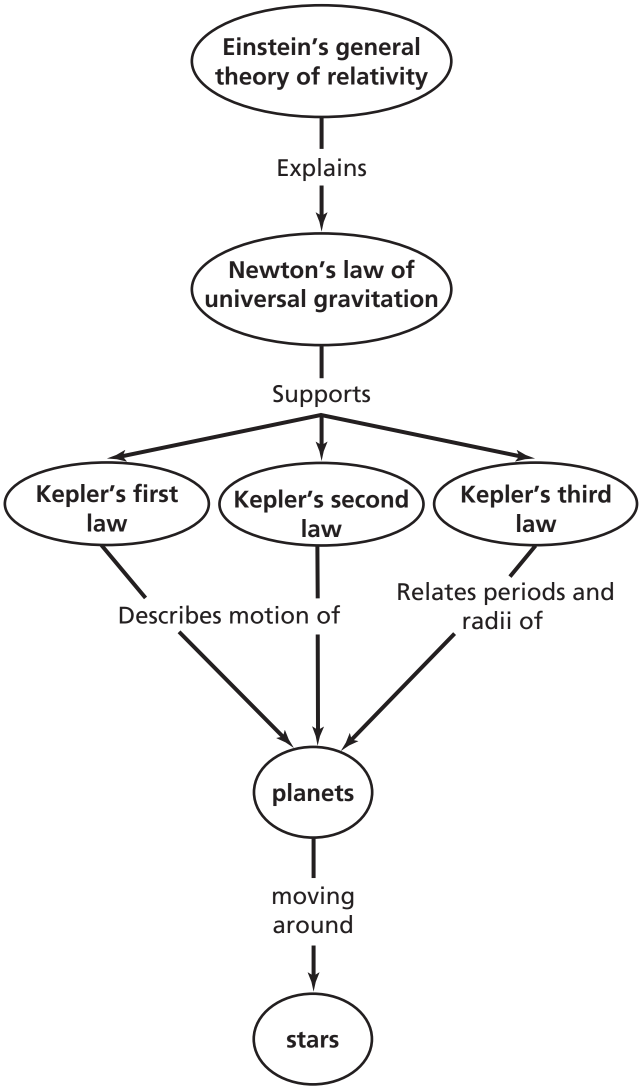
Earth rotates toward the east, and its velocity adds to the velocity given to the satellite by the rocket, thereby reducing the velocity that the rocket must supply.

Chapter Assessment

Concept Mapping

page 190

22. Create a concept map using these terms: *planets, stars, Newton's law of universal gravitation, Kepler's first law, Kepler's second law, Kepler's third law, Einstein's general theory of relativity.*



Kepler's first and second laws describe the motion of a single planet. Kepler's third law describes the periods versus the orbital radii of all planets around a star. Newton's law of universal gravitation supports Kepler's laws. Einstein's theory explains Newton's and Kepler's laws.

Mastering Concepts

page 190

23. In 1609, Galileo looked through his telescope at Jupiter and saw four moons. The name of one of the moons that he saw is Io. Restate Kepler's first law for Io and Jupiter. (7.1)

The path of Io is an ellipse, with Jupiter at one focus.

24. Earth moves more slowly in its orbit during summer in the northern hemisphere than it does during winter. Is it closer to the Sun in summer or in winter? (7.1)

Because Earth moves more slowly in its orbit during summer, by Kepler's second law, it must be farther from the Sun. Therefore, Earth is closer to the Sun in the winter months.

25. Is the area swept out per unit of time by Earth moving around the Sun equal to the area swept out per unit of time by Mars moving around the Sun? (7.1)

No. The equality of the area swept out per unit of time applies to each planet individually.

26. Why did Newton think that a force must act on the Moon? (7.1)

Newton knew that the Moon followed a curved path; therefore, it was accelerated. He also knew that a force is required for acceleration.

27. How did Cavendish demonstrate that a gravitational force of attraction exists between two small objects? (7.1)

He carefully measured the masses, the distance between the masses, and the force of attraction. He then calculated *G* using Newton's law of universal gravitation.

28. What happens to the gravitational force between two masses when the distance between the masses is doubled? (7.1)

According to Newton, $F \propto 1/r^2$. If the distance is doubled, the force is cut to one-fourth.

29. According to Newton's version of Kepler's third law, how would the ratio T^2/r^3 change if the mass of the Sun were doubled? (7.1)

Because $T^2/r^3 = 4\pi^2/Gm_S$, if the mass of the Sun, m_S, is doubled, the ratio will be halved.

30. How do you answer the question, "What keeps a satellite up?" (7.2)

Its speed; it is falling all the time.

31. A satellite is orbiting Earth. On which of the following does its speed depend? (7.2)

a. mass of the satellite

b. distance from Earth

c. mass of Earth

Speed depends only on b, the distance from the Earth, and c, the mass of Earth.

32. What provides the force that causes the centripetal acceleration of a satellite in orbit? (7.2)

gravitational attraction to the central body

33. During space flight, astronauts often refer to forces as multiples of the force of gravity on Earth's surface. What does a force of 5*g* mean to an astronaut? (7.2)

A force of 5*g* means that an astronaut's weight is five times heavier than it is on Earth. The force exerted on the astronaut is five times the force of Earth's gravitational force.

34. Newton assumed that a gravitational force acts directly between Earth and the Moon. How does Einstein's view of the attractive force between the two bodies differ from Newton's view? (7.2)

Einstein's view is that gravity is an effect of the curvature of space as a result of the presence of mass, whereas Newton's view of gravity is that it is a force acting directly between objects. Thus, according to Einstein, the attraction between Earth and the Moon is the effect of curvature of space caused by their combined masses.

35. Show that the dimensions of *g* in the equation $g = F/m$ are in m/s^2. (7.2)

The units of $\frac{F}{m}$ are $\frac{\text{N}}{\text{kg}} = \frac{\text{kg·m/s}^2}{\text{kg}} = \text{m/s}^2$

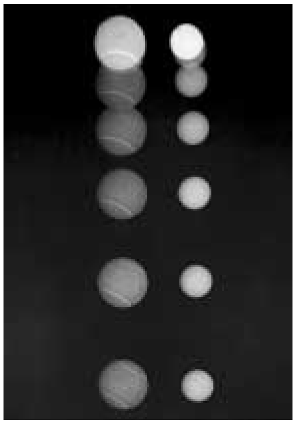
36. If Earth were twice as massive but remained the same size, what would happen to the value of *g*? (7.2)

The value of *g* would double.

Applying Concepts

pages 190–191

37. **Golf Ball** The force of gravity acting on an object near Earth's surface is proportional to the mass of the object. **Figure 7-18** shows a tennis ball and golf ball in free fall. Why does a tennis ball not fall faster than a golf ball?



■ **Figure 7-18**

$$F = G\frac{m_1m_2}{r^2}$$

m_1 = Earth's mass

$$a = \frac{F}{m_2}$$

m_2 = object's mass

Thus, $a = \frac{Gm_1}{r^2}$

The acceleration is independent of the object's mass. This is because more massive objects require more force to accelerate at the same rate.

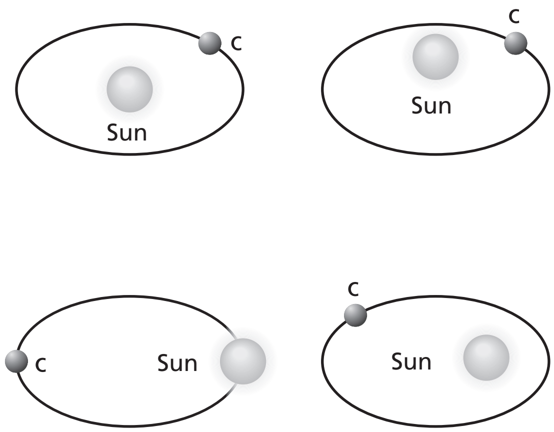
38. What information do you need to find the mass of Jupiter using Newton's version of Kepler's third law?

You must know the period and orbital radius of at least one of its satellites.

39. The mass of Pluto was not known until a satellite of the planet was discovered. Why?

Orbital motion of a planet does not depend on its mass and cannot be used to find the mass. A satellite orbiting the planet is necessary to find the planet's mass.

40. Decide whether each of the orbits shown in **Figure 7-19** is a possible orbit for a planet.



■ **Figure 7-19**

Only d (lower right) is possible. a (top left) and b (top right) do not have the Sun at a focus, and in c (lower left), the planet is not in orbit around the Sun.

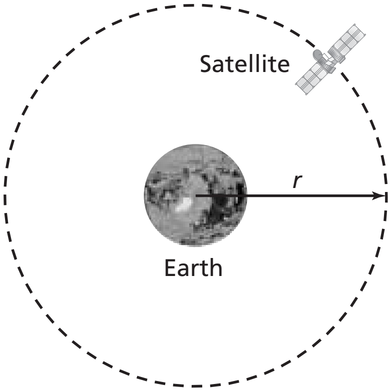
41. The Moon and Earth are attracted to each other by gravitational force. Does the more-massive Earth attract the Moon with a greater force than the Moon attracts Earth? Explain.

No. The forces constitute an action-reaction pair, so under Newton's third law, they are equal and opposite.

42. What would happen to the value of G if Earth were twice as massive, but remained the same size?

Nothing. *G* is a universal constant, and it is independent of Earth's mass. However, the force of attraction would double.

43. **Figure 7-20** shows a satellite orbiting Earth. Examine the equation $v = \sqrt{\frac{Gm_E}{r}}$, relating the speed of an orbiting satellite and its distance from the center of Earth. Does a satellite with a large or small orbital radius have the greater velocity?



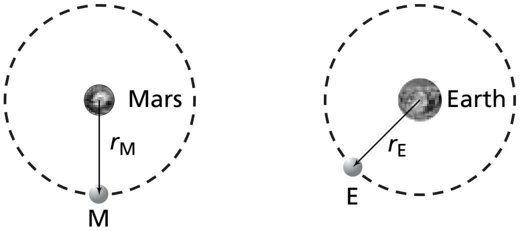
■ **Figure 7-20** (Not to scale)

A satellite with a small radius has the greater velocity.

44. Space Shuttle If a space shuttle goes into a higher orbit, what happens to the shuttle's period?

Because $T = 2\pi\sqrt{\frac{r^3}{Gm}}$, if the orbital radius increases, so will the period.

45. Mars has about one-ninth the mass of Earth. **Figure 7-21** shows satellite M, which orbits Mars with the same orbital radius as satellite E, which orbits Earth. Which satellite has a smaller period?



■ **Figure 7-21** (Not to scale)

Because $T = 2\pi\sqrt{\frac{r^3}{Gm}}$, as the mass of the planet increases, the period of the satellite decreases. Because Earth has a larger mass than Mars, Earth's satellite will have a smaller period.

46. Jupiter has about 300 times the mass of Earth and about ten times Earth's radius. Estimate the size of *g* on the surface of Jupiter.

$g \propto \frac{m_E}{{r_E}^2}$. If Jupiter has 300 times the mass and ten times the radius of Earth,

$g \propto \frac{300}{10^2} = 3$. Thus, *g* on Jupiter is three times that on Earth.

47. A satellite is one Earth radius above the surface of Earth. How does the acceleration due to gravity at that location compare to acceleration at the surface of Earth?

$d = r_E + r_E = 2r_E$

so, $a = g\left(\frac{r_E}{2r_E}\right)^2 = \frac{1}{4}g$

48. If a mass in Earth's gravitational field is doubled, what will happen to the force exerted by the field upon the mass?

It also will double.

49. Weight Suppose that yesterday your body had a mass of 50.0 kg. This morning you stepped on a scale and found that you had gained weight.

a. What happened, if anything, to your mass?

Your mass increased.

b. What happened, if anything, to the ratio of your weight to your mass?

The ratio remained constant because it is equal to the gravitational field at the location, a constant = *g*.

50. As an astronaut in an orbiting space shuttle, how would you go about "dropping" an object down to Earth?

To "drop" an object down to Earth, you would have to launch it backward at the same speed at which you are traveling in orbit. With respect to Earth, the object's speed perpendicular to Earth's gravity would be zero, and it could then "drop" down to Earth. However, the object is likely to burn up as a result of friction with Earth's atmosphere on the way down.

51. Weather Satellites The weather pictures that you see every day on TV come from a spacecraft in a stationary position relative to the surface of Earth, 35,700 km above Earth's equator. Explain how it can stay in exactly the same position day after day. What would happen if it were closer? Farther out? *Hint: Draw a pictorial model.*

The satellite is positioned as close to the equator as possible so it doesn't appear to have much north-south movement. Because it is placed at that distance, the satellite has a period of 24.0 h. If it were positioned any closer, its period would be less than 24.0 h and it would appear to move toward the east. If it were positioned any farther, its period would be longer than 24.0 h.

Mastering Problems

7.1 Planetary Motion and Gravitation

pages 191–192

Level 1

52. Jupiter is 5.2 times farther from the Sun than Earth is. Find Jupiter's orbital period in Earth years.

$$\left(\frac{T_J}{T_E}\right)^2 = \left(\frac{r_J}{r_E}\right)^3$$

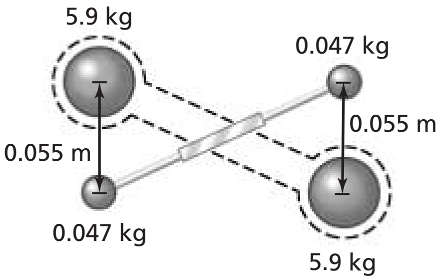
$$T_J = \sqrt{\left(\frac{r_J}{r_E}\right)^3 T_E{}^2}$$

$$= \sqrt{\left(\frac{5.2}{1.0}\right)^3 (1.0\ \text{y})^2}$$

$$= \sqrt{141\ \text{y}^2}$$

$$= 12\ \text{y}$$

53. **Figure 7-22** shows a Cavendish apparatus like the one used to find *G*. It has a large lead sphere that is 5.9 kg in mass and a small one with a mass of 0.047 kg. Their centers are separated by 0.055 m. Find the force of attraction between them.



■ **Figure 7-22**

$$F = G\frac{m_S m_J}{r^2}$$

$$= (6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)\frac{(5.9\ \text{kg})(4.7\times10^{-2}\ \text{kg})}{(5.5\times10^{-2}\ \text{m})^2}$$

$$= 6.1\times10^{-9}\ \text{N}$$

54. Use Table 7-1 on p. 173 to compute the gravitational force that the Sun exerts on Jupiter.

$$F = G\frac{m_1 m_2}{r^2}$$

$$= (6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)\frac{(1.99\times10^{30}\ \text{kg})(1.90\times10^{27}\ \text{kg})}{(7.78\times10^{11}\ \text{m})^2}$$

$$= 4.17\times10^{23}\ \text{N}$$

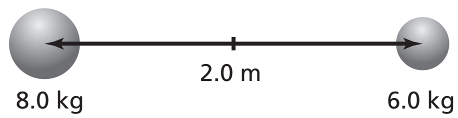
55. Tom has a mass of 70.0 kg and Sally has a mass of 50.0 kg. Tom and Sally are standing 20.0 m apart on the dance floor. Sally looks up and sees Tom. She feels an attraction. If the attraction is gravitational, find its size. Assume that both Tom and Sally can be replaced by spherical masses.

$$F = G\frac{m_T m_S}{r^2}$$

$$= (6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)\frac{(70.0\ \text{kg})(50.0\ \text{kg})}{(20.0\ \text{m})^2}$$

$$= 5.84\times10^{-10}\ \text{N}$$

56. Two balls have their centers 2.0 m apart, as shown in **Figure 7-23.** One ball has a mass of 8.0 kg. The other has a mass of 6.0 kg. What is the gravitational force between them?



■ **Figure 7-23**

$$F = G\frac{m_1 m_2}{r^2}$$

$$= (6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)\frac{(8.0\ \text{kg})(6.0\ \text{kg})}{(2.0\ \text{m})^2}$$

$$= 8.0\times10^{-10}\ \text{N}$$

57. Two bowling balls each have a mass of 6.8 kg. They are located next to each other with their centers 21.8 cm apart. What gravitational force do they exert on each other?

$$F = G\frac{m_1 m_2}{r^2}$$

$$= (6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)\frac{(6.8\ \text{kg})(6.8\ \text{kg})}{(0.218\ \text{m})^2}$$

$$= 6.5\times10^{-8}\ \text{N}$$

58. Assume that you have a mass of 50.0 kg. Earth has a mass of 5.97×10^{24} kg and a radius of 6.38×10^{6} m.

a. What is the force of gravitational attraction between you and Earth?

Sample answer:

$$F = G\frac{m_S m_E}{r^2}$$

$$= (6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)\frac{(50.0\ \text{kg})(5.97\times10^{24}\ \text{kg})}{(6.38\times10^{6}\ \text{m})^2}$$

$$= 489\ \text{N}$$

b. What is your weight?

Sample answer:

$$F_g = mg = (50.0\ \text{kg})(9.80\ \text{m/s}^2)$$

$$= 4.90\times10^{2}\ \text{N}$$

59. The gravitational force between two electrons that are 1.00 m apart is 5.54×10^{-71} N. Find the mass of an electron.

$$F = G\frac{m_1 m_2}{r^2}, \text{ where } m_1 = m_2 = m_e$$

$$\text{So } m_e = \sqrt{\frac{Fr^2}{G}}$$

$$= \sqrt{\frac{(5.54\times10^{-71}\ \text{N})(1.00\ \text{m})^2}{6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2}}$$

$$= 9.11\times10^{-31}\ \text{kg}$$

60. A 1.0-kg mass weighs 9.8 N on Earth's surface, and the radius of Earth is roughly 6.4×10^{6} m.

a. Calculate the mass of Earth.

$$F = G\frac{m_1 m_2}{r^2}$$

$$m_E = \frac{Fr^2}{Gm}$$

$$= \frac{(9.8\ \text{N})(6.4\times10^{6}\ \text{m})^2}{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(1.0\ \text{kg})}$$

$$= 6.0\times10^{24}\ \text{kg}$$

b. Calculate the average density of Earth.

$$V = \frac{4}{3}\pi r^3 = \frac{(4\pi)(6.4\times10^{6}\ \text{m})^3}{3}$$

$$= 1.1\times10^{21}\ \text{m}^3$$

$$D = \frac{m}{V} = \frac{6.0\times10^{24}\ \text{kg}}{1.1\times10^{21}\ \text{m}^3}$$

$$= 5.5\times10^{3}\ \text{kg/m}^3$$

61. Uranus Uranus requires 84 years to circle the Sun. Find Uranus's orbital radius as a multiple of Earth's orbital radius.

$$\left(\frac{T_U}{T_E}\right)^2 = \left(\frac{r_U}{r_E}\right)^3$$

$$\frac{r_U}{r_E} = \sqrt[3]{\left(\frac{T_U}{T_E}\right)^2}$$

$$= \sqrt[3]{\left(\frac{84\ \text{y}}{1.0\ \text{y}}\right)^2}$$

$$= 19$$

$$\text{So } r_U = 19r_E$$

62. Venus Venus has a period of revolution of 225 Earth days. Find the distance between the Sun and Venus as a multiple of Earth's orbital radius.

$$\left(\frac{T_V}{T_E}\right)^2 = \left(\frac{r_V}{r_E}\right)^3$$

$$\frac{r_V}{r_E} = \sqrt[3]{\left(\frac{T_V}{T_E}\right)^2}$$

$$= \sqrt[3]{\left(\frac{225\ \text{days}}{365\ \text{days}}\right)^2}$$

$$= 0.724$$

$$\text{So } r_V = 0.724r_E$$

Level 2

63. If a small planet, D, were located 8.0 times as far from the Sun as Earth is, how many years would it take the planet to orbit the Sun?

$$\left(\frac{T_D}{T_E}\right)^2 = \left(\frac{r_D}{r_E}\right)^3$$

$$T_D = \sqrt{\left(\frac{r_D}{r_E}\right)^3 T_E{}^2} = \sqrt{\left(\frac{8.0}{1.0}\right)^3 (1.0\text{ y})^2} = 23\text{ years}$$

64. Two spheres are placed so that their centers are 2.6 m apart. The force between the two spheres is 2.75×10^{-12} N. What is the mass of each sphere if one sphere is twice the mass of the other sphere?

$$F = G\frac{m_1 m_2}{r^2}\text{, where } m_2 = 2m_1$$

$$F = G\frac{(m_1)(2m_1)}{r^2}$$

$$m_1 = \sqrt{\frac{Fr^2}{2G}}$$

$$= \sqrt{\frac{(2.75\times10^{-12}\text{ N})(2.6\text{ m})^2}{(2)(6.67\times10^{-11}\text{ N·m}^2/\text{kg}^2)}}$$

= 0.3733 kg or 0.37 kg to two significant digits

$m_2 = 2m_1 = (2)(0.3733\text{ kg}) = 0.7466$ **kg or 0.75 to two significant digits**

65. The Moon is 3.9×10^5 km from Earth's center and 1.5×10^8 km from the Sun's center. If the masses of the Moon, Earth, and the Sun are 7.3×10^{22} kg, 6.0×10^{24} kg, and 2.0×10^{30} kg, respectively, find the ratio of the gravitational forces exerted by Earth and the Sun on the Moon.

$$F = G\frac{m_1 m_2}{r^2}$$

Earth on Moon: $F_E = (6.67\times10^{-11}\text{ N·m}^2/\text{kg}^2)\frac{(6.0\times10^{24}\text{ kg})(7.3\times10^{22}\text{ kg})}{(3.9\times10^8\text{ m})^2}$

$= 1.9\times10^{20}$ N

Sun on Moon: $F_E = (6.67\times10^{-11}\text{ N·m}^2/\text{kg}^2)\frac{(2.0\times10^{30}\text{ kg})(7.3\times10^{22}\text{ kg})}{(1.5\times10^{11}\text{ m})^2}$

$= 4.3\times10^{20}$ N

Ratio is $\frac{F_E}{F_S} = \frac{1.9\times10^{20}\text{ N}}{4.3\times10^{20}\text{ N}} = \frac{1.0}{2.3}$

The Sun pulls more than twice as hard on the Moon as does Earth.

66. Toy Boat A force of 40.0 N is required to pull a 10.0-kg wooden toy boat at a constant velocity across a smooth glass surface on Earth. What force would be required to pull the same wooden toy boat across the same glass surface on the planet Jupiter?

$\mu = \frac{F_f}{F_N} = \frac{F_f}{m_b g}$, **where** m_b **is the mass of the toy boat.**

On Jupiter, the normal force is equal to the gravitational attraction between the toy boat and Jupiter, or

$$F_N = G\frac{m_b m_J}{r_J{}^2}$$

Now $\mu = \frac{F_f}{F_N}$, **so** $F_{fJ} = \mu F_N = \mu G\frac{m_b m_J}{r_J{}^2}$

But $\mu = \frac{F_f}{m_b g}$**, so** F_{fJ}

$$= F_f G \frac{m_b m_J}{m_b g r_J^2} = F_f G \frac{m_J}{g r_J^2} = \frac{(40.0\text{ N})(6.67\times10^{-11}\text{ N·m}^2/\text{kg}^2)(1.90\times10^{27}\text{ kg})}{(9.80\text{ m/s}^2)(7.15\times10^7\text{ m})^2}$$

$$= 101\text{ N}$$

67. Mimas, one of Saturn's moons, has an orbital radius of 1.87×10^8 m and an orbital period of about 23.0 h. Use Newton's version of Kepler's third law to find Saturn's mass.

$$T^2 = \left(\frac{4\pi^2}{Gm}\right)r^3$$

$$m = \frac{4\pi^2 r^3}{GT^2}$$

$$= \frac{4\pi^2(1.87\times10^8\text{ m})^3}{(6.67\times10^{-11}\text{ N·m}^2/\text{kg}^2)(8.28\times10^4\text{ s})^2}$$

$$= 5.6\times10^{26}\text{ kg}$$

Level 3

68. The Moon is 3.9×10^8 m away from Earth and has a period of 27.33 days. Use Newton's version of Kepler's third law to find the mass of Earth. Compare this mass to the mass found in problem 60.

$$T^2 = \left(\frac{4\pi^2}{Gm}\right)r^3$$

$$m = \left(\frac{4\pi^2}{G}\right)\frac{r^3}{T^2}$$

$$= \left(\frac{4\pi^2}{(6.67\times10^{-11}\text{ N·m}^2/\text{kg}^2)}\right)\frac{(3.9\times10^8\text{ m})^3}{(2.361\times10^6\text{ s})^2}$$

$$= 6.3\times10^{24}\text{ kg}$$

The mass is considerably close to that found in problem 60.

69. **Halley's Comet** Every 74 years, comet Halley is visible from Earth. Find the average distance of the comet from the Sun in astronomical units (AU).

For Earth, $r = 1.0$ **AU and** $T = 1.0$ **y**

$$\left(\frac{r_a}{r_b}\right)^3 = \left(\frac{T_a}{T_b}\right)^2$$

$$r_a = \sqrt[3]{r_b^3\left(\frac{T_a}{T_b}\right)^2} = \sqrt[3]{(1.0\text{ AU})^3\left(\frac{74\text{ y}}{1.0\text{ y}}\right)^2}$$

$$= 18\text{ AU}$$

70. Area is measured in m^2, so the rate at which area is swept out by a planet or satellite is measured in m^2/s.

a. How quickly is an area swept out by Earth in its orbit about the Sun?

$r = 1.50\times10^{11}$ **m and**

$T = 3.156\times10^7$ **s, in 365.25 days = 1.00 y**

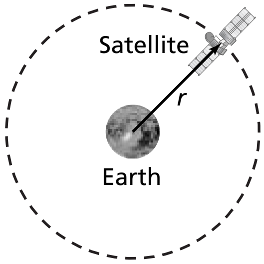
$$\frac{\pi r^2}{T} = \frac{\pi(1.50\times10^{11}\text{ m})^2}{3.156\times10^7\text{ s}} = 2.24\times10^{15}\text{ m}^2/\text{s}$$

b. How quickly is an area swept out by the Moon in its orbit about Earth? Use 3.9×10^8 m as the average distance between Earth and the Moon, and 27.33 days as the period of the Moon.

$$\frac{\pi(3.9\times10^8\ \text{m})^2}{2.36\times10^6\ \text{s}} = 2.0\times10^{11}\ \text{m}^2/\text{s}$$

7.2 Using the Law of Universal Gravitation
pages 192–193
Level 1

71. Satellite A geosynchronous satellite is one that appears to remain over one spot on Earth, as shown in **Figure 7-24.** Assume that a geosynchronous satellite has an orbital radius of 4.23×10^7 m.



■ **Figure 7-24** (Not to scale)

a. Calculate its speed in orbit.

$$v = \sqrt{\frac{Gm_E}{r}}$$

$$= \sqrt{\frac{(6.67\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2)(5.97\text{x}10^{24}\ \text{kg})}{4.23\times10^7\ \text{m}}}$$

$$= 3.07\times10^3\ \text{m/s or } 3.07\ \text{km/s}$$

b. Calculate its period.

$$T = 2\pi\sqrt{\frac{r^3}{Gm_E}}$$

$$= 2\pi\sqrt{\frac{(4.23\times10^7\ \text{m})^3}{(6.67\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2)(5.97\times10^{24}\ \text{kg})}}$$

$$= 2\pi\sqrt{1.90\times10^8\ \text{s}^2}$$

$$= 8.66\times10^4\ \text{s or } 24.1\ \text{h}$$

72. Asteroid The asteroid Ceres has a mass of 7×10^{20} kg and a radius of 500 km.

a. What is g on the surface of Ceres?

$$g = \frac{Gm}{r^2}$$

$$= \frac{(6.67\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2)(7\times10^{20}\ \text{kg})}{(500\times10^3\ \text{m})^2}$$

$$= 0.2\ \text{m/s}^2$$

b. How much would a 90-kg astronaut weigh on Ceres?

$$F_g = mg = (90\ \text{kg})(0.2\ \text{m/s}^2) = 20\ \text{N}$$

73. **Book** A 1.25-kg book in space has a weight of 8.35 N. What is the value of the gravitational field at that location?

$$g = \frac{F}{m} = \frac{8.35\text{ N}}{1.25\text{ kg}} = 6.68\text{ N/kg}$$

74. The Moon's mass is 7.34×10^{22} kg, and it is 3.8×10^{8} m away from Earth. Earth's mass is 5.97×10^{24} kg.

a. Calculate the gravitational force of attraction between Earth and the Moon.

$$F = G\frac{m_E m_M}{r^2}$$

$$= (6.67\times10^{-11}\text{ N·m}^2/\text{kg}^2)\frac{(5.98\times10^{24}\text{ kg})(7.34\times10^{22}\text{ kg})}{(3.8\times10^{8}\text{ m})^2}$$

$$= 2.0\times10^{20}\text{ N}$$

b. Find Earth's gravitational field at the Moon.

$$g = \frac{F}{m} = \frac{2.03\times10^{20}\text{ N}}{7.34\times10^{22}\text{ kg}} = 0.0028\text{ N/kg}$$

Note that 2.03×10^{20} N instead of 2.0×10^{20} N is used to prevent roundoff error.

75. Two 1.00-kg masses have their centers 1.00 m apart. What is the force of attraction between them?

$$F_g = G\frac{m_1 m_2}{r^2}$$

$$= \frac{(6.67\times10^{-11}\text{ N·m}^2/\text{kg}^2)(1.00\text{ kg})(1.00\text{ kg})}{(1.00\text{ m})^2}$$

$$= 6.67\times10^{-11}\text{ N}$$

Level 2

76. The radius of Earth is about 6.38×10^{3} km. A 7.20×10^{3}-N spacecraft travels away from Earth. What is the weight of the spacecraft at the following distances from Earth's surface?

a. 6.38×10^{3} km

$$d = r_E + r_E = 2r_E$$

Therefore, $F_g = \frac{1}{4}$ original weight $= \left(\frac{1}{4}\right)(7.20\times10^{3}\text{ N}) = 1.80\times10^{3}\text{ N}$

b. 1.28×10^{4} km

$$d = r_E + 2r_E = 3r_E$$

$$F_g = \left(\frac{1}{9}\right)(7.20\times10^{3}\text{ N}) = 8.00\times10^{2}\text{ N}$$

77. **Rocket** How high does a rocket have to go above Earth's surface before its weight is half of what it is on Earth?

$$F_g \propto \frac{1}{r^2}$$

So $r \propto \sqrt{\frac{1}{F_g}}$

If the weight is $\frac{1}{2}$, the distance is $\sqrt{2}(r_E)$ or

$$r = \sqrt{2}(6.38\times10^{6}\ \text{m}) = 9.02\times10^{6}\ \text{m}$$

$$9.02\times10^{6}\ \text{m} - 6.38\times10^{6}\ \text{m} = 2.64\times10^{6}\ \text{m}$$
$$= 2.64\times10^{3}\ \text{km}$$

78. Two satellites of equal mass are put into orbit 30.0 m apart. The gravitational force between them is 2.0×10^{-7} N.

a. What is the mass of each satellite?

$$F = G\frac{m_1m_2}{r^2},\ m_1 = m_2 = m$$

$$m = \sqrt{\frac{Fr^2}{G}} = \sqrt{\frac{(2.0\times10^{-7}\ \text{N})(30.0\ \text{m})^2}{6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2}}$$

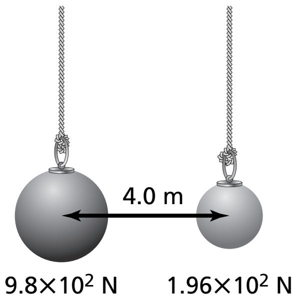
$$= 1.6\times10^{3}\ \text{kg}$$

b. What is the initial acceleration given to each satellite by gravitational force?

$$F_{\text{net}} = ma$$

$$a = \frac{F_{\text{net}}}{m} = \frac{2.0\times10^{-7}\ \text{N}}{1.6\times10^{3}\ \text{kg}} = 1.3\times10^{-10}\ \text{m/s}^2$$

79. Two large spheres are suspended close to each other. Their centers are 4.0 m apart, as shown in **Figure 7-25.** One sphere weighs 9.8×10^2 N. The other sphere has a weight of 1.96×10^2 N. What is the gravitational force between them?



■ **Figure 7-25**

$$m_1 = \frac{F_g}{g} = \frac{9.8\times10^{2}\ \text{N}}{9.80\ \text{m/s}^2} = 1.0\times10^{2}\ \text{kg}$$

$$m_2 = \frac{F_g}{g} = \frac{1.96\times10^{2}\ \text{N}}{9.80\ \text{m/s}^2} = 2.00\times10^{1}\ \text{kg}$$

$$F = G\frac{m_1m_2}{r^2}$$

$$= \frac{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(1.0\times10^{1}\ \text{kg})(2.00\times10^{1}\ \text{kg})}{(4.0\ \text{m})^2}$$

$$= 8.3\times10^{-9}\ \text{N}$$

80. Suppose the centers of Earth and the Moon are 3.9×10^{8} m apart, and the gravitational force between them is about 1.9×10^{20} N. What is the approximate mass of the Moon?

$$F = G\frac{m_E m_M}{r^2}$$

$$m_M = \frac{Fr^2}{Gm_E}$$

$$= \frac{(1.9\times10^{20}\ \text{N})(3.9\times10^{8}\ \text{m})^2}{(6.67\times10^{-11}\ \text{N·m/kg}^2)(5.97\times10^{24}\ \text{kg})}$$

$$= 7.3\times10^{22}\ \text{kg}$$

81. On the surface of the Moon, a 91.0-kg physics teacher weighs only 145.6 N. What is the value of the Moon's gravitational field at its surface?

$F_g = mg$,

So $g = \frac{F_g}{m} = \frac{145.6\ \text{N}}{91.0\ \text{kg}} = 1.60\ \text{N/kg}$

Level 3

82. The mass of an electron is 9.1×10^{-31} kg. The mass of a proton is 1.7×10^{-27} kg. An electron and a proton are about 0.59×10^{-10} m apart in a hydrogen atom. What gravitational force exists between the proton and the electron of a hydrogen atom?

$$F = G\frac{m_e m_p}{r^2}$$

$$= \frac{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(9.1\times10^{-31}\ \text{kg})(1.7\times10^{-27}\ \text{kg})}{(1.0\times10^{-10}\ \text{m})^2}$$

$$= 1.0\times10^{-47}\ \text{N}$$

83. Consider two spherical 8.0-kg objects that are 5.0 m apart.

a. What is the gravitational force between the two objects?

$$F = G\frac{m_1 m_2}{r^2}$$

$$= \frac{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(8.0\ \text{kg})(8.0\ \text{kg})}{(5.0\ \text{m})^2}$$

$$= 1.7\times10^{-10}\ \text{N}$$

b. What is the gravitational force between them when they are 5.0×10^{1} m apart?

$$F = G\frac{m_1 m_2}{r^2}$$

$$= \frac{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(8.0\ \text{kg})(8.0\ \text{kg})}{(5.0\times10^{1}\ \text{m})^2}$$

$$= 1.7\times10^{-12}\ \text{N}$$

84. If you weigh 637 N on Earth's surface, how much would you weigh on the planet Mars? Mars has a mass of 6.42×10^{23} kg and a radius of 3.40×10^{6} m.

$$m = \frac{F_g}{g} = \frac{637\ \text{N}}{9.80\ \text{m/s}^2} = 65.0\ \text{kg}$$

$$F = G\frac{m_1 m_2}{r^2}$$

$$= \frac{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(65.0\ \text{kg})(6.37\times10^{23}\ \text{kg})}{(3.43\times10^{6}\ \text{m})^2}$$

$$= 235\ \text{N}$$

85. Using Newton's version of Kepler's third law and information from Table 7-1 on page 173, calculate the period of Earth's Moon if the orbital radius were twice the actual value of 3.9×10^{8} m.

$$T_M = \sqrt{\left(\frac{4\pi^2}{Gm_E}\right)(r^3)}$$

$$= \sqrt{\left(\frac{4\pi^2}{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(5.979\times10^{24}\ \text{kg})}\right)(7.8\times10^{8}\ \text{m})^3}$$

$$= 6.85\times10^{6}\ \text{s or 79 days}$$

86. Find the value of g, acceleration due to gravity, in the following situations.

a. Earth's mass is triple its actual value, but its radius remains the same.

$$g = \frac{Gm_E}{(r_E)^2} = 9.80\ \text{m/s}^2$$

$$2m_E \rightarrow 2g = 2(9.80\ \text{m/s}^2) = 19.6\ \text{m/s}^2$$

b. Earth's radius is tripled, but its mass remains the same.

$$g = \frac{Gm_E}{(r_E)^2} = 9.80\ \text{m/s}^2$$

$$2r_E \rightarrow \frac{g}{4} = \frac{9.80\ \text{m/s}^2}{4} = 2.45\ \text{m/s}^2$$

c. Both the mass and radius of Earth are doubled.

$$g = \frac{Gm_E}{(r_E)^2}$$

$$2m_E \text{ and } 2r_E \rightarrow \frac{2g}{4} = \frac{2(9.80\ \text{m/s}^2)}{4} = 4.90\ \text{m/s}^2$$

87. Astronaut What would be the strength of Earth's gravitational field at a point where an 80.0-kg astronaut would experience a 25.0 percent reduction in weight?

$$F_g = mg = (80.0\ \text{kg})(9.80\ \text{m/s}^2) = 784\ \text{N}$$

$$F_{g,\ \text{reduced}} = (784\ \text{N})(0.750) = 588\ \text{N}$$

$$g_{\text{reduced}} = \frac{F_{g,\ \text{reduced}}}{m} = \frac{588\ \text{N}}{80.0\ \text{kg}} = 7.35\ \text{m/s}^2$$

Mixed Review

pages 193–194

Level 1

88. Use the information for Earth in Table 7-1 on page 173 to calculate the mass of the Sun, using Newton's version of Kepler's third law.

$$T^2 = \left(\frac{4\pi^2}{Gm}\right)r^3,$$

so $mT^2 = \left(\frac{4\pi^2}{G}\right)r^3$ and

$$m = \left(\frac{4\pi^2}{G}\right)\frac{r^3}{T^2}$$

$$= \left(\frac{4\pi^2}{6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2}\right)\frac{(1.50\times10^{11}\ \text{m})^3}{(3.156\times10^7\ \text{s})^2}$$

$$= 2.01\times10^{30}\ \text{kg}$$

89. Earth's gravitational field is 7.83 N/kg at the altitude of the space shuttle. At this altitude, what is the size of the force of attraction between a student with a mass of 45.0 kg and Earth?

$$g = \frac{F}{m}$$

$$F = mg = (45.0\ \text{kg})(7.83\ \text{N/kg}) = 352\ \text{N}$$

90. Use the data from Table 7-1 on page 173 to find the speed and period of a satellite that orbits Mars 175 km above its surface.

$$r = r_M + 175\ \text{km} = 3.40\times10^6\ \text{m} + 0.175\times10^6\ \text{m}$$

$$= 3.58\times10^6\ \text{m}$$

$$v = \sqrt{\frac{GM_M}{r}}$$

$$= \sqrt{\frac{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(6.42\times10^{23}\ \text{kg})}{3.58\times10^6\ \text{m}}}$$

$$= 3.46\times10^3\ \text{m/s}$$

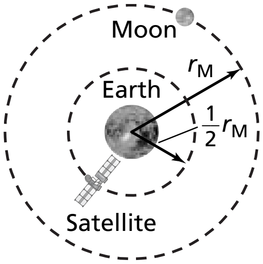
$$T = 2\pi\sqrt{\frac{r^3}{GM_M}}$$

$$= 2\pi\sqrt{\frac{(3.58\times10^6\ \text{m})^3}{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(6.42\times10^{23}\ \text{kg})}}$$

$$= 6.45\times10^3\ \text{s or } 1.79\ \text{h}$$

Level 2

91. Satellite A satellite is placed in orbit, as shown in **Figure 7-26,** with a radius that is half the radius of the Moon's orbit. Find the period of the satellite in units of the period of the Moon.



■ **Figure 7-26**

$$\left(\frac{T_s}{T_M}\right)^2 = \left(\frac{r_s}{r_M}\right)^3$$

$$\text{So, } T_s = \sqrt{\left(\frac{r_s}{r_M}\right)^3 T_M} = \sqrt{\left(\frac{0.50r_M}{r_M}\right)^3 T_M{}^2}$$

$$= \sqrt{0.125T_M{}^2}$$

$$= 0.35T_M$$

92. Cannonball The Moon's mass is 7.3×10^{22} kg and its radius is 1785 km. If Newton's thought experiment of firing a cannonball from a high mountain were attempted on the Moon, how fast would the cannonball have to be fired? How long would it take the cannonball to return to the cannon?

$$v = \sqrt{\frac{Gm}{r}}$$

$$= \sqrt{\frac{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(7.3\times10^{22}\ \text{kg})}{1.785\times10^6\ \text{m}}}$$

$$= 1.7\times10^3\ \text{m/s}$$

$$T = 2\pi\sqrt{\frac{r^3}{Gm}}$$

$$= 2\pi\sqrt{\frac{(1.785\times10^6\ \text{m})^3}{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(7.3\times10^{22}\ \text{kg})}}$$

$$= 6.8\times10^3\ \text{s}$$

93. The period of the Moon is one month. Answer the following questions assuming that the mass of Earth is doubled.

a. What would the period of the Moon be? Express your results in months.

$$T = 2\pi\sqrt{\frac{r^3}{Gm}}$$

So, if Earth's mass were doubled, but the radius remained the same, then the period would be reduced by a factor of $\frac{1}{\sqrt{2}}$, or 0.707 months.

b. Where would a satellite with an orbital period of one month be located?

$$\left(\frac{T}{2\pi}\right)^2 = \frac{r^3}{Gm}$$

$$r^3 = \left(\frac{T}{2\pi}\right)^2(Gm)$$

Thus, r^3 would be doubled, or r would be increased by $2^{\frac{1}{3}} = 1.26$ times the present radius of the Moon.

c. How would the length of a year on Earth be affected?

The length of a year on Earth would not be affected. It does not depend on Earth's mass.

Level 3

94. How fast would a planet of Earth's mass and size have to spin so that an object at the equator would be weightless? Give the period of rotation of the planet in minutes.

The centripetal acceleration must equal the acceleration due to gravity so that the surface of the planet would not have to supply any force (otherwise known as weight).

$$\frac{mv^2}{r} = G\frac{m_Em}{r^2}$$

$$v = \sqrt{\frac{Gm_E}{r}}$$

But, $v = \frac{2\pi r}{T}$, **so** $T = \frac{2\pi r}{v} = \frac{2\pi r}{\sqrt{\frac{Gm_E}{r}}}$

$$= 2\pi\sqrt{\frac{r^3}{Gm_E}}$$

$$= 2\pi\sqrt{\frac{(6.38\times10^6\ \text{m})^3}{(6.67\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2)(5.97\times10^{24}\ \text{kg})}}$$

$$= 5.07\times10^3\ \text{s} = 84.5\ \text{min}$$

95. Car Races Suppose that a Martian base has been established and car races are being considered. A flat, circular race track has been built for the race. If a car can achieve speeds of up to 12 m/s, what is the smallest radius of a track for which the coefficient of friction is 0.50?

The force that causes the centripetal acceleration is the static friction force:

$$F_{static} \leq \mu_s mg$$

The centripetal acceleration is $a_c = \frac{v^2}{r}$

So, $\frac{mv^2}{r} \leq \mu_s mg$

Thus, $r \geq \frac{v^2}{\mu_s g}$

Note that $g = \frac{Gm}{(r_{planet})^2}$

To find g on Mars, the following calculation is used.

$m_{Mars} = 6.37\times10^{23}$ kg, and $R_{Mars} = 3.43\times10^{6}$ m

So, $g_{Mars} = 3.61$ m/s^2

Therefore, $R \geq \frac{(12\text{ m/s})^2}{(0.50)(3.61\text{ m/s}^2)}$

$R \geq 8.0\times10^{1}$ m

96. ***Apollo 11*** On July 19, 1969, *Apollo 11's* revolution around the Moon was adjusted to an average orbit of 111 km. The radius of the Moon is 1785 km, and the mass of the Moon is 7.3×10^{22} kg.

a. How many minutes did *Apollo 11* take to orbit the Moon once?

$r_{orbit} = 1785\times10^{3}\text{ m} + 111\times10^{3}\text{ m}$

$$T = 2\pi\sqrt{\frac{r^3}{Gm}}$$

$$= 2\pi\sqrt{\frac{(1896\times10^{3}\text{ m})^3}{(6.67\times10^{-11}\text{ N·m}^2/\text{kg}^2)(7.3\times10^{22}\text{ kg})}}$$

$$= 7.4\times10^{3}\text{ s}$$

$$= 1.2\times10^{2}\text{ min}$$

b. At what velocity did *Apollo 11* orbit the Moon?

$$v = \sqrt{\frac{Gm}{r_{orbit}}}$$

$$= \sqrt{\frac{(6.67\times10^{-11}\text{ N·m}^2/\text{kg}^2)(7.3\times10^{22}\text{ kg})}{1896\times10^{3}\text{ m}}}$$

$$= 1.6\times10^{3}\text{ m/s}$$

Thinking Critically

page 194

97. Analyze and Conclude Some people say that the tides on Earth are caused by the pull of the Moon. Is this statement true?

a. Determine the forces that the Moon and the Sun exert on a mass, *m,* of water on Earth. Your answer will be in terms of *m* with units of N.

$$F_{S,\,m} = 6.67\times10^{-11}\text{ N·m}^2/\text{kg}^2\left(\frac{(1.99\times10^{30}\text{ kg})(m)}{(1.50\times10^{11}\text{ m})^2}\right)$$

$$= (5.90\times10^{-3}\text{ N})m$$

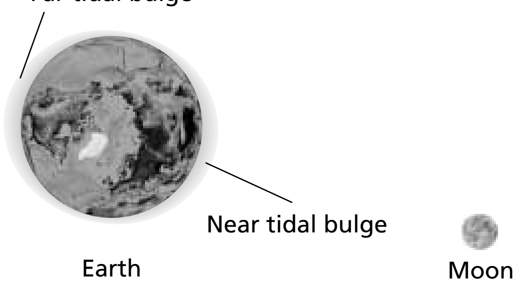
$$F_{M,\,m} = 6.67\times10^{-11}\text{ N·m}^2/\text{kg}^2\left(\frac{(7.36\times10^{22}\text{ kg})(m)}{(3.80\times10^{8}\text{ m})^2}\right)$$

$$= (3.40\times10^{-5}\text{ N})m$$

b. Which celestial body, the Sun or the Moon, has a greater pull on the waters of Earth?

The Sun pulls approximately 100 times stronger on the waters of Earth.

c. Determine the difference in force exerted by the Moon on the water at the near surface and the water at the far surface (on the opposite side) of Earth, as illustrated in **Figure 7-27.** Again, your answer will be in terms of *m* with units of N.



■ **Figure 7-27** (Not to scale)

$$F_{m,\,mA} - F_{m,\,mB} = (6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(7.36\times10^{22}\ \text{kg})(m)\left(\frac{1}{(3.80\times10^{8}\ \text{m} - 6.37\times10^{6}\ \text{m})^2} - \frac{1}{(3.80\times10^{8}\ \text{m} + 6.37\times10^{6}\ \text{m})^2}\right)$$

$$= (2.28\times10^{-6}\ \text{N})m$$

d. Determine the difference in force exerted by the Sun on water at the near surface and on water at the far surface (on the opposite side) of Earth.

$$F_{S,\,mA} - F_{S,\,mB} = (6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(1.99\times10^{30}\ \text{kg})(m)\left(\frac{1}{(1.50\times10^{11}\ \text{m} - 6.37\times10^{6}\ \text{m})^2} - \frac{1}{(1.50\times10^{11}\ \text{m} + 6.37\times10^{6}\ \text{m})^2}\right)$$

$$= (1.00\times10^{-6}\ \text{N})m$$

e. Which celestial body has a greater difference in pull from one side of Earth to the other?

the Moon

f. Why is the statement that the tides result from the pull of the Moon misleading? Make a correct statement to explain how the Moon causes tides on Earth.

The tides are primarily due to the difference between the pull of the Moon on Earth's near side and Earth's far side.

98. Make and Use Graphs Use Newton's law of universal gravitation to find an equation where *x* is equal to an object's distance from Earth's center, and *y* is its acceleration due to gravity. Use a graphing calculator to graph this equation, using 6400–6600 km as the range for *x* and 9–10 m/s^2 as the range for *y*. The equation should be of the form $y = c(1/x^2)$. Trace along this graph and find *y* for the following locations.

a. at sea level, 6400 km

$c = (Gm_E)(10^6\ \text{m}^2/\text{km}^2) = 4.0\times10^8$ **units**

acc = 9.77 m/s^2

b. on top of Mt. Everest, 6410 km

9.74 m/s^2

c. in a typical satellite orbit, 6500 km

9.47 m/s^2

d. in a much higher orbit, 6600 km

9.18 m/s^2

Writing in Physics

page 194

99. Research and describe the historical development of the measurement of the distance between the Sun and Earth.

One of the earliest crude measurements was made by James Bradley in 1732. The answers also should discuss measurements of the transits of Venus done in the 1690s.

100. Explore the discovery of planets around other stars. What methods did the astronomers use? What measurements did they take? How did they use Kepler's third law?

Astronomers measure the star's tiny velocity due to the gravitational force exerted on it by a massive planet. The velocity is calculated by measuring the Doppler shift of the star's light that results from that motion. The velocity oscillates back and forth as the planets orbit the star, allowing calculation of the planet's period. From the size of the velocity they can estimate the planet's distance and mass. By comparing the distances and periods of planets in solar systems with multiple planets and using Kepler's third law, astronomers can better separate the distances and masses of stars and planets.

Cumulative Review

page 194

101. Airplanes A jet airplane took off from Pittsburgh at 2:20 P.M. and landed in Washington, DC, at 3:15 P.M. on the same day. If the jet's average speed while in the air was 441.0 km/h, what is the distance between the cities? (Chapter 2)

$\Delta t = 55 \text{ min} = 0.917 \text{ h}$

$\bar{v} = \frac{\Delta d}{\Delta t}$

$\Delta d = \bar{v}\Delta t$

$= (441.0 \text{ km/h})(0.917 \text{ h})$

$= 404 \text{ km}$

102. Carolyn wants to know how much her brother Jared weighs. He agrees to stand on a scale for her, but only if they are riding in an elevator. If he steps on the scale while the elevator is accelerating upward at 1.75 m/s^2 and the scale reads 716 N, what is Jared's usual weight on Earth? (Chapter 4)

Identify Jared as the system and upward as positive.

$F_{\text{net}} = F_{\text{scale on Jared}} - F_{\text{Earth's mass on Jared}}$

$= ma$

$$F_{\text{scale on Jared}} = F_{\text{Earth's mass on Jared}} + \left(\frac{F_{\text{Earth's mass on Jared}}}{g}\right)a$$
$$= F_{\text{Earth's mass on Jared}}\left(1 + \frac{a}{g}\right)$$

$$F_{\text{Earth's mass on Jared}} = \frac{F_{\text{scale on Jared}}}{\left(1 + \frac{a}{g}\right)}$$
$$= \frac{716\text{ N}}{\left(1 + \frac{1.75\text{ m/s}^2}{9.80\text{ m/s}^2}\right)}$$
$$= 608\text{ N}$$

103. Potato Bug A 1.0-g potato bug is walking around the outer rim of an upside-down flying disk. If the disk has a diameter of 17.2 cm and the bug moves at a rate of 0.63 cm/s, what is the centripetal force acting on the bug? What agent provides this force? (Chapter 6)

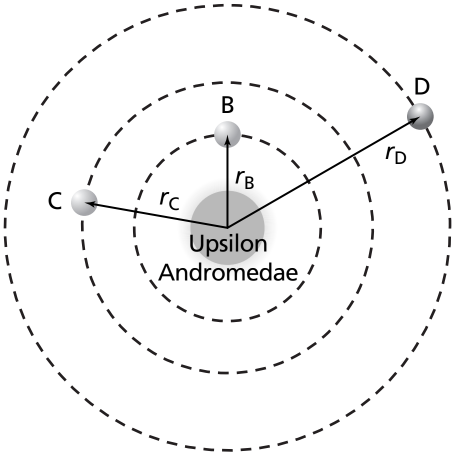
$$F_c = \frac{mv^2}{r} = \frac{(0.0010\text{ kg})(0.0063\text{ cm})^2}{0.086\text{ m}} = 5.0\times10^{-7}\text{ N,}$$

provided by the frictional force between the bug and the flying disk

Challenge Problem

page 176

Astronomers have detected three planets that orbit the star Upsilon Andromedae. Planet B has an average orbital radius of 0.059 AU and a period of 4.6170 days. Planet C has an average orbital radius of 0.829 AU and a period of 241.5 days. Planet D has an average orbital radius of 2.53 AU and a period of 1284 days. (Distances are given in astronomical units (AU)—Earth's average distance from the Sun. The distance from Earth to the Sun is 1.00 AU.)



1. Do these planets obey Kepler's third law?

Test by calculating the following ratio $\frac{r^3}{T^2}$.

For planet B, $\frac{{r_B}^3}{{T_B}^2} = \frac{(0.059\text{ AU})^3}{(4.6170\text{ days})^2} = 9.6\times10^{-6}\text{ AU}^3/\text{days}^2$

For planet C, $\frac{r_C^{\,3}}{T_C^{\,2}} = \frac{(0.829\ \text{AU})^3}{(241.5\ \text{days})^2} = 9.77\times10^{-6}\ \text{AU}^3/\text{days}^2$

For planet D, $\frac{r_D^{\,3}}{T_D^{\,2}} = \frac{(2.53\ \text{AU})^3}{(1284\ \text{days})^2} = 9.82\times10^{-6}\ \text{AU}^3/\text{days}^2$

These values are quite close, so Kepler's third law is obeyed.

2. Find the mass of the star Upsilon Andromedae in units of the Sun's mass.

$$\frac{r^3}{T^2} = \frac{Gm_{\text{central body}}}{4\pi^2}$$

For the Earth-Sun system, $\frac{r^3}{T^2} = \frac{(1.000\ \text{AU})^3}{(1.000\ \text{y})^2} = 1.000\ \text{AU}^3/\text{y}^2$

For the planet C-Upsilon system,

$$\frac{r^3}{T^2} = 9.77\times10^{-6}\ \text{AU}^3/\text{days}^2$$

$$= (9.77\times10^{-6}\ \text{AU}^3/\text{days}^2)(365\ \text{days/y})^2 = 1.30\ \text{AU}^3/\text{y}^2$$

$$= \frac{Gm_{\text{star}}}{4\pi^2}$$

The ratio of the two shows the star's slightly heavier mass to be 1.30 that of the Sun.

CHAPTER

8 Rotational Motion

Practice Problems

8.1 Describing Rotational Motion pages 197–200

page 200

1. What is the angular displacement of each of the following hands of a clock in 1 h? State your answer in three significant digits.

a. the second hand

$\Delta\theta = (60)(-2\pi \text{ rad})$

$= -120\pi \text{ rad or } -377 \text{ rad}$

b. the minute hand

$\Delta\theta = -2\pi \text{ rad or } -6.28 \text{ rad}$

c. the hour hand

$\Delta\theta = \left(\frac{1}{12}\right)(-2\pi \text{ rad})$

$= \frac{-\pi}{6} \text{ rad or } 0.524 \text{ rad}$

2. If a truck has a linear acceleration of 1.85 m/s^2 and the wheels have an angular acceleration of 5.23 rad/s^2, what is the diameter of the truck's wheels?

$r = \frac{a}{\alpha}$

$= \frac{1.85 \text{ m/s}^2}{5.23 \text{ rad/s}^2}$

$= 0.354 \text{ m}$

Thus, the diameter is 0.707 m.

3. The truck in the previous problem is towing a trailer with wheels that have a diameter of 48 cm.

a. How does the linear acceleration of the trailer compare with that of the truck?

The changes in velocity are the same, so the linear accelerations are the same.

b. How do the angular accelerations of the wheels of the trailer and the wheels of the truck compare?

Because the radius of the wheel is reduced from 35.4 cm to 24 cm, the angular acceleration will be increased.

$\alpha_1 = 5.23 \text{ rad/s}^2$

$\alpha_2 = \frac{a_2}{r} = \frac{1.85 \text{ m/s}^2}{0.24 \text{ m}}$

$= 7.7 \text{ rad/s}^2$

4. You want to replace the tires on your car with tires that have a larger diameter. After you change the tires, for trips at the same speed and over the same distance, how will the angular velocity and number of revolutions change?

Because $\omega = \frac{v}{r}$, if r is increased, ω will decrease. The number of revolutions will also decrease.

Section Review

8.1 Describing Rotational Motion pages 197–200

page 200

5. Angular Displacement A movie lasts 2 h. During that time, what is the angular displacement of each of the following?

a. the hour hand

$\Delta\theta = \left(\frac{1}{6}\right)(-2\pi \text{ rad}) = \frac{-\pi}{3} \text{ rad}$

b. the minute hand

$\Delta\theta = (2)(-2\pi \text{ rad}) = -4\pi \text{ rad}$

6. Angular Velocity The Moon rotates once on its axis in 27.3 days. Its radius is 1.74×10^6 m.

a. What is the period of the Moon's rotation in seconds?

period = (27.3 day)(24 h/day)(3600 s/h)

$$= 2.36\times10^{6} \text{ s}$$

b. What is the frequency of the Moon's rotation in rad/s?

$$\omega = \frac{1}{\text{period}}$$

$$= \frac{1}{2.36\times10^{6}} \text{ rev/s, or}$$

$$2.66\times10^{-6} \text{ rad/s}$$

c. What is the linear speed of a rock on the Moon's equator due only to the Moon's rotation

$$v = r\omega$$

$$= (1.74\times10^{6} \text{ m})(2.66\times10^{-6} \text{ rad/s})$$

$$= 4.63 \text{ m/s}$$

d. Compare this speed with the speed of a person on Earth's equator due to Earth's rotation.

The speed on Earth's equator is 464 m/s, or about 100 times faster.

7. Angular Displacement The ball in a computer mouse is 2.0 cm in diameter. If you move the mouse 12 cm, what is the angular displacement of the ball?

$$d = r\theta$$

$$\text{so } \theta = \frac{d}{r} = \frac{12 \text{ cm}}{1.0 \text{ cm}} = 12 \text{ rad}$$

8. Angular Displacement Do all parts of the minute hand on a watch have the same angular displacement? Do they move the same linear distance? Explain.

angular displacement—yes; linear distance—no, because linear distance is a function of the radius

9. Angular Acceleration In the spin cycle of a clothes washer, the drum turns at 635 rev/min. If the lid of the washer is opened, the motor is turned off. If the drum requires 8.0 s to slow to a stop, what is the angular acceleration of the drum?

$$\omega_i = 635 \text{ rpm} = 66.53 \text{ rad/s}$$

$$\omega_f = 0.0, \text{ so } \Delta\omega = -66.5 \text{ rad/s}$$

$$\text{and } \alpha = \frac{\Delta\omega}{\Delta t} = \frac{-66.5 \text{ rad/s}}{8.0 \text{ s}} = -8.3 \text{ rad/s}^2$$

10. Critical Thinking A CD-ROM has a spiral track that starts 2.7 cm from the center of the disk and ends 5.5 cm from the center. The disk drive must turn the disk so that the linear velocity of the track is a constant 1.4 m/s. Find the following.

a. the angular velocity of the disk (in rad/s and rev/min) for the start of the track

$$\omega = \frac{v}{r}$$

$$= \frac{1.4 \text{ m/s}}{0.027 \text{ m}}$$

$$= 52 \text{ rad/s or } 5.0\times10^{2} \text{ rev/min}$$

b. the disk's angular velocity at the end of the track

$$\omega = \frac{v}{r}$$

$$= \frac{1.4 \text{ m/s}}{0.055 \text{ m}}$$

$$= 25 \text{ rad/s or } 2.4\times10^{2} \text{ rev/min}$$

c. the disk's angular acceleration if the disk is played for 76 min

$$\alpha = \frac{\Delta\omega}{\Delta t} = \frac{\omega_f - \omega_i}{\Delta t}$$

$$= \frac{-25 \text{ rad/s} - 52 \text{ rad/s}}{(76 \text{ min})(60 \text{ s/min})}$$

$$= -5.9\times10^{-3} \text{ rad/s}^2$$

Practice Problems

8.2 Rotational Dynamics pages 201–210

page 203

11. Consider the wrench in Example Problem 1. What force is needed if it is applied to the wrench at a point perpendicular to the wrench?

$\tau = Fr \sin\theta$

so $F = \dfrac{\tau}{r \sin\theta}$

$= \dfrac{35\ \text{N·m}}{(0.25\ \text{m})(\sin 90.0°)}$

$= 1.4\times10^{2}\ \text{N}$

12. If a torque of 55.0 N·m is required and the largest force that can be exerted by you is 135 N, what is the length of the lever arm that must be used?

For the shortest possible lever arm, θ = 90.0°.

$\tau = Fr \sin\theta$

so $r = \dfrac{\tau}{F \sin\theta}$

$= \dfrac{55.0\ \text{N·m}}{(135\ \text{N})(\sin 90.0°)}$

$= 0.407\ \text{m}$

13. You have a 0.234-m-long wrench. A job requires a torque of 32.4 N·m, and you can exert a force of 232 N. What is the smallest angle, with respect to the vertical, at which the force can be exerted?

$\tau = Fr \sin\theta$

so $\theta = \sin^{-1}\left(\dfrac{\tau}{Fr}\right)$

$= \sin^{-1}\left(\dfrac{32.4\ \text{N·m}}{(232\ \text{N})(0.234\ \text{m})}\right)$

$= 36.6°$

14. You stand on the pedal of a bicycle. If you have a mass of 65 kg, the pedal makes an angle of 35° above the horizontal, and the pedal is 18 cm from the center of the chain ring, how much torque would you exert?

The angle between the force and the radius is 90° − 35° = 55°.

$\tau = Fr \sin\theta$

$= mgr \sin\theta$

$= (65\ \text{kg})(9.80\ \text{m/s}^2)(0.18\ \text{m})(\sin 55°)$

$= 94\ \text{N·m}$

15. If the pedal in problem 14 is horizontal, how much torque would you exert? How much torque would you exert when the pedal is vertical?

Horizontal θ = 90.0°

so $\tau = Fr \sin\theta$

$= mgr \sin\theta$

$= (65\ \text{kg})(9.80\ \text{m/s}^2)(0.18\ \text{m})(\sin 90.0°)$

$= 1.1\times10^{2}\ \text{N·m}$

Vertical θ = 0.0°

So $\tau = Fr \sin\theta$

$= mgr \sin\theta$

$= (65\ \text{kg})(9.80\ \text{m/s}^2)(0.18\ \text{m})(\sin 0.0°)$

$= 0.0\ \text{N·m}$

page 205

16. Ashok, whose mass is 43 kg, sits 1.8 m from the center of a seesaw. Steve, whose mass is 52 kg, wants to balance Ashok. How far from the center of the seesaw should Steve sit?

$F_A r_A = F_S r_S$

so $r_S = \dfrac{F_A r_A}{F_S}$

$= \dfrac{m_A g r_A}{m_S g}$

$= \dfrac{m_A r_A}{m_S}$

$= \dfrac{(43\ \text{kg})(1.8\ \text{m})}{52\ \text{kg}}$

$= 1.5\ \text{m}$

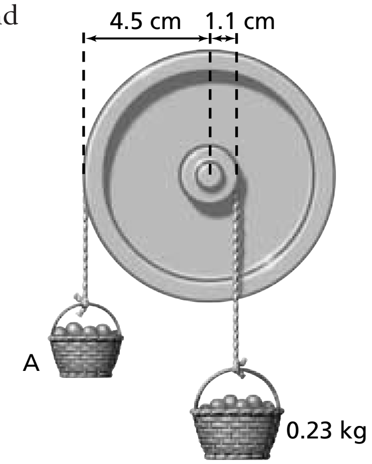
17. A bicycle-chain wheel has a radius of 7.70 cm. If the chain exerts a 35.0-N force on the wheel in the clockwise direction, what torque is needed to keep the wheel from turning?

$\tau_{chain} = F_g r$

$= (-35.0\ N)(0.0770\ m)$
$= -2.70\ N{\cdot}m$

Thus, a torque of +2.70 N·m must be exerted to balance this torque.

18. Two baskets of fruit hang from strings going around pulleys of different diameters, as shown in **Figure 8-6.** What is the mass of basket A?



■ **Figure 8-6**

$\tau_1 = \tau_2$

$F_1 r_1 = F_2 r_2$

$m_1 g r_1 = m_2 g r_2$

$m_1 = \frac{m_2 r_2}{r_1}$

$= \frac{(0.23\ kg)(1.1\ cm)}{4.5\ cm}$

$= 0.056\ kg$

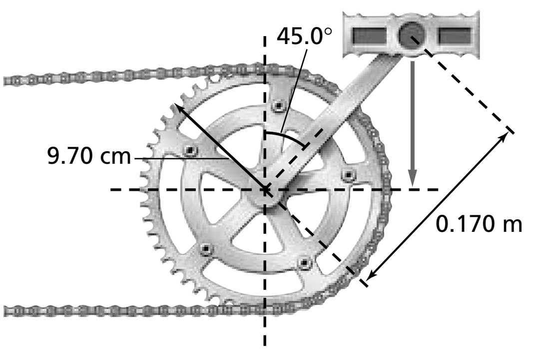
19. Suppose the radius of the larger pulley in problem 18 was increased to 6.0 cm. What is the mass of basket A now?

$m_1 = \frac{m_2 r_2}{r_1}$

$= \frac{(0.23\ kg)(1.1\ cm)}{6.0\ cm}$

$= 0.042\ kg$

20. A bicyclist, of mass 65.0 kg, stands on the pedal of a bicycle. The crank, which is 0.170 m long, makes a 45.0° angle with the vertical, as shown in **Figure 8-7.** The crank is attached to the chain wheel, which has a radius of 9.70 cm. What force must the chain exert to keep the wheel from turning?



■ **Figure 8-7**

$\tau_{cr} = -\tau_{ch}$

$F_{cr} r_{cr} \sin \theta = -F_{ch} r_{ch}$

so $F_{ch} = \frac{-F_{cr} r_{cr} \sin \theta}{r_{ch}}$

$= \frac{-mg r_{cr} \sin \theta}{r_{ch}}$

$= \frac{-(65.0\ kg)(9.80\ m/s^2)(0.170\ m)(\sin 45.0°)}{0.097\ m}$

$= 789\ N$

page 208

21. Two children of equal masses sit 0.3 m from the center of a seesaw. Assuming that their masses are much greater than that of the seesaw, by how much is the moment of inertia increased when they sit 0.6 m from the center?

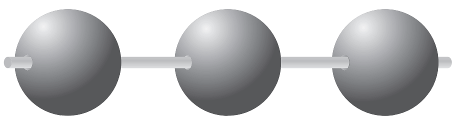
For the mass of the two children, $I = mr^2 + mr^2 = 2mr^2$.

When r is doubled, I is multiplied by a factor of 4.

22. Suppose there are two balls with equal diameters and masses. One is solid, and the other is hollow, with all its mass distributed at its surface. Are the moments of inertia of the balls equal? If not, which is greater?

The more of the mass that is located far from the center, the greater the moment of inertia. Thus, the hollow ball has a greater value of I.

23. **Figure 8-9** shows three massive spheres on a rod of very small mass. Consider the moment of inertia of the system, first when it is rotated about sphere A, and then when it is rotated about sphere C. Are the moments of inertia the same or different? Explain. If the moments of inertia are different, in which case is the moment of inertia greater?



■ **Figure 8-9**

The moments of inertia are different. If the spacing between spheres is r and each sphere has mass m, then rotation about sphere A is

$I = mr^2 + m(2r)^2 = 5mr^2$.

Rotation about sphere C is

$I = mr^2 + mr^2 = 2mr^2$.

The moment of inertia is greater when rotating around sphere A.

24. Each sphere in the previous problem has a mass of 0.10 kg. The distance between spheres A and C is 0.20 m. Find the moment of inertia in the following instances: rotation about sphere A, rotation about sphere C.

About sphere A:

$$I = mr^2 + m(2r)^2$$
$$= 5mr^2$$
$$= (5)(0.10\text{ kg})(0.20\text{ m})^2$$
$$= 0.020\text{ kg·m}^2$$

About sphere C:

$$I = mr^2 + mr^2$$
$$= 2mr^2$$
$$= (2)(0.10\text{ kg})(0.20\text{ m})^2$$
$$= 0.0080\text{ kg·m}^2$$

page 210

25. Consider the wheel in Example Problem 4. If the force on the strap were twice as great, what would be the speed of rotation of the wheel after 15 s?

Torque is now twice as great. The angular acceleration is also twice as great, so the change in angular velocity is twice as great. Thus, the final angular velocity is 32π rad/s, or 16 rev/s.

26. A solid wheel accelerates at 3.25 rad/s^2 when a force of 4.5 N exerts a torque on it. If the wheel is replaced by a wheel with all of its mass on the rim, the moment of inertia is given by $I = mr^2$. If the same angular velocity were desired, what force would have to be exerted on the strap?

The angular acceleration has not changed, but the moment of inertia is twice as great. Therefore, the torque must be twice as great. The radius of the wheel is the same, so the force must be twice as great, or 9.0 N.

27. A bicycle wheel can be accelerated either by pulling on the chain that is on the gear or by pulling on a string wrapped around the tire. The wheel's radius is 0.38 m, while the radius of the gear is 0.14 m. If you obtained the needed acceleration with a force of 15 N on the chain, what force would you need to exert on the string?

The torque on the wheek comes from either the chain or the string.

$$\tau_{\text{chain}} = I_{\text{wheel}}\alpha_{\text{wheel}}$$

$$\tau_{\text{wheel}} = I_{\text{wheel}}\alpha_{\text{wheel}}$$

Thus, $\tau_{\text{chain}} = \tau_{\text{wheel}}$

$$F_{\text{chain}}r_{\text{gear}} = F_{\text{string}}r_{\text{wheel}}$$

$$F_{\text{string}} = \frac{F_{\text{chain}}r_{\text{gear}}}{r_{\text{wheel}}}$$

$$= \frac{(15\text{ N})(0.14\text{ m})}{0.38\text{ m}}$$

$$= 5.5\text{ N}$$

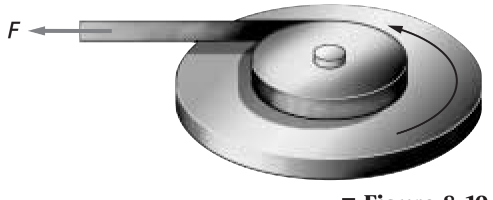
28. The bicycle wheel in problem 27 is used with a smaller gear whose radius is 0.11 m. The wheel can be accelerated either by pulling on the chain that is on thegear or by pulling string that is wrapped around the tire. If you obtained the needed acceleration with a force of 15 N on the chain, what force would you need to exert on the string?

$$F_{\text{string}} = \frac{F_{\text{chain}}r_{\text{gear}}}{r_{\text{wheel}}}$$

$$= \frac{(15\text{ N})(0.11\text{ m})}{0.38\text{ m}}$$

$$= 4.3\text{ N}$$

29. A disk with a moment of inertia of 0.26 kg·m^2 is attached to a smaller disk mounted on the same axle. The smaller disk has a diameter of 0.180 m and a mass of 2.5 kg. A strap is wrapped around the smaller disk, as shown in **Figure 8-10.** Find the force needed to give this system an angular acceleration of 2.57 rad/s^2.



■ **Figure 8-10**

$$\alpha = \frac{\tau}{I} = \frac{Fr}{I}$$

$$\text{so } F = \frac{I\alpha}{r}$$

$$= \frac{(I_{\text{small}} + I_{\text{large}})\alpha}{r}$$

$$= \frac{\left(\frac{1}{2}m_{\text{small}}r_{\text{small}}^2 + I_{\text{large}}\right)\alpha}{r}$$

$$= \frac{\left(\left(\frac{1}{2}\right)(2.5\text{ kg})(0.090\text{ m})^2 + 0.26\text{ kg·m}^2\right)(2.57\text{ rad/s}^2)}{0.090\text{ m}}$$

$$= 7.7\text{ N}$$

Section Review

8.2 Rotational Dynamics pages 201–210

page 210

30. Torque Vijesh enters a revolving door that is not moving. Explain where and how Vijesh should push to produce a torque with the least amount of force.

To produce a torque with the least force, you should push as close to the edge as possible and at right angles to the door.

31. Lever Arm You try to open a door, but you are unable to push at a right angle to the door. So, you push the door at an angle of 55° from the perpendicular. How much harder would you have to push to open the door just as fast as if you were to push it at 90°?

The angle between the force and the radius is 35°. Torque is $\tau = Fr \sin \theta$. Because $\sin 90° = 1$, and $\sin 35° = 0.57$, you would have to increase the force by a ratio of $\frac{1}{0.57} = 1.75$ to obtain the same torque.

32. Net Torque Two people are pulling on ropes wrapped around the edge of a large wheel. The wheel has a mass of 12 kg and a diameter of 2.4 m. One person pulls in a clockwise direction with a 43-N force, while the other pulls in a counterclockwise direction with a 67-N force. What is the net torque on the wheel?

$$\tau_{net} = \tau_1 + \tau_2$$
$$= F_1 r + F_2 r$$
$$= (F_1 + F_2)\left(\frac{1}{2}d\right)$$
$$= (-43\text{ N} + 67\text{ N})\left(\frac{1}{2}\right)(2.4\text{ m})$$
$$= 29\text{ N·m}$$

33. Moment of Inertia Refer to **Table 8-2** on page 206 and rank the moments of inertia from least to greatest of the following objects: a sphere, a wheel with almost all of its mass at the rim, and a solid disk. All have equal masses and diameters. Explain the advantage of using the one with the least moment of inertia.

from least to greatest: sphere $\left(\frac{2}{5}mr^2\right)$, solid disk $\left(\frac{1}{2}mr^2\right)$, wheel ($mr^2$)

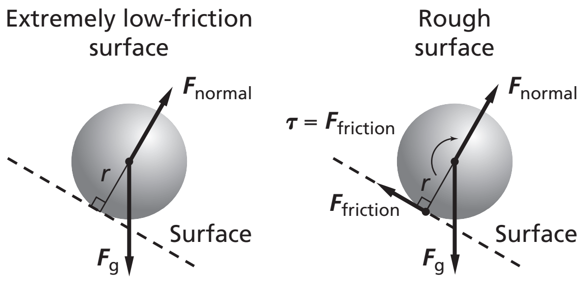
The less the moment of inertia, the less torque needed to give an object the same angular acceleration.

34. Newton's Second Law for Rotational Motion A rope is wrapped around a pulley and pulled with a force of 13.0 N. The pulley's radius is 0.150 m. The pulley's rotational speed goes from 0.0 to 14.0 rev/min in 4.50 s. What is the moment of inertia of the pulley?

$$I = \frac{\tau}{\alpha}$$
$$= \frac{Fr}{\frac{\Delta\omega}{\Delta t}}$$
$$= \frac{Fr\Delta t}{\omega_f - \omega_i}$$
$$= \frac{(13.0\text{ N})(0.150\text{ m})(4.50\text{ s})}{\left(14.0\ \frac{\text{rev}}{\text{min}} - 0.0\ \frac{\text{rev}}{\text{min}}\right)\left(\frac{2\pi\text{ rad}}{\text{rev}}\right)\left(\frac{\text{min}}{60\text{ s}}\right)}$$
$$= 5.99\text{ kg·m}^2$$

35. Critical Thinking A ball on an extremely low-friction, tilted surface, will slide downhill without rotating. If the surface is rough, however, the ball will roll. Explain why, using a free-body diagram.

Torque: $\tau = Fr \sin \theta$. The force is due to friction, and the torque causes the ball to rotate clockwise. If the surface is friction-free, then there is no force parallel to the surface, no torque, and thus no rotation. Remember, forces acting on the pivot point (the center of the ball) are ignored.



Practice Problems

8.3 Equilibrium pages 211–217

page 215

36. What would be the forces exerted by the two sawhorses if the ladder in Example Problem 5 had a mass of 11.4 kg?

Because no distances have changed, the equations are still valid:

$$F_B = \frac{r_g mg}{r_B}$$

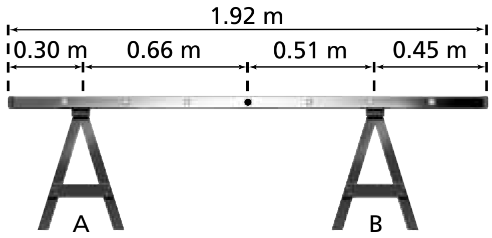
$$F_B = \frac{(0.30\text{ m})(11.4\text{ kg})(9.80\text{ m/s}^2)}{1.05\text{ m}} = 32\text{ N}$$

$$F_A = mg\left(1 - \frac{r_g}{r_B}\right)$$

$$= (11.4\text{ kg})(9.80\text{ m/s}^2)\left(1 - \frac{0.30\text{ m}}{1.05\text{ m}}\right)$$

$$= 8.0\times10^1\text{ N}$$

37. A 7.3-kg ladder, 1.92 m long, rests on two sawhorses, as shown in **Figure 8-15.** Sawhorse A, on the left, is located 0.30 m from the end, and sawhorse B, on the right, is located 0.45 m from the other end. Choose the axis of rotation to be the center of mass of the ladder.



■ **Figure 8-15**

a. What are the torques acting on the ladder?

clockwise: $\tau_A = F_A r_A$

$$= -F_A(0.96\text{ m} - 0.30\text{ m})$$

$$= -(0.66\text{ m})F_A$$

counterclockwise:

$$\tau_B = F_B r_B$$

$$= F_B(0.96\text{ m} - 0.45\text{ m})$$

$$= (0.51\text{ m})F_B$$

b. Write the equation for rotational equilibrium.

$$\tau_{net} = \tau_A + \tau_B = 0$$

so $\tau_B = -\tau_A$

$$(0.51\text{ m})F_B = -(-(0.66\text{ m})F_A)$$

$$(0.51\text{ m})F_B = (0.66\text{ m})F_A$$

c. Solve the equation for F_A in terms of F_g.

$$F_g = F_A + F_B$$

thus, $F_A = F_g - F_B$

$$= F_g - \frac{(0.66\text{ m})F_A}{0.51\text{ m}}$$

or $F_A = \dfrac{F_g}{1 + \frac{0.66\text{ m}}{0.51\text{ m}}}$

$$= \frac{ma}{1 + \frac{0.66\text{ m}}{0.51\text{ m}}}$$

$$= \frac{(7.3\text{ kg})(9.80\text{ m/s}^2)}{1 + \frac{0.66\text{ m}}{0.51\text{ m}}}$$

$$= 31\text{ N}$$

d. How would the forces exerted by the two sawhorses change if A were moved very close to, but not directly under, the center of mass?

F_A would become greater, and F_B would be less.

38. A 4.5-m-long wooden plank with a 24-kg mass is supported in two places. One support is directly under the center of the board, and the other is at one end. What are the forces exerted by the two supports?

Pick the center of mass of the board as the pivot. The unsupported end exerts no torque, so the supported end does not have to exert any torque. Therefore, all the force is exerted by the center support. That force is equal to the weight of the board:

$$F_{center} = F_g = (24\ kg)(9.80\ m/s^2)$$
$$= 2.4\times10^2\ N$$

$$F_{end} = 0\ N$$

39. A 85-kg diver walks to the end of a diving board. The board, which is 3.5 m long with a mass of 14 kg, is supported at the center of mass of the board and at one end. What are the forces on the two supports?

Choose the center of mass of the board as the pivot. The force of Earth's gravity on the board is exerted totally on the support under the center of mass.

$$\tau_{end} = -\tau_{diver}$$

$$F_{end}r_{end} = -F_{diver}r_{diver}$$

Thus, $F_{end} = \frac{-F_{diver}r_{diver}}{r_{end}}$

$$= \frac{-m_{diver}gr_{diver}}{r_{end}}$$

$$= \frac{-(85\ kg)(9.80\ m/s^2)(1.75\ m)}{1.75\ m}$$

$$= -8.3\times10^2\ N$$

To find the force on the center support, notice that because the board is not moving,

$$F_{end} + F_{center} = F_{diver} + F_g$$

Thus, $F_{center} = F_{diver} + F_g - F_{end}$

$$= 2F_{diver} + F_g$$

$$= 2m_{diver}g + m_{board}g$$

$$= g(2m_{diver}g + m_{board})$$

$$= (9.80\ m/s^2)(2(85\ kg) + 14\ kg)$$

$$= 1.8\times10^3\ N$$

Section Review

8.3 Equilibrium pages 211–217

page 217

40. Center of Mass Can the center of mass of an object be located in an area where the object has no mass? Explain.

Yes, an object moves as if all its mass is concentrated at the center of mass. There is nothing in the definition that requires any or all of the object's mass to be at that location.

41. Stability of an Object Why is a modified vehicle with its body raised high on risers less stable than a similar vehicle with its body at normal height?

The center of mass of the vehicle will be raised, but the size of its base will not be increased. Therefore, it needs to be tipped at a smaller angle to get the center of mass outside the base of the vehicle.

42. Conditions for Equilibrium Give an example of an object for each of the following conditions.

a. rotational equilibrium, but not translational equilibrium

a book that is dropped so it falls without rotating

b. translational equilibrium, but not rotational equilibrium

a seesaw that is not balanced and rotates until one person's feet hit the ground

43. Center of Mass Where is the center of mass of a roll of masking tape?

It is in the middle of the roll, in the open space.

44. Locating the Center of Mass Describe how you would find the center of mass of this textbook.

Obtain a piece of string and attach a small weight to it. Suspend the string and the weight from one corner of the book. Draw a line along the string. Suspend the two from another corner of the book. Again, draw a line along the string. The point where the lines cross is the center of mass.

45. Rotating Frames of Reference A penny is placed on a rotating, old-fashioned record turntable. At the highest speed, the penny starts sliding outward. What are the forces acting on the penny?

Earth's mass exerts a downward force. The turntable's surface exerts both an upward force to balance gravity and an inward force due to friction that gives the penny its centripetal acceleration. There is no outward force. If it were not for friction, the penny would move in a straight line.

46. Critical Thinking You have learned why the winds around a low-pressure area move in a counterclockwise direction. Would the winds move in the same or opposite direction in the southern hemisphere? Explain.

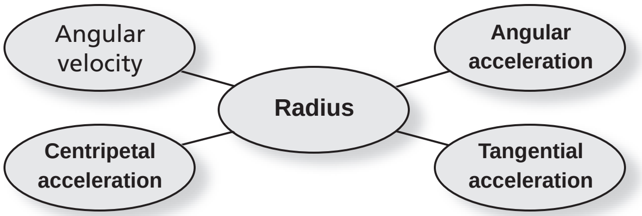
They would move in the opposite direction. Winds from the north move from the equator, where the linear speed due to rotation is highest, to mid-latitudes, where it is lower. Thus, the winds bend to the east. Winds from the south blow from regions where the linear speed is low to regions where it is higher; thus, they bend to the west. These two factors result in a clockwise rotation around a low-pressure area.

Chapter Assessment

Concept Mapping

page 222

47. Complete the following concept map using the following terms: *angular acceleration, radius, tangential acceleration, centripetal acceleration.*



Mastering Concepts

page 222

48. A bicycle wheel rotates at a constant 25 rev/min. Is its angular velocity decreasing, increasing, or constant? (8.1)

It is constant.

49. A toy rotates at a constant 5 rev/min. Is its angular acceleration positive, negative, or zero? (8.1)

It is zero.

50. Do all parts of Earth rotate at the same rate? Explain. (8.1)

Yes, because all parts of a rigid body rotate at the same rate.

51. A unicycle wheel rotates at a constant 14 rev/min. Is the total acceleration of a point on the tire inward, outward, tangential, or zero? (8.1)

It is inward (centripetal).

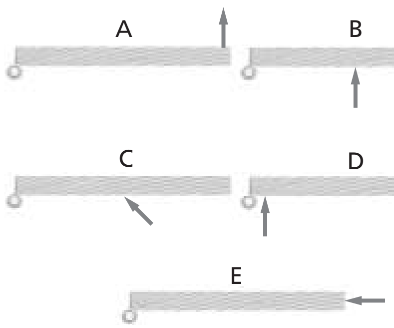
52. Think about some possible rotations of your textbook. Are the moments of inertia about these three axes the same or different? Explain. (8.2)

They are all different. The one with the most mass, farthest from the axis, has the greatest moment of inertia.

53. Torque is important when tightening bolts. Why is force not important? (8.2)

An angular acceleration must be produced to tighten a bolt. Different torques can be exerted with wrenches of different lengths.

54. Rank the torques on the five doors shown in **Figure 8-18** from least to greatest. Note that the magnitude of all the forces is the same. (8.2)



■ **Figure 8-18**

0 = E < D < C < B < A

55. Explain how you can change an object's angular frequency. (8.2)

Change the amount of torque applied to the object or change the moment of inertia.

56. To balance a car's wheel, it is placed on a vertical shaft and weights are added to make the wheel horizontal. Why is this equivalent to moving the center of mass until it is at the center of the wheel? (8.3)

When the wheel is balanced so it does not tilt (rotate) in any direction, then there is no net torque on it. This means that the center of mass is at the pivot point.

57. A stunt driver maneuvers a monster truck so that it is traveling on only two wheels. Where is the center of mass of the truck? (8.3)

It is directly above the line between the points where the two wheels are touching the ground. There is no net torque on the truck, so it is momentarily stable.

58. Suppose you stand flat-footed, then you rise and balance on tiptoe. If you stand with your toes touching a wall, you cannot balance on tiptoe. Explain. (8.3)

Your center of mass must be above the point of support. But your center of mass is roughly in the center of your body. Thus, while you are on your toes, about half of your body must be in front of your toes, and half must be behind. If your toes are against the wall, no part of your body can be in front of your toes.

59. Why does a gymnast appear to be floating on air when she raises her arms above her head in a leap? (8.3)

She moves her center of mass closer to her head.

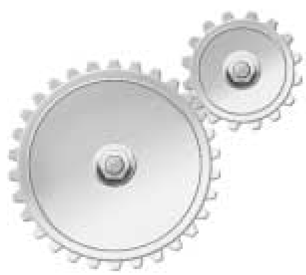
60. Why is a vehicle with wheels that have a large diameter more likely to roll over than a vehicle with wheels that have a smaller diameter? (8.3)

The center of mass of the vehicle with the larger wheels is located at a higher point. Thus it does not have to be tilted very far before it rolls over.

Applying Concepts

pages 222–223

61. Two gears are in contact and rotating. One is larger than the other, as shown in **Figure 8-19.** Compare their angular velocities. Also compare the linear velocities of two teeth that are in contact.



■ **Figure 8-19**

The teeth have identical linear velocities. Because the radii are different and $\omega = \frac{v}{r}$, the angular velocities are different.

62. Videotape When a videotape is rewound, why does it wind up fastest towards the end?

The machine turns the spool at a constant angular velocity. Towards the end, the spool has the greatest radius. Because $v = r\omega$, the velocity of the tape is fastest when the radius is greatest.

63. Spin Cycle What does a spin cycle of a washing machine do? Explain in terms of the forces on the clothes and water.

In the spin cycle, the water and clothes undergo great centripetal accelerations. The drum can exert forces on the clothes, but when the water reaches the holes in the drum, no inward force can be exerted on it and it therefore moves in a straight line, out of the drum.

64. How can you experimentally find the moment of inertia of an object?

You can apply a known torque and measure the resulting angular acceleration.

65. Bicycle Wheels Three bicycle wheels have masses that are distributed in three different ways: mostly at the rim, uniformly, and mostly at the hub. The wheels all have the same mass. If equal torques are applied to them, which one will have the greatest angular acceleration? Which one will have the least?

The more mass there is far from the axis, the greater the moment of inertia. If torque is fixed, the greater the moment of inertia, the less the angular acceleration. Thus, the wheel with mass mostly at the hub has the least moment of inertia and the greatest angular acceleration. The wheel with mass mostly near the rim has the greatest moment of inertia and the least angular acceleration.

66. Bowling Ball When a bowling ball leaves a bowler's hand, it does not spin. After it has gone about half the length of the lane, however, it does spin. Explain how its rotation rate increased and why it does not continue to increase.

Its rotation rate can be increased only if a torque is applied to it. The frictional force of the alley on the ball provides this force. Once the ball is rolling so that there is no velocity difference between the surface of the ball and the alley, then there is no more frictional force and thus no more torque.

67. Flat Tire Suppose your car has a flat tire. You get out your tools and find a lug wrench to remove the nuts off the bolt studs. You find it impossible to turn the nuts. Your friend suggests ways you might produce enough torque to turn them. What three ways might your friend suggest?

Put an extension pipe on the end of the wrench to increase the lever arm, exert your force at right angles to the wrench, or exert a greater force, perhaps by standing on the end of the wrench.

68. Tightrope Walkers Tightrope walkers often carry long poles that sag so that the ends are lower than the center as shown in **Figure 8-20.** How does such a pole increase the tightrope walker's stability? *Hint: Consider both center of mass and moment of inertia.*

■ **Figure 8-20**

The pole increases moment of inertia because of its mass and length. The drooping ends of the pole bring the center of mass closer to the wire, thus reducing the torque on the walker. The increased moment of inertia and decreased torque both reduce the angular acceleration if the walker becomes unbalanced. The walker can also use the pole to easily shift the center of mass over the wire to compensate for instability.

69. **Merry-Go-Round** While riding a merry-go-round, you toss a key to a friend standing on the ground. For your friend to be able to catch the key, should you toss it a second or two before you reach the spot where your friend is standing or wait until your friend is directly behind you? Explain.

You have forward tangential velocity, so the key will leave your hand with that velocity. Therefore, you should toss it early.

70. Why can you ignore forces that act on the axis of rotation of an object in static equilibrium when determining the net torque?

The torque caused by these forces is zero because the lever arm is zero.

71. In solving problems about static equilibrium, why is the axis of rotation often placed at a point where one or more forces are acting on the object?

That makes the torque caused by that force equal to zero, reducing the number of torques that must be calculated.

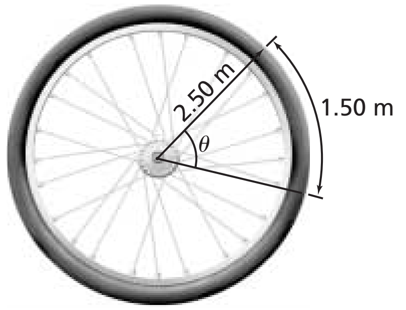
Mastering Problems

8.1 Describing Rotational Motion

pages 223–224

Level 1

72. A wheel is rotated so that a point on the edge moves through 1.50 m. The radius of the wheel is 2.50 m, as shown in **Figure 8-21.** Through what angle (in radians) is the wheel rotated?



■ **Figure 8-21**

$$d = r\theta$$

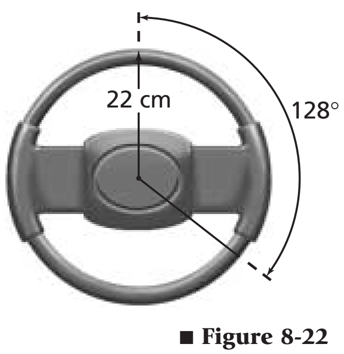
$$\text{so } \theta = \frac{d}{r} = \frac{1.50\text{ m}}{2.50\text{ m}} = 0.600\text{ rad}$$

73. The outer edge of a truck tire that has a radius of 45 cm has a velocity of 23 m/s. What is the angular velocity of the tire in rad/s?

$$v = r\omega,$$

$$\omega = \frac{v}{r} = \frac{23\text{ m/s}}{0.45\text{ m}} = 51\text{ rad/s}$$

74. A steering wheel is rotated through 128°, as shown in **Figure 8-22.** Its radius is 22 cm. How far would a point on the steering wheel's edge move?



■ **Figure 8-22**

$d = r\theta$

$= (0.22\ \text{m})(128°)\left(\frac{2\pi\ \text{rad}}{360°}\right) = 0.49\ \text{m}$

75. Propeller A propeller spins at 1880 rev/min.

a. What is its angular velocity in rad/s?

$\omega = \left(1880\ \frac{\text{rev}}{\text{min}}\right)\left(\frac{2\pi\ \text{rad}}{\text{rev}}\right)\left(\frac{\text{min}}{60\ \text{s}}\right)$

$= 197\ \text{rad/s}$

b. What is the angular displacement of the propeller in 2.50 s?

$\theta = \omega t$

$= (197\ \text{rad/s})(2.50\ \text{s})$

$= 492\ \text{rad}$

76. The propeller in the previous problem slows from 475 rev/min to 187 rev/min in 4.00 s. What is its angular acceleration?

$\alpha = \frac{\Delta\omega}{\Delta t}$

$= \frac{\omega_f - \omega_i}{\Delta t}$

$= \frac{(187\ \text{rev/min} - 475\ \text{rev/min})}{4.00\ \text{s}}\left(\frac{2\pi\ \text{rad}}{\text{rev}}\right)\left(\frac{1\ \text{min}}{60\ \text{s}}\right)$

$= -7.54\ \text{rad/s}^2$

77. An automobile wheel with a 9.00 cm radius, as shown in **Figure 8-23,** rotates at 2.50 rad/s. How fast does a point 7.00 cm from the center travel?

■ **Figure 8-23**

$v = r\omega$

$= (7.00\ \text{cm})(2.50\ \text{rad/s})$

$= 17.5\ \text{cm/s}$

Level 2

78. Washing Machine A washing machine's two spin cycles are 328 rev/min and 542 rev/min. The diameter of the drum is 0.43 m.

a. What is the ratio of the centripetal accelerations for the fast and slow spin cycles? Recall that $a_c = \frac{v^2}{r}$ and $v = rw$.

$\frac{a_{fast}}{a_{slow}} = \frac{r\omega_{fast}^2}{r\omega_{slow}^2}$

$= \frac{(542\ \text{rev/min})^2}{(328\ \text{rev/min})^2}$

$= 2.73$

b. What is the ratio of the linear velocity of an object at the surface of the drum for the fast and slow spin cycles?

$\frac{v_{fast}}{v_{slow}} = \frac{\omega_{fast} r}{\omega_{slow} r}$

$= \frac{\omega_{fast}}{\omega_{slow}}$

$= \frac{542\ \text{rev/min}}{328\ \text{rev/min}}$

$= 1.65$

79. Find the maximum centripetal acceleration in terms of g for the washing machine in problem 78.

$a_c = \omega^2 r\left(\frac{1\ g}{9.80\ \text{m/s}^2}\right)$

$= \left(542\ \text{rev/min}\left(\frac{2\pi\ \text{rad}}{\text{rev}}\right)\left(\frac{1\ \text{min}}{60\ \text{s}}\right)\right)^2\left(\frac{0.43\ \text{m}}{2}\right)\left(\frac{1\ g}{9.80\ \text{m/s}^2}\right)$

$= 71g$

Level 3

80. A laboratory ultracentrifuge is designed to produce a centripetal acceleration of $0.35\times10^6\ g$ at a distance of 2.50 cm from the axis. What angular velocity in rev/min is required?

$a_c = \omega^2 r$

so $\omega = \sqrt{\frac{a_c}{r}}$

$= \sqrt{\frac{(0.35\times10^6)(9.80\text{ m/s}^2)}{0.025\text{ m}}}\left(\frac{\text{rev}}{2\pi\text{ rad}}\right)\left(\frac{60\text{ s}}{1\text{ min}}\right)$

$= 1.1\times10^5$ rev/min

8.2 Rotational Dynamics

page 224

Level 1

81. **Wrench** A bolt is to be tightened with a torque of 8.0 N·m. If you have a wrench that is 0.35 m long, what is the least amount of force you must exert?

$\tau = Fr\sin\theta$

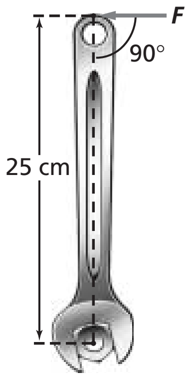
so $F = \frac{\tau}{r\sin\theta}$

For the least possible force, the angle is 90.0°, then

$F = \frac{8.0\text{ N·m}}{(0.35\text{ m})(\sin 90.0°)}$

$= 23$ N

82. What is the torque on a bolt produced by a 15-N force exerted perpendicular to a wrench that is 25 cm long, as shown in **Figure 8-24?**



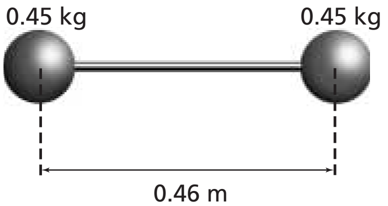
■ **Figure 8-24**

$\tau = Fr\sin\theta$

$= (15\text{ N})(0.25\text{ m})(\sin 90.0°)$

$= 3.8$ N·m

83. A toy consisting of two balls, each 0.45 kg, at the ends of a 0.46-m-long, thin, lightweight rod is shown in **Figure 8-25.** Find the moment of inertia of the toy. The moment of inertia is to be found about the center of the rod.



■ **Figure 8-25**

$I = mr^2$

$= (0.45\text{ kg})(0.23\text{ m})^2 + (0.45\text{ kg})(0.23\text{ m})^2$

$= 0.048$ kg·m^2

Level 2

84. A bicycle wheel with a radius of 38 cm is given an angular acceleration of 2.67 rad/s^2 by applying a force of 0.35 N on the edge of the wheel. What is the wheel's moment of inertia?

$\alpha = \frac{\tau}{I}$

$I = \frac{\tau}{\alpha}$

$= \frac{Fr\sin\theta}{\alpha}$

$= \frac{(0.35\text{ N})(0.38\text{ m})(\sin 90.0°)}{2.67\text{ rad/s}^2}$

$= 0.050$ kg·m^2

Level 3

85. **Toy Top** A toy top consists of a rod with a diameter of 8.0-mm and a disk of mass 0.0125 kg and a diameter of 3.5 cm. The moment of inertia of the rod can be neglected. The top is spun by wrapping a string around the rod and pulling it with a velocity that increases from zero to 3.0 m/s over 0.50 s.

a. What is the resulting angular velocity of the top?

$$\omega_f = \frac{v_f}{r_{rod}}$$

$$= \frac{3.0\ \text{m/s}}{\left(\frac{1}{2}\right)(0.0080\ \text{m})}$$

$$= 7.5\times10^2\ \text{rad/s}$$

b. What force was exerted on the string?

$\tau = Fr_{rod} \sin \theta$ **and** $\tau = \alpha I$

Thus, $Fr_{rod} \sin \theta = \alpha I$

$$F = \frac{\alpha I}{r_{rod} \sin \theta}$$

$$= \frac{\left(\frac{\Delta\omega}{\Delta t}\right)\left(\frac{1}{2}\right)mr_{disk}^2}{r_{rod} \sin \theta}$$

$$= \frac{\Delta\omega m r_{disk}^2}{2\Delta t r_{rod} \sin \theta}$$

$$= \frac{(\omega_f - \omega_i) m r_{disk}^2}{2\Delta t r_{rod} \sin \theta}$$

$$= \frac{(7.5\times10^2\ \text{rad/s} - 0.0\ \text{rad/s})(0.0125\ \text{kg})\left(\frac{0.035\ \text{m}}{2}\right)^2}{(2)(0.50\ \text{s})\left(\frac{0.0080\ \text{m}}{2}\right)(\sin 90.0°)}$$

$$= 0.72\ \text{N}$$

8.3 Equilibrium
page 224

Level 1

86. A 12.5-kg board, 4.00 m long, is being held up on one end by Ahmed. He calls for help, and Judi responds.

a. What is the least force that Judi could exert to lift the board to the horizontal position? What part of the board should she lift to exert this force?

At the opposite end, she will only lift half the mass.

$$F_{least} = mg$$

$$= \left(\frac{1}{2}\right)(12.5\ \text{kg})(9.80\ \text{m/s}^2)$$

$$= 61.2\ \text{N}$$

b. What is the greatest force that Judi could exert to lift the board to the horizontal position? What part of the board should she lift to exert this force?

At the board's center of mass (middle), she will lift the entire mass.

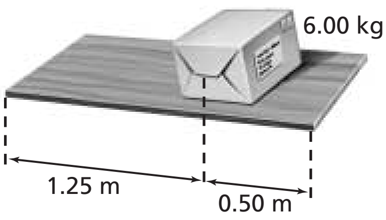
$$F_{greatest} = mg$$

$$= (12.5\ \text{kg})(9.80\ \text{m/s}^2)$$

$$= 122\ \text{N}$$

Level 2

87. Two people are holding up the ends of a 4.25-kg wooden board that is 1.75 m long. A 6.00-kg box sits on the board, 0.50 m from one end, as shown in **Figure 8-26.** What forces do the two people exert?



■ **Figure 8-26**

In equilibrium, the sum of all forces is zero and the sum of the torques about an axis of rotation is zero.

$F_{left} + F_{right} + F_{board} + F_{box} = 0$

$\tau_{left} + \tau_{right} + \tau_{board} + \tau_{box} = 0$

We can choose the axis of rotation at the location of one of the unknown forces (F_{left}) so that torque is eliminated, thus simplifying the calculations.

$F_{left}r_{left} + F_{right}r_{right} + F_{board}r_{board} + F_{box}r_{box} = 0$

$F_{left}r_{left} + F_{right}r_{right} + m_{board}gr_{board} + m_{box}gr_{box} = 0$

$F_{left}(0) + F_{right}(1.25\text{ m} + 0.50\text{ m}) + (4.25\text{ kg})(-9.80\text{ m/s}^2)\left(\frac{1.25\text{ m} + 0.50\text{ m}}{2}\right) +$
$(6.00\text{ kg})(-9.80\text{ m/s}^2)(1.25\text{ m}) = 0$

$F_{right} = 63\text{ N}$

Substituting this into the force equation,

$F_{left} + F_{right} + F_{board} + F_{box} = 0$

$F_{left} = -F_{right} - F_{board} - F_{box}$

$= -F_{right} - m_{board}g - m_{box}g$

$= -(63\text{ N}) - (4.25\text{ kg})(-9.80\text{ m/s}^2)$
$- (6.00\text{ kg})(-9.80\text{ m/s}^2)$

$= 37\text{ N}$

Level 3

88. A car's specifications state that its weight distribution is 53 percent on the front tires and 47 percent on the rear tires. The wheel base is 2.46 m. Where is the car's center of mass?

Let the center of mass be x from the front of the car. Let the weight of the car be F_g.

$\tau_{front} = \tau_{rear}$

$F_{front}r_{front} = F_{rear}r_{rear}$

$(0.53\ F_g)x = (0.47\ F_g)(2.46\text{ m} - x)$

$x = 1.16\text{ m}$

Mixed Review

pages 224–225

Level 1

89. A wooden door of mass, *m*, and length, *l*, is held horizontally by Dan and Ajit. Dan suddenly drops his end.

a. What is the angular acceleration of the door just after Dan lets go?

The torque is due to the gravitational force. The force at the center of mass is *mg*.

Thus, $\alpha = \frac{\tau}{I}$

$= \frac{Fr \sin\theta}{\left(\frac{1}{3}\right)ml^2}$

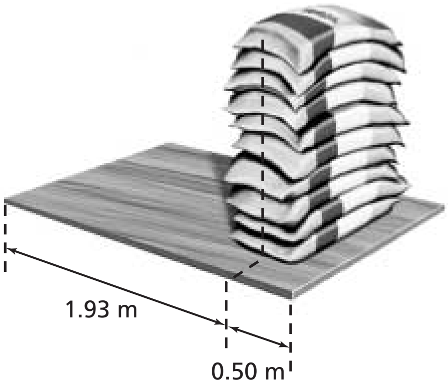
$= \frac{mg\left(\frac{1}{2}l\right)(\sin 90.0°)}{\left(\frac{1}{3}\right)ml^2}$

$= \frac{3}{2}gl$

b. Is the acceleration constant? Explain.

No; the angle between the door and the weight is changing, and therefore the torque is also changing. Thus, the acceleration changes.

90. Topsoil Ten bags of topsoil, each weighing 175 N, are placed on a 2.43-m-long sheet of wood. They are stacked 0.50 m from one end of the sheet of wood, as shown in **Figure 8-27.** Two people lift the sheet of wood, one at each end. Ignoring the weight of the wood, how much force must each person exert?



■ **Figure 8-27**

In equilibrium, the sum of the forces is zero and the sum of the torques is zero.

$F_{left} + F_{right} + F_{bags} = 0$

$\tau_{left} + \tau_{right} + \tau_{bags} = 0$

Choose the location of F_{right} **as the axis of rotation to make that torque zero.**

Then,

$\tau_{left} = -\tau_{bags}$

$F_{left}r_{left} = -F_{bags}r_{bags}$

$F_{left} = \frac{-F_{bags}r_{bags}}{r_{left}}$

$= \frac{-(10)(-175\text{ N})(0.50\text{ m})}{2.43\text{ m}}$

$= 3.6\times10^2\text{ N}$

Substitute this into the force equation.

$F_{left} + F_{right} + F_{bags} = 0$

$F_{right} = -F_{left} - F_{bags}$

$= -3.6\times10^2\text{ N} - 10(-175\text{ N})$

$= 1.4\times10^2\text{ N}$

91. Basketball A basketball is rolled down the court. A regulation basketball has a diameter of 24.1 cm, a mass of 0.60 kg, and a moment of inertia of 5.8×10^{-3} kg·m^2. The basketball's initial velocity is 2.5 m/s.

a. What is its initial angular velocity?

$\omega = \frac{v}{r}$

$= \frac{2.5\text{ m/s}}{\frac{1}{2}(0.241\text{ m})}$

$= 21\text{ rad/s}$

b. The ball rolls a total of 12 m. How many revolutions does it make?

$d = r\theta$

so $\theta = \frac{d}{r}$

$= \frac{12\text{ m}}{\left(\frac{1}{2}\right)(0.241\text{ m})}\left(\frac{\text{rev}}{2\pi\text{ rad}}\right)$

$= 16\text{ rev}$

c. What is its total angular displacement?

$d = r\theta$

so $\theta = \frac{d}{r}$

$= \frac{12\text{ m}}{\left(\frac{1}{2}\right)(0.241\text{ m})}$

$= 1.0\times10^2\text{ rad}$

92. The basketball in the previous problem stops rolling after traveling 12 m.

a. If its acceleration was constant, what was its angular acceleration?

$$v_f^2 = v_i^2 + 2ad$$

so $a = \frac{-v_i^2}{2d}$

Thus, $\alpha = \frac{a}{r} = \frac{-v_i^2}{2rd}$

$$= \frac{-(2.5\text{ m/s})^2}{2\left(\frac{1}{2}\right)(0.241\text{ m})(12\text{ m})}$$

$$= -2.2\text{ rad/s}^2$$

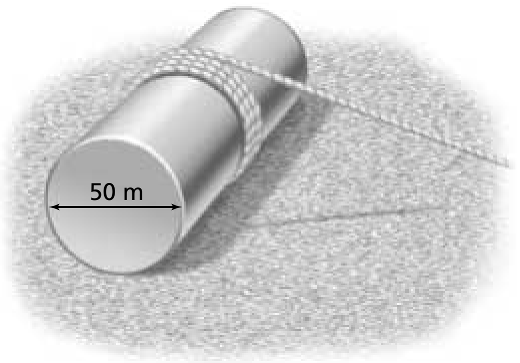
b. What torque was acting on it as it was slowing down?

$$\tau = I\alpha$$

$$= (5.8\times10^{-3}\text{ kg·m}^2)(-2.2\text{ rad/s}^2)$$

$$= -1.3\times10^{-2}\text{ N·m}$$

93. A cylinder with a 50 m diameter, as shown in **Figure 8-28,** is at rest on a surface. A rope is wrapped around the cylinder and pulled. The cylinder rolls without slipping.



■ **Figure 8-28**

a. After the rope has been pulled a distance of 2.50 m at a constant speed, how far has the center of mass of the cylinder moved?

The center of mass is always over the point of contact with the surface for a uniform cylinder. Therefore the center of mass has moved 2.50 m.

b. If the rope was pulled a distance of 2.50 m in 1.25 s, how fast was the center of mass of the cylinder moving?

$$v = \frac{d}{t}$$

$$= \frac{(2.50\text{ m})}{(1.25\text{ s})}$$

$$= 2.00\text{ m/s}$$

c. What is the angular velocity of the cylinder?

$$\omega = \frac{v}{r}$$

$$= \frac{2.00\text{ m/s}}{\left(\frac{1}{2}\right)(50\text{ m})}$$

$$= 8\times10^{-2}\text{ rad/s}$$

94. Hard Drive A hard drive on a modern computer spins at 7200 rpm (revolutions per minute). If the drive is designed to start from rest and reach operating speed in 1.5 s, what is the angular acceleration of the disk?

$$\alpha = \frac{\Delta\omega}{\Delta t} = \frac{\omega_f - \omega_i}{\Delta t}$$

$$= \frac{(7200\text{ rpm} - 0\text{ rpm})}{1.5\text{ s}}\left(\frac{2\pi\text{ rad}}{\text{rev}}\right)\left(\frac{1\text{ min}}{60\text{ s}}\right)$$

$$= 5.0\times10^2\text{ rad/s}^2$$

95. Speedometers Most speedometers in automobiles measure the angular velocity of the transmission and convert it to speed. How will increasing the diameter of the tires affect the reading of the speedometer?

Because increasing the diameter decreases the angular velocity, it will also decrease the reading of the speedometer.

96. A box is dragged across the floor using a rope that is a distance *h* above the floor. The coefficient of friction is 0.35. The box is 0.50 m high and 0.25 m wide. Find the force that just tips the box.

Let *M* equal the mass of the box. The center of mass of the box is 0.25 m above the floor. The box just tips when the torques on it are equal.

$$\tau_{rope} = \tau_{friction}$$

$$F_{rope}r_{rope} = F_{friction}r_{friction}$$

$$F_{rope} = \frac{F_{friction} r_{friction}}{r_{rope}}$$

$$= \frac{\mu M g r_{friction}}{r_{rope}}$$

$$= \frac{(0.35)M(9.80\ m/s^2)(0.25\ m)}{h - 0.25\ m}$$

$$= \frac{(0.86\ m^2/s^2)M}{h - 0.25\ m}$$

Note that when you pull the box at the height of its center of mass, the denominator becomes zero. That is, you can pull with any amount of force and not tip the box.

97. The second hand on a watch is 12 mm long. What is the velocity of its tip?

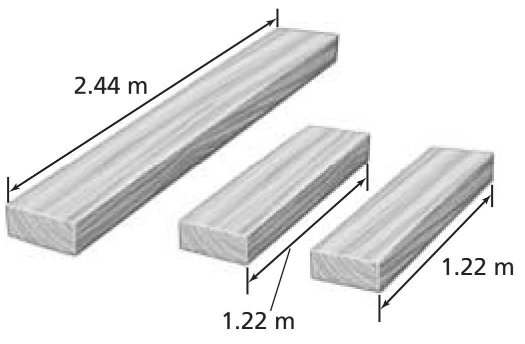
$$v = r\omega$$

$$= (0.012\ m)(-2\pi\ rad/min)\left(\frac{min}{60\ s}\right)$$

$$= -1.3\times10^{-3}\ m/s$$

Level 2

98. Lumber You buy a 2.44-m-long piece of 10 cm × 10 cm lumber. Your friend buys a piece of the same size and cuts it into two lengths, each 1.22 m long, as shown in **Figure 8-29.** You each carry your lumber on your shoulders.



■ **Figure 8-29**

a. Which load is easier to lift? Why?

The masses are the same, so the weights are the same. Thus, the same upward force is required to lift each load.

b. Both you and your friend apply a torque with your hands to keep the lumber from rotating. Which load is easier to keep from rotating? Why?

The longer piece of lumber would be easier to keep from rotating because it has a greater moment of inertia.

99. Surfboard Harris and Paul carry a surfboard that is 2.43 m long and weighs 143 N. Paul lifts one end with a force of 57 N.

a. What force must Harris exert?

$$F_H = F_g - F_P$$

$$= 143\ N - 57\ N$$

$$= 86\ N$$

b. What part of the board should Harris lift?

Choose the point of rotation at the end where Paul lifts.

$$\tau_H = \tau_g$$

$$F_H r_H = F_g r_g$$

$$r_H = \frac{F_g r_g}{F_H}$$

$$= \frac{(143\ N)\left(\frac{2.43\ m}{2}\right)}{86\ N}$$

$$= 2.0\ m$$

Thus, Harris has to lift 2.0 m from Paul's end of the board.

100. A steel beam that is 6.50 m long weighs 325 N. It rests on two supports, 3.00 m apart, with equal amounts of the beam extending from each end. Suki, who weighs 575 N, stands on the beam in the center and then walks toward one end. How close to the end can she come before the beam begins to tip?

Each support is 1.75 m from the end of the beam. Choose the point of rotation to be the support at the end closer to Suki. The center of mass of the beam is 1.50 m from that support. The beam will just begin to tip when Suki's torque (τ_S) equals the torque of the beam's center of mass (τ_{cm}) and the entire weight is on the support closest to Suki.

$$\tau_S = \tau_{cm}$$

$$F_S r_S = F_{cm} r_{cm}$$

$$r_S = \frac{F_{cm}r_{cm}}{F_S}$$

$$= \frac{(325\ N)\left(\frac{3.00\ m}{2}\right)}{575\ N}$$

$$= 0.848\ m$$

That is Suki can move 0.848 m from the support or 1.75 − 0.848 = 0.90 m from the end.

Thinking Critically

pages 225–226

101. Apply Concepts Consider a point on the edge of a rotating wheel.

a. Under what conditions can the centripetal acceleration be zero?

when $\omega = 0.0$

b. Under what conditions can the tangential (linear) acceleration be zero?

when $\alpha = 0.0$

c. Can the tangential acceleration be nonzero while the centripetal acceleration is zero? Explain.

When $\omega = 0.0$ instantaneously, but α is not zero, ω will keep changing.

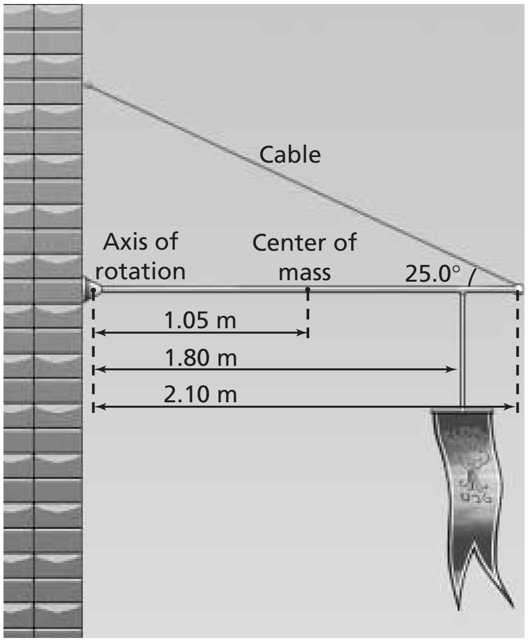
d. Can the centripetal acceleration be nonzero while the tangential acceleration is zero? Explain.

Yes, as long as ω is constant but not zero.

102. Apply Concepts When you apply the brakes in a car, the front end dips. Why?

The road exerts a force on the tires that brings the car to rest. The center of mass is above the road. Therefore, there is a net torque on the car, causing it to rotate in the direction that forces the front down.

103. Analyze and Conclude A banner is suspended from a horizontal, pivoted pole, as shown in **Figure 8-30.** The pole is 2.10 m long and weighs 175 N. The banner, which weighs 105 N, is suspended 1.80 m from the pivot point or axis of rotation. What is the tension in the cable supporting the pole?



■ **Figure 8-30**

We can use torques to find the vertical component (F_{Ty}) of the tension. The counterclockwise torques are in equilibrium with the clockwise torques.

$$\tau_{ccw} = \tau_{cw}$$

$$\tau_{cable} = \tau_{pole} + \tau_{banner}$$

$$F_{Ty}r_{cable} = F_{pole}r_{pole} + F_{banner}r_{banner}$$

$$F_{Ty} = \frac{F_{pole}r_{pole} + F_{banner}r_{banner}}{r_{cable}}$$

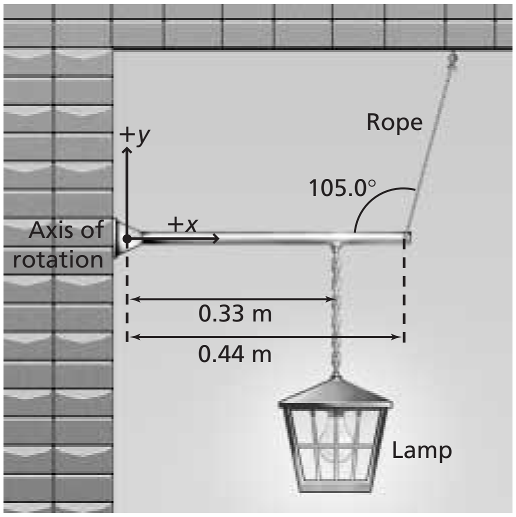
The total tension, then, is

$$F_T = \frac{F_{Ty}}{\sin 25°} = \frac{F_{pole}r_{pole} + F_{banner}r_{banner}}{r_{cable}\sin 25°}$$

$$= \frac{(175\ N)(1.05\ m) + (105\ N)(1.80\ m)}{(2.10\ m)\sin 25°}$$

$$= 420\ N$$

104. Analyze and Conclude A pivoted lamp pole is shown in **Figure 8-31.** The pole weighs 27 N, and the lamp weighs 64 N.



■ **Figure 8-31**

a. What is the torque caused by each force?

$$\tau_g = F_g r \sin\theta$$
$$= (27\ \text{N})(0.22\ \text{m})(\sin 90.0°)$$
$$= 5.9\ \text{N·m}$$

$$\tau_{lamp} = F_{lamp} r \sin\theta$$
$$= (64\ \text{N})(0.33\ \text{m})(\sin 90.0°)$$
$$= 21\ \text{N·m}$$

b. Determine the tension in the rope supporting the lamp pole.

Use the torques to find the vertical component (F_{Ty}) of the tension. The counterclockwise torques are in equilibrium with the clockwise torques.

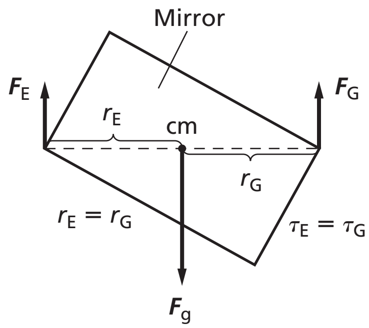
$$\tau_{ccw} = \tau_{cw}$$
$$\tau_{rope} = \tau_{pole} + \tau_{lamp}$$
$$F_{Ty} r_{rope} = F_{pole} r_{pole} + F_{lamp} r_{lamp}$$
$$F_{Ty} = \frac{F_{pole} r_{pole} + F_{lamp} r_{lamp}}{r_{rope}}$$

The total tension, then, is

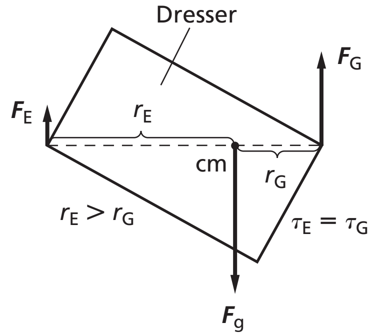
$$F_T = \frac{F_{Ty}}{\sin 105°}$$
$$= \frac{F_{pole} r_{pole} + F_{lamp} r_{lamp}}{r_{rope} \sin 105°}$$
$$= \frac{(27\ \text{N})\left(\frac{0.44\ \text{m}}{2}\right) + (64\ \text{N})(0.33\ \text{m})}{(0.44\ \text{m})(\sin 105°)}$$
$$= 64\ \text{N}$$

105. Analyze and Conclude Gerald and Evelyn carry the following objects up a flight of stairs: a large mirror, a dresser, and a television. Evelyn is at the front end, and Gerald is at the bottom end. Assume that both Evelyn and Gerald exert only upward forces.

a. Draw a free-body diagram showing Gerald and Evelyn exerting the same force on the mirror.

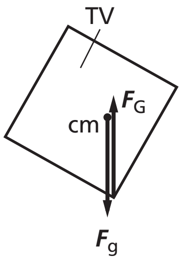


b. Draw a free-body diagram showing Gerald exerting more force on the bottom of the dresser.



c. Where would the center of mass of the television have to be so that Gerald carries all the weight?

directly above where Gerald is lifting



Writing in Physics

page 226

106. Astronomers know that if a satellite is too close to a planet, it will be torn apart by tidal forces. That is, the difference in the gravitational force on the part of the satellite nearest the planet and the part farthest from the planet is stronger than the forces holding the satellite together. Do research on the Roche limit and determine how close the Moon would have to orbit Earth to be at the Roche limit.

For a planet and a moon with identical densities, the Roche limit is 2.446 times the radius of the planet. Earth's Roche limit is 18,470 km.

107. Automobile engines are rated by the torque that they produce. Research and explain why torque is an important quantity to measure.

The force exerted by the ground on the tire accelerates the car. This force is produced by the engine. It creates the force by rotating the axle. The torque is equal to the force on the edge of the tire multiplied by the radius of the tire. Gears in the transmission may cause the force to change, but they do not change the torque. Therefore, the amount of torque created by the engine is delivered to the wheels.

Cumulative Review

page 226

108. Two blocks, one of mass 2.0 kg and the other of mass 3.0 kg, are tied together with a massless rope. This rope is strung over a massless, resistance-free pulley. The blocks are released from rest. Find the following. (Chapter 4)

a. the tension in the rope

The tension on the rope is

$$T - m_2g = m_2a$$

$$T - m_3g = m_3a$$

Thus,

$$a = \left(\frac{m_3 - m_2}{m_3 + m_2}\right)g$$

Substitute into the first equation.

$$T = \left(\frac{2m_2m_3}{m_2 + m_3}\right)g$$

$$= \frac{2(2\text{ kg})(3\text{ kg})}{2\text{ kg} + 3\text{ kg}}(9.80\text{ m/s}^2)$$

$$= 24\text{ N}$$

b. the acceleration of the blocks.

Substitute into the equation for a.

$$a = \left(\frac{m_3 - m_2}{m_3 + m_2}\right)g$$

$$= \left(\frac{3\text{ kg} - 2\text{ kg}}{3\text{ kg} + 2\text{ kg}}\right)(9.80\text{ m/s}^2)$$

$$= 1.96\text{ m/s}^2$$

109. Eric sits on a see-saw. At what angle, relative to the vertical, will the component of his weight parallel to the plane be equal to one-third the perpendicular component of his weight? (Chapter 5)

$$F_{g,\text{ parallel}} = F_g \sin\theta$$

$$F_{g,\text{ perpendicular}} = F_g \cos\theta$$

$$F_{g,\text{ perpendicular}} = 3F_{g,\text{ parallel}}$$

$$3 = \frac{F_{g,\text{ perpendicular}}}{F_{g,\text{ parallel}}}$$

$$3 = \frac{F_g \cos\theta}{F_g \sin\theta} = \frac{1}{\tan\theta}$$

$$\theta = \tan^{-1}(3) = 71.6°$$

110. The pilot of a plane wants to reach an airport 325 km due north in 2.75 hours. A wind is blowing from the west at 30.0 km/h. What heading and airspeed should be chosen to reach the destination on time? (Chapter 6)

Let *g* be the distance north to the airport, *x* be the westward deflection, and h be the actual distance traveled. First, find the heading as the angle *θ* traveled eastward from the northward path.

$$\tan\theta = \frac{v_x}{v_y}$$

$$\theta = \tan^{-1}\left(\frac{v_x}{v_y}\right)$$

$$= \tan^{-1}\left(\frac{v_x t_y}{d_y}\right)$$

$$= \tan^{-1}\left(\frac{(30.0\text{ km/h})(2.75\text{ h})}{325\text{ km}}\right)$$

$$= 14.3° \text{ west of north}$$

The airspeed, then, should be

$$v_h{}^2 = v_x{}^2 + v_y{}^2$$

$$v_h = (v_x{}^2 + v_y{}^2)^{\frac{1}{2}}$$

$$= \left(v_x{}^2 + \frac{d_y{}^2}{t_y{}^2}\right)^{\frac{1}{2}}$$

$$= \left((30.0\text{ km/h})^2 + \frac{(325\text{ km})^2}{(2.75\text{ h})^2}\right)^{\frac{1}{2}}$$

$$= 122\text{ km/h}$$

111. A 60.0-kg speed skater with a velocity of 18.0 m/s comes into a curve of 20.0-m radius. How much friction must be exerted between the skates and ice to negotiate the curve? (Chapter 6)

$$F_f = F_{net} = \frac{mv^2}{r}$$

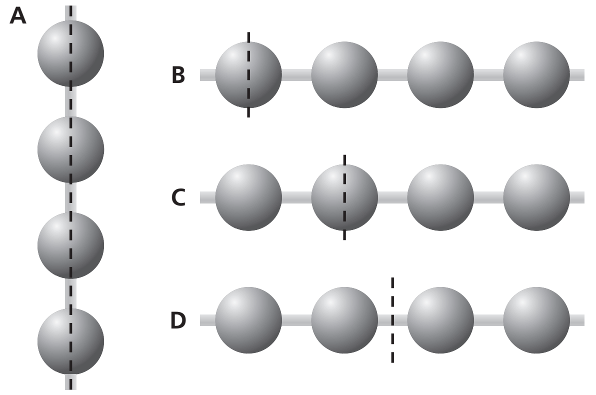
$$= \frac{(60.0\text{ kg})(18.0\text{ m/s})^2}{20.0\text{ m}} = 972\text{ N}$$

Challenge Problem

page 208

Rank the objects shown in the diagram according to their moments of inertia about the indicated axes. All spheres have equal masses and all separations are the same.

b > c > d > a



CHAPTER 9

Momentum and Its Conservation

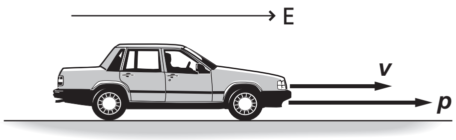
Practice Problems

9.1 Impulse and Momentum pages 229–235

page 233

1. A compact car, with mass 725 kg, is moving at 115 km/h toward the east. Sketch the moving car.

a. Find the magnitude and direction of its momentum. Draw an arrow on your sketch showing the momentum.



$$p = mv$$

$$= (725\text{ kg})(115\text{ km/h})\left(\frac{1000\text{ m}}{1\text{ km}}\right)\left(\frac{1\text{ h}}{3600\text{ s}}\right)$$

$$= 2.32\times10^{4}\text{ kg·m/s eastward}$$

b. A second car, with a mass of 2175 kg, has the same momentum. What is its velocity?

$$v = \frac{p}{m}$$

$$= \frac{(2.32\times10^{4}\text{ kg·m/s})\left(\frac{3600\text{ s}}{1\text{ h}}\right)\left(\frac{1\text{ km}}{1000\text{ m}}\right)}{2175\text{ kg}}$$

$$= 38.4\text{ km/h eastward}$$

2. The driver of the compact car in the previous problem suddenly applies the brakes hard for 2.0 s. As a result, an average force of 5.0×10^{3} N is exerted on the car to slow it down.

$$\Delta t = 2.0\text{ s}$$

$$F = -5.0\times10^{3}\text{ N}$$

a. What is the change in momentum; that is, the magnitude and direction of the impulse, on the car?

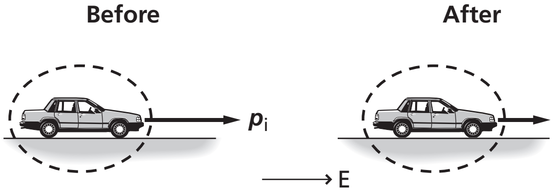
$$\text{impulse} = F\Delta t$$

$$= (-5.0\times10^{3}\text{ N})(2.0\text{ s})$$

$$= -1.0\times10^{4}\text{ N·s}$$

The impulse is directed westward and has a magnitude of 1.0×10^{4} N·s.

b. Complete the "before" and "after" sketches, and determine the momentum and the velocity of the car now.



$$p_i = 2.32\times10^{4}\text{ kg·m/s eastward}$$

$$F\Delta t = \Delta p = p_f - p_i$$

$$p_f = F\Delta t + p_i$$

$$= -1.0\times10^{4}\text{ kg·m/s} + 2.32\times10^{4}\text{ kg·m/s}$$

$$= 1.3\times10^{4}\text{ kg·m/s eastward}$$

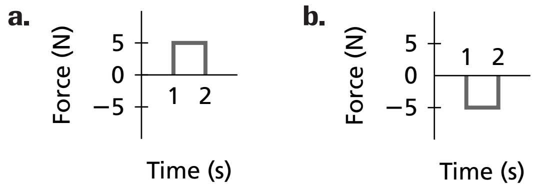
$$p_f = mv_f$$

$$v_f = \frac{p_f}{m} = \frac{1.3\times10^{4}\text{ kg·m/s}}{725\text{ kg}}$$

$$= 18\text{ m/s}$$

$$= 65\text{ km/h eastward}$$

3. A 7.0-kg bowling ball is rolling down the alley with a velocity of 2.0 m/s. For each impulse, shown in **Figures 9-3a** and **9-3b,** find the resulting speed and direction of motion of the bowling ball.



■ **Figure 9-3**

a. $F\Delta t = p_f - p_i = mv_f - mv_i$

$$v_f = \frac{F\Delta t - mv_f}{m}$$

$$= \frac{(5.0\ \text{N})(1.0\ \text{s}) + (7.0\ \text{kg})(2.0\ \text{m/s})}{7.0\ \text{kg}}$$

= 2.7 m/s in the same direction as the original velocity

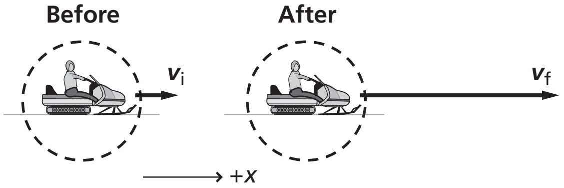
b. $$v_f = \frac{F\Delta t - mv_f}{m}$$

$$= \frac{(-5.0\ \text{N})(1.0\ \text{s}) + (7.0\ \text{kg})(2.0\ \text{m/s})}{7.0\ \text{kg}}$$

= 1.3 m/s in the same direction as the original velocity

4. The driver accelerates a 240.0-kg snowmobile, which results in a force being exerted that speeds up the snowmobile from 6.00 m/s to 28.0 m/s over a time interval of 60.0 s.

a. Sketch the event, showing the initial and final situations.



b. What is the snowmobile's change in momentum? What is the impulse on the snowmobile?

$\Delta p = F\Delta t$

$= m(v_f - v_i)$

= (240.0 kg)(28.0 m/s − 6.00 m/s)

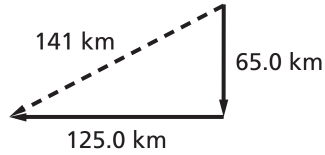
= 5.28×10³ kg·m/s

c. What is the magnitude of the average force that is exerted on the snowmobile?

$$F = \frac{\Delta p}{\Delta t} = \frac{5.28\times10^3\ \text{kg·m/s}}{60.0\ \text{s}}$$

= 88.0 N

5. Suppose a 60.0-kg person was in the vehicle that hit the concrete wall in Example Problem 1. The velocity of the person equals that of the car both before and after the crash, and the velocity changes in 0.20 s. Sketch the problem.



a. What is the average force exerted on the person?

$F\Delta t = \Delta p = p_f - p_i$

$$F = \frac{p_f - p_i}{\Delta t}$$

$$F = \frac{p_f - mv_i}{\Delta t}$$

$$= \frac{(0.0\ \text{kg·m/s}) - (60.0\ \text{kg})(94\ \text{km/h})}{0.20\ \text{s}}\left(\frac{1000\ \text{m}}{1\ \text{km}}\right)\left(\frac{1\ \text{h}}{3600\ \text{s}}\right)$$

= 7.8×10³ N opposite to the direction of motion

b. Some people think that they can stop their bodies from lurching forward in a vehicle that is suddenly braking by putting their hands on the dashboard. Find the mass of an object that has a weight equal to the force you just calculated. Could you lift such a mass? Are you strong enough to stop your body with your arms?

$F_g = mg$

$$m = \frac{F_g}{g} = \frac{7.8\times10^3\ \text{N}}{9.80\ \text{m/s}^2} = 8.0\times10^2\ \text{kg}$$

Such a mass is too heavy to lift. You cannot safely stop yourself with your arms.

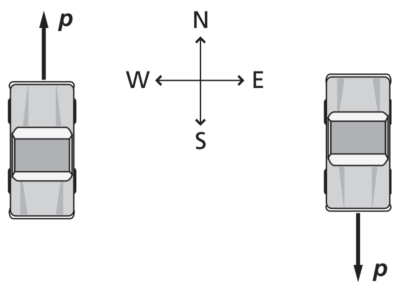
Section Review

9.1 Impulse and Momentum pages 229–235

page 235

6. Momentum Is the momentum of a car traveling south different from that of the same car when it travels north at the same speed? Draw the momentum vectors to support your answer.

Yes, momentum is a vector quantity, and the momenta of the two cars are in opposite directions.



7. **Impulse and Momentum** When you jump from a height to the ground, you let your legs bend at the knees as your feet hit the floor. Explain why you do this in terms of the physics concepts introduced in this chapter.

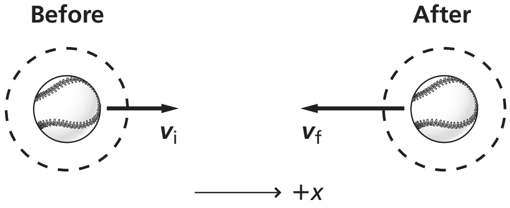
You reduce the force by increasing the length of time it takes to stop the motion of your body.

8. **Momentum** Which has more momentum, a supertanker tied to a dock or a falling raindrop?

The raindrop has more momentum, because a supertanker at rest has zero momentum.

9. **Impulse and Momentum** A 0.174-kg softball is pitched horizontally at 26.0 m/s. The ball moves in the opposite direction at 38.0 m/s after it is hit by the bat.

a. Draw arrows showing the ball's momentum before and after the bat hits it.



b. What is the change in momentum of the ball?

$$\Delta p = m(v_f - v_i)$$
$$= (0.174\ \text{kg})(38.0\ \text{m/s} - (-26.0\ \text{m/s}))$$
$$= 11.1\ \text{kg·m/s}$$

c. What is the impulse delivered by the bat?

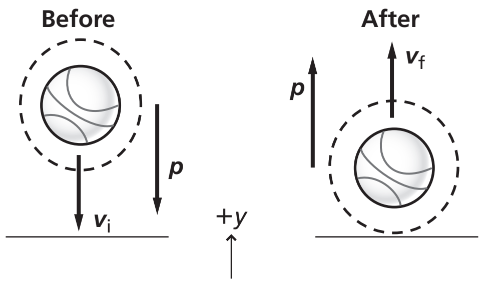
$$F\Delta t = p_f - p_i$$
$$= \Delta p$$
$$= 11.1\ \text{kg·m/s}$$
$$= 11.1\ \text{N·s}$$

d. If the bat and softball are in contact for 0.80 ms, what is the average force that the bat exerts on the ball?

$$F\Delta t = m(v_f - v_i)$$
$$F = \frac{m(v_f - v_i)}{\Delta t}$$
$$= \frac{(0.174\ \text{kg})(38.0\ \text{m/s} - (-26.0\ \text{m/s}))}{(0.80\ \text{ms})\left(\frac{1\ \text{s}}{1000\ \text{ms}}\right)}$$
$$= 1.4\times10^4\ \text{N}$$

10. **Momentum** The speed of a basketball as it is dribbled is the same when the ball is going toward the floor as it is when the ball rises from the floor. Is the basketball's change in momentum equal to zero when it hits the floor? If not, in which direction is the change in momentum? Draw the basketball's momentum vectors before and after it hits the floor.

No, the change in momentum is upward. Before the ball hits the floor, its momentum vector is downward. After the ball hits the floor, its momentum vector is upward.



11. **Angular Momentum** An ice-skater spins with his arms outstretched. When he pulls his arms in and raises them above his head, he spins much faster than before. Did a torque act on the ice-skater? If not, how could his angular velocity have increased?

No torque acted on him. By drawing his arms in and keeping them close to the axis of rotation, he decreased his moment of inertia. Because the angular momentum did not change, the skater's angular velocity increased.

12. **Critical Thinking** An archer shoots arrows at a target. Some of the arrows stick in the target, while others bounce off. Assuming that the masses of the arrows and the velocities of the arrows are the same, which arrows produce a bigger impulse on the target? *Hint: Draw a diagram to show the momentum of the arrows before and after hitting the target for the two instances.*

The ones that bounce off give more impulse because they end up with some momentum in the reverse direction, meaning they have a larger change in momentum.

Practice Problems

9.2 Conservation of Momentum pages 236–245

page 238

13. Two freight cars, each with a mass of 3.0×10^5 kg, collide and stick together. One was initially moving at 2.2 m/s, and the other was at rest. What is their final speed?

$$p_i = p_f$$

$$mv_{Ai} + mv_{Bi} = 2mv_f$$

$$v_f = \frac{v_{Ai} + v_{Bi}}{2}$$

$$= \frac{2.2\text{ m/s} + 0.0\text{ m/s}}{2}$$

$$= 1.1\text{ m/s}$$

14. A 0.105-kg hockey puck moving at 24 m/s is caught and held by a 75-kg goalie at rest. With what speed does the goalie slide on the ice?

$$p_{Pi} + p_{Gi} = p_{Pf} + p_{Gf}$$

$$m_Pv_{Pi} + m_Gv_{Gi} = m_Pv_{Pf} + m_Gv_{Gf}$$

Because $v_{Gi} = 0.0$ **kg·m/s,**

$$m_Pv_{Pi} = (m_P + m_G)v_f$$

where $v_f = v_{Pf} = v_{Gf}$ **is the common final speed of the goalie and the puck.**

$$v_f = \frac{m_Pv_{Pi}}{(m_P + m_G)}$$

$$= \frac{(0.105\text{ kg})(24\text{ m/s})}{(0.105\text{ kg} + 75\text{ kg})} = 0.034\text{ m/s}$$

15. A 35.0-g bullet strikes a 5.0-kg stationary piece of lumber and embeds itself in the wood. The piece of lumber and bullet fly off together at 8.6 m/s. What was the original speed of the bullet?

$$m_bv_{bi} + m_wv_{wi} = (m_b + m_w)v_f$$

where v_f **is the common final speed of the bullet and piece of lumber.**

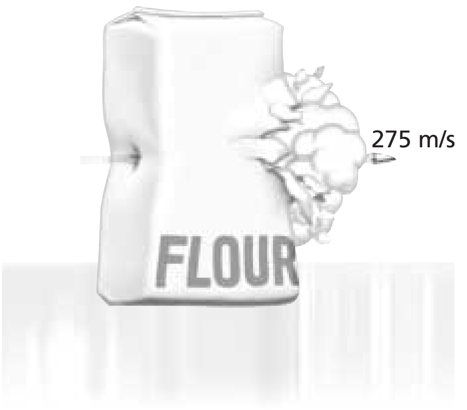
Because $v_{wi} = 0.0$ **m/s,**

$$v_{bi} = \frac{(m_b + m_w)v_f}{m_b}$$

$$= \frac{(0.0350\text{ kg} + 5.0\text{ kg})(8.6\text{ m/s})}{0.0350\text{ kg}}$$

$$= 1.2\times10^3\text{ m/s}$$

16. A 35.0-g bullet moving at 475 m/s strikes a 2.5-kg bag of flour that is on ice, at rest. The bullet passes through the bag, as shown in **Figure 9-7,** and exits it at 275 m/s. How fast is the bag moving when the bullet exits?



■ **Figure 9-7**

$$m_Bv_{Bi} + m_Fv_{Fi} = m_Bv_{Bf} + m_Fv_{Ff}$$

where $v_{Fi} = 0.0$ **m/s**

$$v_{Ff} = \frac{(m_Bv_{Bi} - m_Bv_{Bf})}{m_F}$$

$$v_{Ff} = \frac{m_B(v_{Bi} - v_{Bf})}{m_F}$$

$$= \frac{(0.0350\text{ kg})(475\text{ m/s} - 275\text{ m/s})}{2.5\text{ kg}}$$

= 2.8 m/s

17. The bullet in the previous problem strikes a 2.5-kg steel ball that is at rest. The bullet bounces backward after its collision at a speed of 5.0 m/s. How fast is the ball moving when the bullet bounces backward?

The system is the bullet and the ball.

$$m_{\text{bullet}}v_{\text{bullet, i}} + m_{\text{ball}}v_{\text{ball, i}} = m_{\text{bullet}}v_{\text{bullet, f}} + m_{\text{ball}}v_{\text{ball, f}}$$

$v_{\text{ball, i}} = 0.0$ **m/s and** $v_{\text{bullet, f}} = -5.0$ **m/s**

$$\text{so } v_{\text{ball, f}} = \frac{m_{\text{bullet}}(v_{\text{bullet, i}} - v_{\text{bullet, f}})}{m_{\text{ball}}} = \frac{(0.0350\text{ kg})(475\text{ m/s} - (-5.0\text{ m/s}))}{2.5\text{ kg}}$$

= 6.7 m/s

18. A 0.50-kg ball that is traveling at 6.0 m/s collides head-on with a 1.00-kg ball moving in the opposite direction at a speed of 12.0 m/s. The 0.50-kg ball bounces backward at 14 m/s after the collision. Find the speed of the second ball after the collision.

Say that the first ball (ball C) is initially moving in the positive (forward) direction.

$$m_Cv_{Ci} + m_Dv_{Di} = m_Cv_{Cf} + m_Dv_{Df}$$

$$\text{so } v_{Df} = \frac{m_Cv_{Ci} + m_Dv_{Di} - m_Cv_{Cf}}{m_D}$$

$$= \frac{(0.50\text{ kg})(6.0\text{ m/s}) + (1.00\text{ kg})(-12.0\text{ m/s}) - (0.50\text{ kg})(-14\text{ m/s})}{1.00\text{ kg}}$$

= −2.0 m/s, or 2.0 m/s in the opposite direction

page 240

19. A 4.00-kg model rocket is launched, expelling 50.0 g of burned fuel from its exhaust at a speed of 625 m/s. What is the velocity of the rocket after the fuel has burned? *Hint: Ignore the external forces of gravity and air resistance.*

$$p_{ri} + p_{\text{fuel, i}} = p_{rf} + p_{\text{fuel, f}}$$

where $p_{rf} + p_{\text{fuel, f}} = 0.0$ **kg·m/s**

If the initial mass of the rocket (including fuel) is $m_r = 4.00$ **kg, then the final mass of the rocket is**

$$m_{rf} = 4.00\text{ kg} - 0.0500\text{ kg} = 3.95\text{ kg}$$

$$0.0\text{ kg·m/s} = m_{rf}v_{rf} + m_{\text{fuel}}v_{\text{fuel, f}}$$

$$v_{rf} = \frac{-m_{\text{fuel}}v_{\text{fuel, f}}}{m_{rf}}$$

$$= \frac{-(0.0500\text{ kg})(-625\text{ m/s})}{3.95\text{ kg}}$$

= 7.91 m/s

20. A thread holds a 1.5-kg cart and a 4.5-kg cart together. After the thread is burned, a compressed spring pushes the carts apart, giving the 1.5-kg cart a speed of 27 cm/s to the left. What is the velocity of the 4.5-kg cart?

Let the 1.5-kg cart be represented by "C" and the 4.5-kg cart be represented by "D".

$p_{Ci} + p_{Di} = p_{Cf} + p_{Df}$

where $p_{Ci} = p_{Di} = 0.0\ \text{kg·m/s}$

$m_D v_{Df} = -m_C v_{Cf}$

so $v_{Df} = \frac{-m_C v_{Cf}}{m_D}$

$= \frac{-(1.5\ \text{kg})(-27\ \text{cm/s})}{4.5\ \text{kg}}$

= 9.0 cm/s to the right

21. Carmen and Judi dock a canoe. 80.0-kg Carmen moves forward at 4.0 m/s as she leaves the canoe. At what speed and in what direction do the canoe and Judi move if their combined mass is 115 kg?

$p_{Ci} + p_{Ji} = p_{Cf} + p_{Jf}$

where $p_{Ci} = p_{Ji} = 0.0\ \text{kg·m/s}$

$m_C v_{Cf} = -m_J v_{Jf}$

so $v_{Jf} = \frac{-m_C v_{Cf}}{m_J}$

$= \frac{-(80.0\ \text{kg})(4.0\ \text{m/s})}{115\ \text{kg}}$

= 2.8 m/s in the opposite direction

page 243

22. A 925-kg car moving north at 20.1 m/s collides with a 1865-kg car moving west at 13.4 m/s. The two cars are stuck together. In what direction and at what speed do they move after the collision?

Before:

$p_{i,y} = m_y v_{i,y}$

$= (925\ \text{kg})(20.1\ \text{m/s})$

$= 1.86\times10^4\ \text{kg·m/s}$

$p_{i,x} = m_x v_{i,x}$

$= (1865\ \text{kg})(-13.4\ \text{m/s})$

$= -2.50\times10^4\ \text{kg·m/s}$

$p_{f,y} = p_{i,y}$

$p_{f,x} = p_{i,x}$

$p_f = p_i$

$= \sqrt{(p_{f,x})^2 + (p_{f,y})^2}$

$$= \sqrt{(-2.50\times10^4\ \text{kg·m/s})^2 + (1.86\times10^4\ \text{kg·m/s})^2}$$

$$= 3.12\times10^4\ \text{kg·m/s}$$

$$v_f = \frac{p_f}{m_1 + m_2}$$

$$= \frac{3.12\times10^4\ \text{kg·m/s}}{(925\ \text{kg} + 1865\ \text{kg})} = 11.2\ \text{m/s}$$

$$\theta = \tan^{-1}\left(\frac{p_{f,\,y}}{p_{f,\,x}}\right)$$

$$= \tan^{-1}\left(\frac{1.86\times10^4\ \text{kg·m/s}}{-2.50\times10^4\ \text{kg·m/s}}\right)$$

$$= 36.6°\ \text{north of west}$$

23. A 1383-kg car moving south at 11.2 m/s is struck by a 1732-kg car moving east at 31.3 m/s. The cars are stuck together. How fast and in what direction do they move immediately after the collision?

Before:

$$p_{i,\,x} = p_{1,\,x} + p_{2,\,x}$$

$$= 0 + m_2v_{2i}$$

$$p_{i,\,y} = p_{1,\,y} + p_{2,\,y}$$

$$= m_1v_{1i} + 0$$

$$p_f = p_i$$

$$= \sqrt{{p_{1,\,x}}^2 + {p_{i,\,y}}^2}$$

$$= \sqrt{(m_2v_{2i})^2 + (m_1v_{1i})^2}$$

$$v_f = \frac{p_f}{m_1 + m_2}$$

$$= \frac{\sqrt{(m_2v_{2i})^2 + (m_1v_{1i})^2}}{m_1 + m_2}$$

$$= \frac{\sqrt{((1732\ \text{kg})(31.3\ \text{m/s}))^2 + ((1383\ \text{kg})(-11.2\ \text{m/s}))^2}}{1383\ \text{kg} + 1782\ \text{kg}}$$

$$= 18.1\ \text{m/s}$$

$$\theta = \tan^{-1}\left(\frac{p_{i,\,y}}{p_{i,\,x}}\right) = \tan^{-1}\left(\frac{m_1v_{1i}}{m_2v_{2i}}\right) = \tan^{-1}\left(\frac{(1383\ \text{kg})(-11.2\ \text{m/s})}{(1732\ \text{kg})(31.3\ \text{m/s})}\right) = 15.9°$$

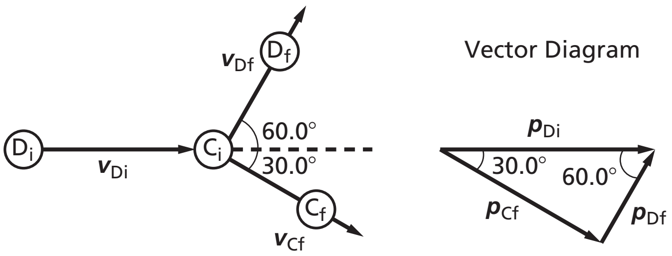
south of east

24. A stationary billiard ball, with a mass of 0.17 kg, is struck by an identical ball moving at 4.0 m/s. After the collision, the second ball moves 60.0° to the left of its original direction. The stationary ball moves 30.0° to the right of the moving ball's original direction. What is the velocity of each ball after the collision?

$$p_{Ci} + p_{Di} = p_{Cf} + p_{Df}$$

where $p_{Ci} = 0.0\ \text{kg·m/s}$

$$m_C = m_D = m = 0.17\ \text{kg}$$



The vector diagram provides final momentum equations for the ball that is initially stationary, C, and the ball that is initially moving, D.

$p_{Cf} = p_{Di} \sin 60.0°$

$p_{Df} = p_{Di} \cos 60.0°$

We can use the momentum equation for the stationary ball to find its final velocity.

$p_{Cf} = p_{Di} \sin 60.0°$

$mv_{Cf} = mv_{Di} \sin 60.0°$

$v_{Cf} = v_{Di} \sin 60.0°$

$= (4.0 \text{ m/s})(\sin 60.0°)$

$= 3.5 \text{ m/s, } 30.0° \text{ to the right}$

We can use the momentum equation for the moving ball to find its velocity.

$p_{Df} = p_{Di} \cos 60.0°$

$mv_{Df} = mv_{Di} \cos 60.0°$

$v_{Df} = v_{Di} \cos 60.0°$

$= (4.0 \text{ m/s})(\cos 60.0°)$

$= 2.0 \text{ m/s, } 60.0° \text{ to the left}$

25. A 1345-kg car moving east at 15.7 m/s is struck by a 1923-kg car moving north. They are stuck together and move with an initial velocity of 14.5 m/s at $\theta = 63.5°$. Was the north-moving car exceeding the 20.1 m/s speed limit?

Before:

$p_{i,x} = m_1 v_{1,i}$

$= (1345 \text{ kg})(15.7 \text{ m/s})$

$= 2.11\times10^4 \text{ kg·m/s}$

$p_f = p_i$

$= (m_1 + m_2)v_f$

$= (1345 \text{ kg} + 1923 \text{ kg})(14.5 \text{ m/s})$

$= 4.74\times10^4 \text{ kg·m/s}$

$p_{f,y} = p_f \sin \theta$

$= (4.74\times10^4 \text{ kg·m/s})(\sin 63.5°)$

$= 4.24\times10^4 \text{ kg·m/s}$

$$p_{f,y} = p_{i,y} = m_2 v_{2,i}$$

$$v_{2,i} = \frac{p_{f,y}}{m_2} = \frac{4.24\times10^4\ \text{kg·m/s}}{1923\ \text{kg}}$$

$$= 22.1\ \text{m/s}$$

Yes, it was exceeding the speed limit.

Section Review

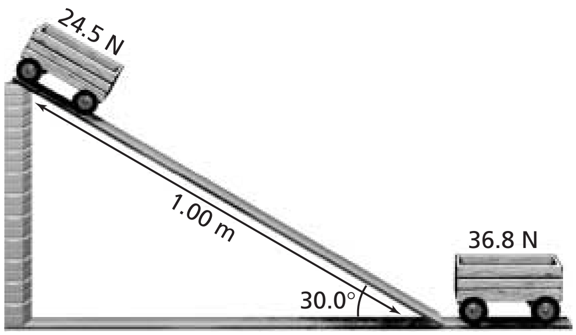
9.2 Conservation of Momentum pages 236–245

page 245

26. Angular Momentum The outer rim of a plastic disk is thick and heavy. Besides making it easier to catch, how does this affect the rotational properties of the plastic disk?

Most of the mass of the disk is located at the rim, thereby increasing its moment of inertia. Therefore, when the disk is spinning, its angular momentum is larger than it would be if more mass were near the center. With a larger angular momentum, the disk flies through the air with more stability.

27. Speed A cart, weighing 24.5 N, is released from rest on a 1.00-m ramp, inclined at an angle of 30.0° as shown in **Figure 9-14.** The cart rolls down the incline and strikes a second cart weighing 36.8 N.



■ **Figure 9-14**

a. Calculate the speed of the first cart at the bottom of the incline.

The force parallel to the surface of the ramp is

$$F_{\parallel} = F_g \sin\theta$$

where

$$a = \frac{F_{\parallel}}{m} \text{ and } m = \frac{F_g}{g}$$

$$\text{so, } a = \frac{F_g \sin\theta}{F_g/g} = g\sin\theta$$

The velocity and acceleration of the cart are related by the motion equation, $v^2 = v_i^2 + 2a(d - d_i)$ with $v_i = 0$ and $d_i = 0$. Thus,

$$v^2 = 2ad$$

$$v = \sqrt{2ad}$$

$$= \sqrt{(2)(g\sin\theta)(d)}$$

$$= \sqrt{(2)(9.80\ \text{m/s}^2)(\sin 30.0°)(1.00\ \text{m})}$$

$$= 3.13\ \text{m/s}$$

b. If the two carts stick together, with what initial speed will they move along?

$$m_C v_{Ci} = (m_C + m_C)v_f$$

$$\text{so, } v_f = \frac{m_C v_{Ci}}{m_C + m_D}$$

$$= \frac{\left(\frac{F_C}{g}\right)v_{Ci}}{\frac{F_C}{g} + \frac{F_D}{g}}$$

$$= \frac{F_C v_{Ci}}{F_C + F_D}$$

$$= \frac{(24.5\ \text{N})(3.13\ \text{m/s})}{24.5\ \text{N} + 36.8\ \text{N}}$$

$$= 1.25\ \text{m/s}$$

28. Conservation of Momentum During a tennis serve, the racket of a tennis player continues forward after it hits the ball. Is momentum conserved in the collision? Explain, making sure that you define the system.

No, because the mass of the racket is much larger than that of the ball, only a small change in its velocity is required. In addition, it is being held by a massive, moving arm that is attached to a body in contact with Earth. Thus, the racket and ball do not comprise an isolated system.

29. Momentum A pole-vaulter runs toward the launch point with horizontal momentum. Where does the vertical momentum come from as the athlete vaults over the crossbar?

The vertical momentum comes from the impulsive force of Earth against the pole. Earth acquires an equal and opposite vertical momentum.

30. **Initial Momentum** During a soccer game, two players come from opposite directions and collide when trying to head the ball. They come to rest in midair and fall to the ground. Describe their initial momenta.

Because their final momenta are zero, their initial momenta were equal and opposite.

31. **Critical Thinking** You catch a heavy ball while you are standing on a skateboard, and then you roll backward. If you were standing on the ground, however, you would be able to avoid moving while catching the ball. Explain both situations using the law of conservation of momentum. Explain which system you use in each case.

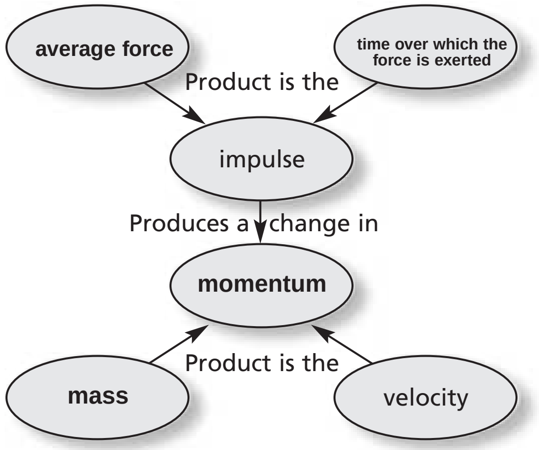
In the case of the skateboard, the ball, the skateboard, and you are an isolated system, and the momentum of the ball is shared. In the second case, unless Earth is included, there is an external force, so momentum is not conserved. If Earth's large mass is included in the system, the change in its velocity is negligible.

Chapter Assessment

Concept Mapping

page 250

32. Complete the following concept map using the following terms: *mass, momentum, average force, time over which the force is exerted.*



Mastering Concepts

page 250

33. Can a bullet have the same momentum as a truck? Explain. (9.1)

Yes, for a bullet to have the same momentum as a truck, it must have a higher velocity because the two masses are not the same.

$m_{bullet}v_{bullet} = m_{truck}v_{truck}$

34. A pitcher throws a curve ball to the catcher. Assume that the speed of the ball doesn't change in flight. (9.1)

a. Which player exerts the larger impulse on the ball?

The pitcher and the catcher exert the same amount of impulse on the ball, but the two impulses are in opposite directions.

b. Which player exerts the larger force on the ball?

The catcher exerts the larger force on the ball because the time interval over which the force is exerted is smaller.

35. Newton's second law of motion states that if no net force is exerted on a system, no acceleration is possible. Does it follow that no change in momentum can occur? (9.1)

No net force on the system means no net impulse on the system and no net change in momentum. However, individual parts of the system may have a

change in momentum as long as the net change in momentum is zero.

36. Why are cars made with bumpers that can be pushed in during a crash? (9.1)

Cars are made with bumpers that compress during a crash to increase the time of a collision, thereby reducing the force.

37. An ice-skater is doing a spin. (9.1)

a. How can the skater's angular momentum be changed?

by applying an external torque

b. How can the skater's angular velocity be changed without changing the angular momentum?

by changing the moment of inertia

38. What is meant by "an isolated system?" (9.2)

An isolated system has no external forces acting on it.

39. A spacecraft in outer space increases its velocity by firing its rockets. How can hot gases escaping from its rocket engine change the velocity of the craft when there is nothing in space for the gases to push against? (9.2)

Momentum is conserved. The change in momentum of gases in one direction must be balanced by an equal change in momentum of the spacecraft in the opposite direction.

40. A cue ball travels across a pool table and collides with the stationary eight ball. The two balls have equal masses. After the collision, the cue ball is at rest. What must be true regarding the speed of the eight ball? (9.2)

The eight ball must be moving with the same velocity that the cue ball had just before the collision.

41. Consider a ball falling toward Earth. (9.2)

a. Why is the momentum of the ball not conserved?

The momentum of a falling ball is not conserved because a net external force, gravity, is acting on it.

b. In what system that includes the falling ball is the momentum conserved?

One such system in which total momentum is conserved includes the ball plus Earth.

42. A falling basketball hits the floor. Just before it hits, the momentum is in the downward direction, and after it hits the floor, the momentum is in the upward direction. (9.2)

a. Why isn't the momentum of the basketball conserved even though the bounce is a collision?

The floor is outside the system, so it exerts an external force, and therefore, an impulse on the ball.

b. In what system is the momentum conserved?

Momentum is conserved in the system of ball plus Earth.

43. Only an external force can change the momentum of a system. Explain how the internal force of a car's brakes brings the car to a stop. (9.2)

The external force of a car's brakes can bring the car to a stop by stopping the wheels and allowing the external frictional force of the road against the tires to stop the car. If there is no friction—for example, if the road is icy—then there is no external force and the car does not stop.

44. Children's playgrounds often have circular-motion rides. How could a child change the angular momentum of such a ride as it is turning? (9.2)

The child would have to exert a torque on it. He or she could stand next to it and exert a force tangential to the circle on the handles as they go past. He or she also could run at the ride and jump onboard.

Applying Concepts

pages 250–251

45. Explain the concept of impulse using physical ideas rather than mathematics.

A force, *F*, exerted on an object over a time, Δt, causes the momentum of the object to change by the quantity $F\Delta t$.

46. Is it possible for an object to obtain a larger impulse from a smaller force than it does from a larger force? Explain.

Yes, if the smaller force acts for a long enough time, it can provide a larger impulse.

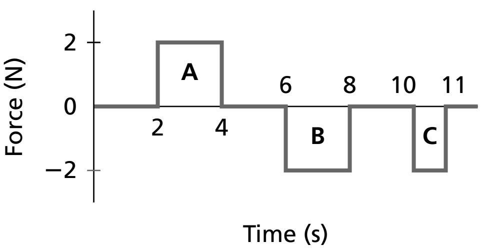
47. Foul Ball You are sitting at a baseball game when a foul ball comes in your direction. You prepare to catch it bare-handed. To catch it safely, should you move your hands toward the ball, hold them still, or move them in the same direction as the moving ball? Explain.

You should move your hands in the same direction the ball is traveling to increase the time of the collision, thereby reducing the force.

48. A 0.11-g bullet leaves a pistol at 323 m/s, while a similar bullet leaves a rifle at 396 m/s. Explain the difference in exit speeds of the two bullets, assuming that the forces exerted on the bullets by the expanding gases have the same magnitude.

The bullet is in the rifle a longer time, so the momentum it gains is larger.

49. An object initially at rest experiences the impulses described by the graph in **Figure 9-15.** Describe the object's motion after impulses A, B, and C.

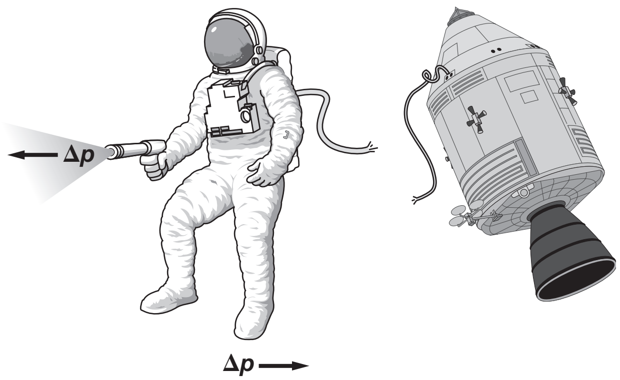


■ **Figure 9-15**

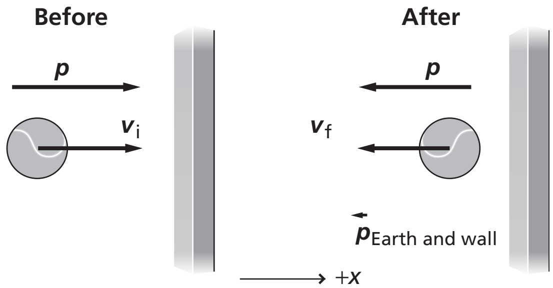
After time A, the object moves with a constant, positive velocity. After time B, the object is at rest. After time C, the object moves with a constant, negative velocity.

50. During a space walk, the tether connecting an astronaut to the spaceship breaks. Using a gas pistol, the astronaut manages to get back to the ship. Use the language of the impulse-momentum theorem and a diagram to explain why this method was effective.

When the gas pistol is fired in the opposite direction, it provides the impulse needed to move the astronaut toward the spaceship.



51. Tennis Ball As a tennis ball bounces off a wall, its momentum is reversed. Explain this action in terms of the law of conservation of momentum. Define the system and draw a diagram as a part of your explanation.



Consider the system to be the ball, the wall, and Earth. The wall and Earth gain some momentum in the collision.

52. Imagine that you command spaceship *Zeldon,* which is moving through interplanetary space at high speed. How could you slow your ship by applying the law of conservation of momentum?

By shooting mass in the form of exhaust gas, at high velocity in the same direction in which you are moving, its momentum would cause the ship's momentum to decrease.

53. Two trucks that appear to be identical collide on an icy road. One was originally at rest. The trucks are stuck together and move at more than half the original speed of the moving truck. What can you conclude about the contents of the two trucks?

If the two trucks had equal masses, they would have moved off at half the speed of the moving truck. Thus, the moving truck must have had a more massive load.

54. Explain, in terms of impulse and momentum, why it is advisable to place the butt of a rifle against your shoulder when first learning to shoot.

When held loosely, the recoil momentum of the rifle works against only the mass of the rifle, thereby producing a larger velocity and striking your shoulder. The recoil momentum must work against the mass of the rifle and you, resulting in a smaller velocity.

55. Bullets Two bullets of equal mass are shot at equal speeds at blocks of wood on a smooth ice rink. One bullet, made of rubber, bounces off of the wood. The other bullet, made of aluminum, burrows into the wood. In which case does the block of wood move faster? Explain.

Momentum is conserved, so the momentum of the block and bullet after the collision equals the momentum of the bullet before the collision. The rubber bullet has a negative momentum after impact, with respect to the block, so the block's momentum must be greater in this case.

Mastering Problems

9.1 Impulse and Momentum

pages 251–252

Level 1

56. Golf Rocío strikes a 0.058-kg golf ball with a force of 272 N and gives it a velocity of 62.0 m/s. How long was Rocío's club in contact with the ball?

$$\Delta t = \frac{m\Delta v}{F} = \frac{(0.058\text{ kg})(62.0\text{ m/s})}{272\text{ N}}$$

$$= 0.013\text{ s}$$

57. A 0.145-kg baseball is pitched at 42 m/s. The batter hits it horizontally to the pitcher at 58 m/s.

a. Find the change in momentum of the ball.

Take the direction of the pitch to be positive.

$$\Delta p = mv_f - mv_i = m(v_f - v_i)$$

$$= (0.145\text{ kg})(-58\text{ m/s} - (+42\text{ m/s}))$$

$$= -14\text{ kg·m/s}$$

b. If the ball and bat are in contact for 4.6×10^{-4} s, what is the average force during contact?

$$F\Delta t = \Delta p$$

$$F = \frac{\Delta p}{\Delta t}$$

$$= \frac{m(v_f - v_i)}{\Delta t}$$

$$= \frac{(0.145\text{ kg})(-58\text{ m/s} - (+42\text{ m/s}))}{4.6\times10^{-4}\text{ s}}$$

$$= -3.2\times10^{4}\text{ N}$$

58. Bowling A force of 186 N acts on a 7.3-kg bowling ball for 0.40 s. What is the bowling ball's change in momentum? What is its change in velocity?

$$\Delta p = F\Delta t$$

$$= (186\text{ N})(0.40\text{ s})$$

$$= 74\text{ N·s}$$

$$= 74\text{ kg·m/s}$$

$$\Delta v = \frac{\Delta p}{m}$$

$$= \frac{F\Delta t}{m}$$

$$= \frac{(186\ \text{N})(0.40\ \text{s})}{7.3\ \text{kg}}$$

$$= 1.0\times10^{1}\ \text{m/s}$$

59. A 5500-kg freight truck accelerates from 4.2 m/s to 7.8 m/s in 15.0 s by the application of a constant force.

a. What change in momentum occurs?

$$\Delta p = m\Delta v = m(v_f - v_i)$$

$$= (5500\ \text{kg})(7.8\ \text{m/s} - 4.2\ \text{m/s})$$

$$= 2.0\times10^{4}\ \text{kg·m/s}$$

b. How large of a force is exerted?

$$F = \frac{\Delta p}{\Delta t}$$

$$= \frac{m(v_f - v_i)}{\Delta t}$$

$$= \frac{(5500\ \text{kg})(7.8\ \text{m/s} - 4.2\ \text{m/s})}{15.0\ \text{s}}$$

$$= 1.3\times10^{3}\ \text{N}$$

60. In a ballistics test at the police department, Officer Rios fires a 6.0-g bullet at 350 m/s into a container that stops it in 1.8 ms. What is the average force that stops the bullet?

$$F = \frac{\Delta p}{\Delta t}$$

$$= \frac{m(v_f - v_i)}{\Delta t}$$

$$= \frac{(0.0060\ \text{kg})(0.0\ \text{m/s} - 350\ \text{m/s})}{1.8\times10^{-3}\ \text{s}}$$

$$= -1.2\times10^{3}\ \text{N}$$

61. Volleyball A 0.24-kg volleyball approaches Tina with a velocity of 3.8 m/s. Tina bumps the ball, giving it a speed of 2.4 m/s but in the opposite direction. What average force did she apply if the interaction time between her hands and the ball was 0.025 s?

$$F = \frac{m\Delta v}{\Delta t}$$

$$= \frac{(0.24\ \text{kg})(-2.4\ \text{m/s} - 3.8\ \text{m/s})}{0.025\ \text{s}}$$

$$= -6.0\times10^{1}\ \text{N}$$

62. Hockey A hockey player makes a slap shot, exerting a constant force of 30.0 N on the hockey puck for 0.16 s. What is the magnitude of the impulse given to the puck?

$$F\Delta t = (30.0\ \text{N})(0.16\ \text{s})$$

$$= 4.8\ \text{N·s}$$

63. Skateboarding Your brother's mass is 35.6 kg, and he has a 1.3-kg skateboard. What is the combined momentum of your brother and his skateboard if they are moving at 9.50 m/s?

$$p = mv$$

$$= (m_{boy} + m_{board})v$$

$$= (35.6\ \text{kg} + 1.3\ \text{kg})(9.50\ \text{m/s})$$

$$= 3.5\times10^{2}\ \text{kg·m/s}$$

64. A hockey puck has a mass of 0.115 kg and is at rest. A hockey player makes a shot, exerting a constant force of 30.0 N on the puck for 0.16 s. With what speed does it head toward the goal?

$$F\Delta t = m\Delta v = m(v_f - v_i)$$

where $v_i = 0$

Thus $v_f = \frac{F\Delta t}{m}$

$$= \frac{(30.0\ \text{N})(0.16\ \text{s})}{0.115\ \text{kg}}$$

$$= 42\ \text{m/s}$$

65. Before a collision, a 25-kg object was moving at +12 m/s. Find the impulse that acted on the object if, after the collision, it moved at the following velocities.

a. +8.0 m/s

$$F\Delta t = m\Delta v = m(v_f - v_i)$$

$$= (25\ \text{kg})(8.0\ \text{m/s} - 12\ \text{m/s})$$

$$= -1.0\times10^{2}\ \text{kg·m/s}$$

b. −8.0 m/s

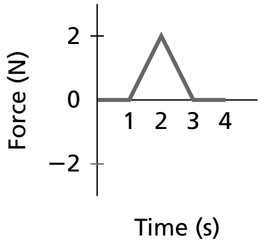
$$F\Delta t = m\Delta v = m(v_f - v_i)$$

$$= (25\ \text{kg})(-8.0\ \text{m/s} - 12\ \text{m/s})$$

$$= -5.0\times10^{2}\ \text{kg·m/s}$$

Level 2

66. A 0.150-kg ball, moving in the positive direction at 12 m/s, is acted on by the impulse shown in the graph in **Figure 9-16.** What is the ball's speed at 4.0 s?



■ **Figure 9-16**

$F\Delta t = m\Delta v$

Area of graph $= m\Delta v$

$\frac{1}{2}(2.0\text{ N})(2.0\text{ s}) = m(v_f - v_i)$

$2.0\text{ N·s} = (0.150\text{ kg})(v_f - 12\text{ m/s})$

$v_f = \frac{2.0\text{ kg·m/s}}{0.150\text{ kg}} + 12\text{ m/s}$

$= 25\text{ m/s}$

67. Baseball A 0.145-kg baseball is moving at 35 m/s when it is caught by a player.

a. Find the change in momentum of the ball.

$\Delta p = m(v_f - v_i)$

$= (0.145\text{ kg})(0.0\text{ m/s} - 35\text{ m/s})$

$= -5.1\text{ kg·m/s}$

b. If the ball is caught with the mitt held in a stationary position so that the ball stops in 0.050 s, what is the average force exerted on the ball?

$\Delta p = F_{average}\Delta t$

so, $F_{average} = \frac{\Delta p}{\Delta t} = \frac{m(v_f - v_i)}{\Delta t}$

$= \frac{(0.145\text{ kg})(0.0\text{ m/s} - 35\text{ m/s})}{0.500\text{ s}}$

$= -1.0\times10^2\text{ N}$

c. If, instead, the mitt is moving backward so that the ball takes 0.500 s to stop, what is the average force exerted by the mitt on the ball?

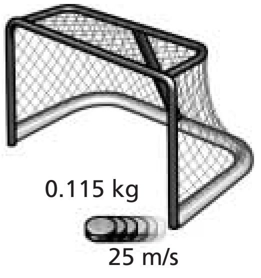
$\Delta p = F_{average}\Delta t$

so, $F_{average} = \frac{\Delta p}{\Delta t} = \frac{m(v_f - v_i)}{\Delta t}$

$= \frac{(0.145\text{ kg})(0.0\text{ m/s} - 35\text{ m/s})}{0.500\text{ s}}$

$= -1.0\times10^1\text{ N}$

68. Hockey A hockey puck has a mass of 0.115 kg and strikes the pole of the net at 37 m/s. It bounces off in the opposite direction at 25 m/s, as shown in **Figure 9-17.**



■ **Figure 9-17**

a. What is the impulse on the puck?

$F\Delta t = m(v_f - v_i)$

$= (0.115\text{ kg})(-25\text{ m/s} - 37\text{ m/s})$

$= -7.1\text{ kg·m/s}$

b. If the collision takes 5.0×10^{-4} s, what is the average force on the puck?

$$F\Delta t = m(v_f - v_i)$$

$$F = \frac{m(v_f - v_i)}{\Delta t}$$

$$= \frac{(0.115\text{ kg})(-25\text{ m/s} - 37\text{ m/s})}{5.0\times10^{-4}\text{ s}}$$

$$= -1.4\times10^{4}\text{ N}$$

69. A nitrogen molecule with a mass of 4.7×10^{-26} kg, moving at 550 m/s, strikes the wall of a container and bounces back at the same speed.

a. What is the impulse the molecule delivers to the wall?

$$F\Delta t = m(v_f - v_i)$$

$$= (4.7\times10^{-26}\text{ kg})(-550\text{ m/s} - 550\text{ m/s})$$

$$= -5.2\times10^{-23}\text{ kg·m/s}$$

The impulse the wall delivers to the molecule is -5.2×10^{-23} kg·m/s. The impulse the molecule delivers to the wall is $+5.2\times10^{-23}$ kg·m/s.

b. If there are 1.5×10^{23} collisions each second, what is the average force on the wall?

$$F\Delta t = m(v_f - v_i)$$

$$F = \frac{m(v_f - v_i)}{\Delta t}$$

For all the collisions, the force is

$$F_{total} = (1.5\times10^{23})\frac{m(v_f - v_i)}{\Delta t}$$

$$= (1.5\times10^{23})\frac{(4.7\times10^{-26}\text{ kg})(-550\text{ m/s} - 550\text{ m/s})}{1.0\text{ s}}$$

$$= 7.8\text{ N}$$

Level 3

70. Rockets Small rockets are used to make tiny adjustments in the speeds of satellites. One such rocket has a thrust of 35 N. If it is fired to change the velocity of a 72,000-kg spacecraft by 63 cm/s, how long should it be fired?

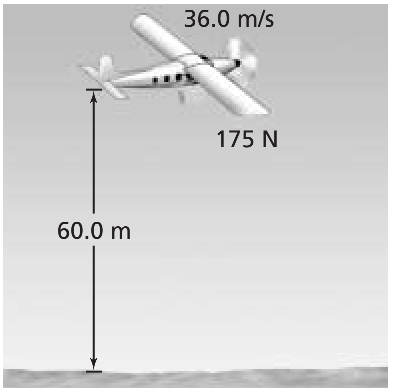
$$F\Delta t = m\Delta v$$

$$\text{so, } \Delta t = \frac{m\Delta t}{F}$$

$$= \frac{(72{,}000\text{ kg})(0.63\text{ m/s})}{35\text{ N}}$$

$$= 1.3\times10^{3}\text{ s, or 22 min}$$

71. An animal rescue plane flying due east at 36.0 m/s drops a bale of hay from an altitude of 60.0 m, as shown in **Figure 9-18.** If the bale of hay weighs 175 N, what is the momentum of the bale the moment before it strikes the ground? Give both magnitude and direction.



■ **Figure 9-18**

First use projectile motion to find the velocity of the bale.

$p = mv$

To find v, consider the horizontal and vertical components.

$v_x = 36.0\text{ m/s}$

$v_y{}^2 = v_{iy}{}^2 + 2dg = 2dg$

Thus,

$v = \sqrt{v_x{}^2 + v_y{}^2} = \sqrt{v_x{}^2 + 2dg}$

The momentum, then, is

$$p = \frac{F_g v}{g} = \frac{F_g\sqrt{v_x{}^2 + 2dg}}{g}$$

$$= \frac{(175\text{ N})\sqrt{(36.0\text{ m/s})^2 + (2)(60.0\text{ m})(9.80\text{ m/s}^2)}}{9.80\text{ m/s}^2}$$

$= 888\text{ kg·m/s}$

The angle from the horizontal is

$$\tan\theta = \frac{v_y}{v_x}$$

$$= \frac{\sqrt{2dg}}{v_x}$$

$$= \frac{\sqrt{(2)(60.0\text{ m})(9.80\text{ m/s}^2)}}{36.0\text{ m/s}}$$

$= 43.6°$

72. Accident A car moving at 10.0 m/s crashes into a barrier and stops in 0.050 s. There is a 20.0-kg child in the car. Assume that the child's velocity is changed by the same amount as that of the car, and in the same time period.

a. What is the impulse needed to stop the child?

$F\Delta t = m\Delta v = m(v_f - v_i)$

$= (20.0\text{ kg})(0.0\text{ m/s} - 10.0\text{ m/s})$

$= -2.00\times10^2\text{ kg·m/s}$

b. What is the average force on the child?

$F\Delta t = m\Delta v = m(v_f - v_i)$

so, $F = \dfrac{m(v_f - v_i)}{\Delta t}$

$$= \frac{(20.0\text{ kg})(0.0\text{ m/s} - 10.0\text{ m/s})}{0.050\text{ s}}$$

$= -4.0\times10^3\text{ N}$

c. What is the approximate mass of an object whose weight equals the force in part **b**?

$F_g = mg$

so, $m = \frac{F_g}{g} = \frac{4.0\times10^3\ \text{N}}{9.80\ \text{m/s}^2}$

$= 4.1\times10^2$ kg

d. Could you lift such a weight with your arm?

No.

e. Why is it advisable to use a proper restraining seat rather than hold a child on your lap?

You would not be able to protect a child on your lap in the event of a collision.

9.2 Conservation of Momentum

pages 252–253

Level 1

73. Football A 95-kg fullback, running at 8.2 m/s, collides in midair with a 128-kg defensive tackle moving in the opposite direction. Both players end up with zero speed.

a. Identify the "before" and "after" situations and draw a diagram of both.

Before: $m_{FB} = 95$ kg

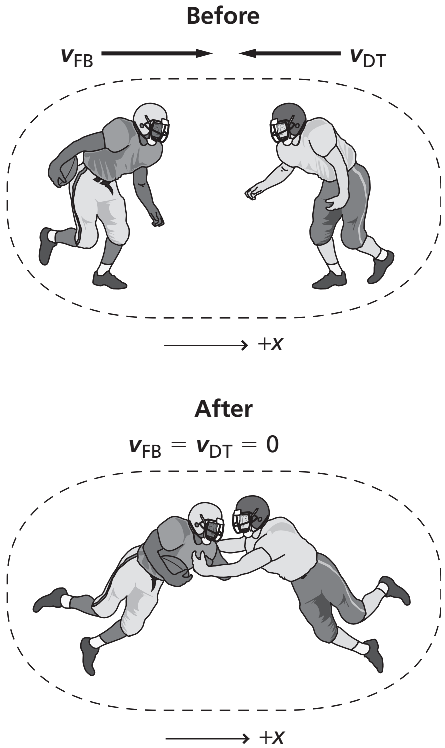
$v_{FB} = 8.2$ m/s

$m_{DT} = 128$ kg

$v_{DT} = ?$

After: $m = 223$ kg

$v_f = 0$ m/s



b. What was the fullback's momentum before the collision?

$p_{FB} = m_{FB}v_{FB} = (95\ \text{kg})(8.2\ \text{m/s})$

$= 7.8\times10^2$ kg·m/s

c. What was the change in the fullback's momentum?

$\Delta p_{FB} = p_f - p_{FB}$

$= 0 - p_{FB} = -7.8\times10^2$ kg·m/s

d. What was the change in the defensive tackle's momentum?

$+7.8\times10^2$ kg·m/s

e. What was the defensive tackle's original momentum?

-7.8×10^2 kg·m/s

f. How fast was the defensive tackle moving originally?

$m_{DT}v_{DT} = -7.8\times10^2$ kg·m/s

so, $v_{DT} = \frac{-7.8\times10^2\ \text{kg·m/s}}{128\ \text{kg}}$

$= -6.1$ m/s

74. Marble C, with mass 5.0 g, moves at a speed of 20.0 cm/s. It collides with a second marble, D, with mass 10.0 g, moving at 10.0 cm/s in the same direction. After the collision, marble C continues with a speed of 8.0 cm/s in the same direction.

a. Sketch the situation and identify the system. Identify the "before" and "after" situations and set up a coordinate system.

Before: $m_C = 5.0$ g

$m_D = 10.0$ g

$v_{Ci} = 20.0$ cm/s

$v_{Di} = 10.0$ cm/s

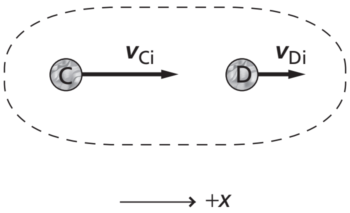
After: $m_C = 5.0$ g

$m_D = 10.0$ g

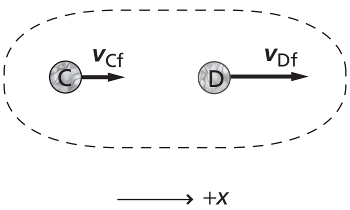
$v_{Cf} = 8.0$ cm/s

$v_{Df} = ?$

Before



After



b. Calculate the marbles' momenta before the collision.

$$m_C v_{Ci} = (5.0\times10^{-3}\text{ kg})(0.200\text{ m/s})$$
$$= 1.0\times10^{-3}\text{ kg·m/s}$$
$$m_D v_{Di} = (1.00\times10^{-2}\text{ kg})(0.100\text{ m/s})$$
$$= 1.0\times10^{-3}\text{ kg·m/s}$$

c. Calculate the momentum of marble C after the collision.

$$m_C v_{Cf} = (5.0\times10^{-3}\text{ kg})(0.080\text{ m/s})$$
$$= 4.0\times10^{-4}\text{ kg·m/s}$$

d. Calculate the momentum of marble D after the collision.

$$p_{Ci} + p_{Di} = p_{Cf} + p_{Df}$$
$$p_{Df} = p_{Ci} + p_{Di} - p_{Cf}$$
$$= 1.00\times10^{-3}\text{ kg·m/s} + 1.00\times10^{-3}\text{ kg·m/s} - 4.0\times10^{-4}\text{ kg·m/s}$$
$$= 1.6\times10^{-3}\text{ kg·m/s}$$

e. What is the speed of marble D after the collision?

$$p_{Df} = m_D v_{Df}$$
$$\text{so, } v_{Df} = \frac{p_{Df}}{m_D}$$
$$= \frac{1.6\times10^{-3}\text{ kg·m/s}}{1.00\times10^{-2}\text{ kg}}$$
$$= 1.6\times10^{-1}\text{ m/s} = 0.16\text{ m/s}$$
$$= 16\text{ cm/s}$$

75. Two lab carts are pushed together with a spring mechanism compressed between them. Upon release, the 5.0-kg cart repels one way with a velocity of 0.12 m/s, while the 2.0-kg cart goes in the opposite direction. What is the velocity of the 2.0-kg cart?

$$m_1 v_i = -m_2 v_f$$
$$v_f = \frac{m_1 v_i}{-m_2}$$
$$= \frac{(5.0\text{ kg})(0.12\text{ m/s})}{-(2.0\text{ kg})}$$
$$= -0.30\text{ m/s}$$

76. A 50.0-g projectile is launched with a horizontal velocity of 647 m/s from a 4.65-kg launcher moving in the same direction at 2.00 m/s. What is the launcher's velocity after the launch?

$$p_{Ci} + p_{Di} = p_{Cf} + p_{Df}$$
$$m_C v_{Ci} + m_D v_{Di} = m_C v_{Cf} + m_D v_{Df}$$
$$\text{so, } v_{Df} = \frac{m_C v_{Ci} + m_D v_{Di} - m_C v_{Cf}}{m_D}$$

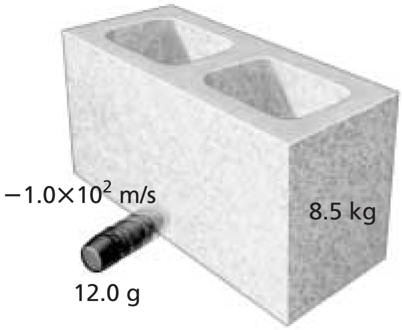
Assuming that the projectile, C, is launched in the direction of the launcher, D, motion,

$$v_{Df} = \frac{(0.0500\ kg)(2.00\ m/s) + (4.65\ kg)(2.00\ m/s) - (0.0500\ kg)(647\ m/s)}{4.65\ kg}$$

= −4.94 m/s, or 4.94 m/s backwards

Level 2

77. A 12.0-g rubber bullet travels at a velocity of 150 m/s, hits a stationary 8.5-kg concrete block resting on a frictionless surface, and ricochets in the opposite direction with a velocity of -1.0×10^2 m/s, as shown in **Figure 9-19.** How fast will the concrete block be moving?



■ **Figure 9-19**

$$m_C v_{Ci} + m_D v_{Di} = m_C v_{Cf} + m_D v_{Df}$$

$$v_{Df} = \frac{m_C v_{Ci} + m_D v_{Di} - m_C v_{Cf}}{m_D}$$

since the block is initially at rest, this becomes

$$v_{Df} = \frac{m_C(v_{Ci} - v_{Cf})}{m_D}$$

$$= \frac{(0.0120\ kg)(150\ m/s - (-1.0\times10^2\ m/s))}{8.5\ kg}$$

= 0.35 m/s

78. Skateboarding Kofi, with mass 42.00 kg, is riding a skateboard with a mass of 2.00 kg and traveling at 1.20 m/s. Kofi jumps off and the skateboard stops dead in its tracks. In what direction and with what velocity did he jump?

$$(m_L v_{Li} + m_s v_{si})v_i = m_L v_{Lf} + m_s v_{sf}$$

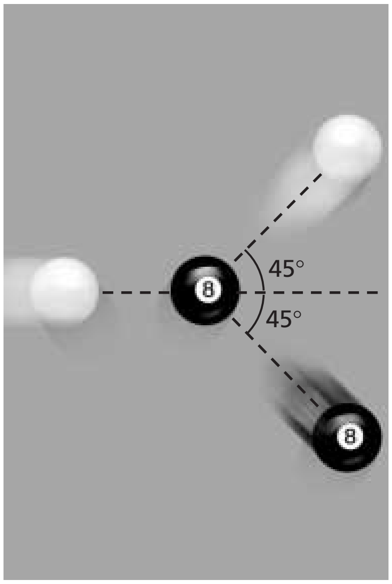
where $v_{sf} = 0$ **and** $v_{Li} = v_{si} = v_i$

Thus $v_{Lf} = \frac{(m_L + m_s)v_i}{m_L}$

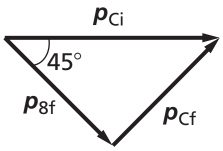
$$= \frac{(42.00\ kg + 2.00\ kg)(1.20\ m/s)}{42.00\ kg}$$

= 1.26 m/s in the same direction as she was riding

79. Billiards A cue ball, with mass 0.16 kg, rolling at 4.0 m/s, hits a stationary eight ball of similar mass. If the cue ball travels 45° above its original path and the eight ball travels 45° below the horizontal, as shown in **Figure 9-20,** what is the velocity of each ball after the collision?



■ **Figure 9-20**



We can get momentum equations from the vector diagram.

$p_{Cf} = p_{Ci} \sin 45°$

$m_C v_{Cf} = m_C v_{Ci} \sin 45°$

$v_{Cf} = v_{Ci} \sin 45°$

$= (4.0 \text{ m/s})(\sin 45°)$

$= 2.8 \text{ m/s}$

For the eight ball,

$p_{8f} = p_{ci} \cos 45°$

$m_8 v_{8f} = m_C v_{Ci}(\cos 45°)$

where $m_8 = m_C$. **Thus,**

$v_{8f} = v_{Ci} \cos 45°$

$= (4.0 \text{ m/s})(\cos 45°)$

$= 2.8 \text{ m/s}$

80. A 2575-kg van runs into the back of an 825-kg compact car at rest. They move off together at 8.5 m/s. Assuming that the friction with the road is negligible, calculate the initial speed of the van.

$p_{Ci} + p_{Di} = p_{Cf} + p_{Df}$

$m_C v_{Ci} = (m_C + m_D)v_f$

so, $v_{Ci} = \dfrac{m_C + m_D}{m_C}$

$v_f = \dfrac{(2575 \text{ kg} + 825 \text{ kg})(8.5 \text{ m/s})}{2575 \text{ kg}}$

$= 11 \text{ m/s}$

Level 3

81. In-line Skating Diego and Keshia are on in-line skates and stand face-to-face, then push each other away with their hands. Diego has a mass of 90.0 kg and Keshia has a mass of 60.0 kg.

a. Sketch the event, identifying the "before" and "after" situations, and set up a coordinate axis.

Before: $m_K = 60.0 \text{ kg}$

$m_D = 90.0 \text{ kg}$

$v_i = 0.0 \text{ m/s}$

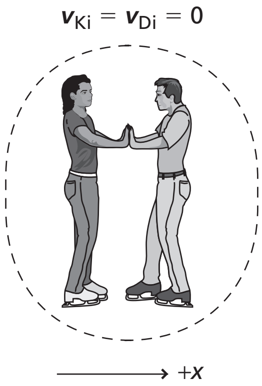
After: $m_K = 60.0 \text{ kg}$

$m_D = 90.0 \text{ kg}$

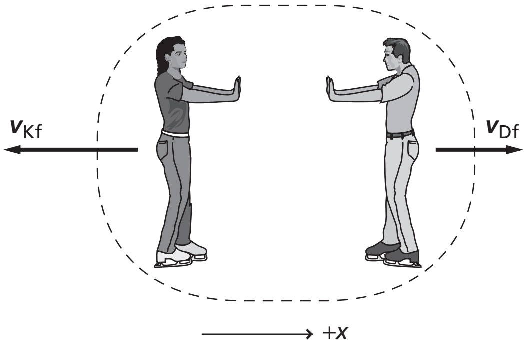
$v_{Kf} = ?$

$v_{Df} = ?$

Before



After



b. Find the ratio of the skaters' velocities just after their hands lose contact.

$p_{Ki} + p_{Di} = 0.0$ **kg·m/s** $= p_{Kf} + p_{Df}$

so, $m_K v_{Kf} + m_D v_{Df} = 0.0$ **kg·m/s**

and $m_K v_{Kf} = -m_D v_{Df}$

Thus, the ratios of the velocities are

$$\frac{v_{Kf}}{v_{Df}} = -\left(\frac{m_D}{m_K}\right) = -\left(\frac{90.0\text{ kg}}{60.0\text{ kg}}\right) = -1.50$$

The negative sign shows that the velocities are in opposite directions.

c. Which skater has the greater speed?

Keshia, who has the smaller mass, has the greater speed.

d. Which skater pushed harder?

The forces were equal and opposite.

82. A 0.200-kg plastic ball moves with a velocity of 0.30 m/s. It collides with a second plastic ball of mass 0.100 kg, which is moving along the same line at a speed of 0.10 m/s. After the collision, both balls continue moving in the same, original direction. The speed of the 0.100-kg ball is 0.26 m/s. What is the new velocity of the 0.200-kg ball?

$$m_C v_{Ci} + m_D v_{Di} = m_C v_{Cf} + m_D v_{Df}$$

so, $v_{Cf} = \dfrac{m_C v_{Ci} + m_D v_{Di} - m_D v_{Df}}{m_C}$

$$= \frac{(0.200\ \text{kg})(0.30\ \text{m/s}) + (0.100\ \text{kg})(0.10\ \text{m/s}) - (0.100\ \text{kg})(0.26\ \text{m/s})}{0.200\ \text{kg}}$$

= 0.22 m/s in the original direction

Mixed Review

pages 253–254

Level 1

83. A constant force of 6.00 N acts on a 3.00-kg object for 10.0 s. What are the changes in the object's momentum and velocity?

The change in momentum is

$$\Delta p = F\Delta t$$
$$= (6.00\ \text{N})(10.0\ \text{s})$$
$$= 60.0\ \text{N·s} = 60.0\ \text{kg·m/s}$$

The change in velocity is found from the impulse.

$$F\Delta t = m\Delta v$$
$$\Delta v = \frac{F\Delta t}{m}$$
$$= \frac{(6.00\ \text{N})(10.0\ \text{s})}{3.00\ \text{kg}}$$
$$= 20.0\ \text{m/s}$$

84. The velocity of a 625-kg car is changed from 10.0 m/s to 44.0 m/s in 68.0 s by an external, constant force.

a. What is the resulting change in momentum of the car?

$$\Delta p = m\Delta v = m(v_f - v_i)$$
$$= (625\ \text{kg})(44.0\ \text{m/s} - 10.0\ \text{m/s})$$
$$= 2.12\times10^4\ \text{kg·m/s}$$

b. What is the magnitude of the force?

$$F\Delta t = m\Delta v$$
$$\text{so, F} = \frac{m\Delta v}{\Delta t}$$
$$= \frac{m(v_f - v_i)}{\Delta t}$$
$$= \frac{(625\ \text{kg})(44.0\ \text{m/s} - 10.0\ \text{m/s})}{68.0\ \text{s}}$$
$$= 313\ \text{N}$$

85. Dragster An 845-kg dragster accelerates on a race track from rest to 100.0 km/h in 0.90 s.

a. What is the change in momentum of the dragster?

$$\Delta p = m(v_f - v_i)$$
$$= (845\ \text{kg})(100.0\ \text{km/h} - 0.0\ \text{km/h})\left(\frac{1000\ \text{m}}{1\ \text{km}}\right)\left(\frac{1\ \text{h}}{3600\ \text{s}}\right)$$
$$= 2.35\times10^4\ \text{kg·m/s}$$

b. What is the average force exerted on the dragster?

$$F = \frac{m(v_f - v_i)}{\Delta t}$$

$$= \frac{(845\text{ kg})(100.0\text{ km/h} - 0.0\text{ km/h})}{0.90\text{ s}}\left(\frac{1000\text{ m}}{1\text{ km}}\right)\left(\frac{1\text{ h}}{3600\text{ s}}\right)$$

$$= 2.6\times10^4\text{ N}$$

c. What exerts that force?

The force is exerted by the track through friction.

Level 2

86. Ice Hockey A 0.115-kg hockey puck, moving at 35.0 m/s, strikes a 0.365-kg jacket that is thrown onto the ice by a fan of a certain hockey team. The puck and jacket slide off together. Find their velocity.

$$m_Pv_{Pi} = (m_P + m_J)v_f$$

$$v_f = \frac{m_Pm_{Pi}}{m_P + m_J}$$

$$= \frac{(0.115\text{ kg})(35.0\text{ m/s})}{(0.115\text{ kg} + 0.365\text{ kg})}$$

$$= 8.39\text{ m/s}$$

87. A 50.0-kg woman, riding on a 10.0-kg cart, is moving east at 5.0 m/s. The woman jumps off the front of the cart and lands on the ground at 7.0 m/s eastward, relative to the ground.

a. Sketch the "before" and "after" situations and assign a coordinate axis to them.

Before: $m_w = 50.0$ kg

$m_c = 10.0$ kg

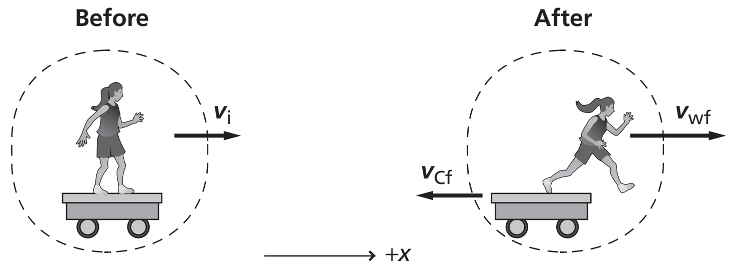
$v_i = 5.0$ m/s

After: $m_w = 50.0$ kg

$m_c = 10.0$ kg

$v_{wf} = 7.0$ m/s

$v_{cf} = ?$



b. Find the cart's velocity after the woman jumps off.

$(m_w + m_c)v_i = m_w v_{wf} + m_c v_{cf}$

so, $v_{cf} = \frac{(m_w + m_c)v_i - m_w v_{wf}}{m_c}$

$= \frac{(50.0 \text{ kg} + 10.0 \text{ kg})(5.0 \text{ m/s}) - (50.0 \text{ kg})(7.0 \text{ m/s})}{10.0 \text{ kg}}$

$= -5.0$ **m/s, or 5.0 m/s west**

88. **Gymnastics** **Figure 9-21** shows a gymnast performing a routine. First, she does giant swings on the high bar, holding her body straight and pivoting around her hands. Then, she lets go of the high bar and grabs her knees with her hands in the tuck position. Finally, she straightens up and lands on her feet.

a. In the second and final parts of the gymnast's routine, around what axis does she spin?

She spins around the center of mass of her body, first in the tuck position and then also as she straightens out.

b. Rank in order, from greatest to least, her moments of inertia for the three positions.

giant swing (greatest), straight, tuck (least)

c. Rank in order, from greatest to least, her angular velocities in the three positions.

tuck (greatest), straight, giant swing (least)

■ **Figure 9-21**

Level 3

89. A 60.0-kg male dancer leaps 0.32 m high.

a. With what momentum does he reach the ground?

$v = v_0^2 + 2dg$

Thus, the velocity of the dancer is

$v = \sqrt{2dg}$

and his momentum is

$$p = mv = m\sqrt{2dg}$$

$$= (60.0\ \text{kg})\sqrt{(2)(0.32\ \text{m})(9.80\ \text{m/s}^2)}$$

$$= 1.5\times10^2\ \text{kg·m/s down}$$

b. What impulse is needed to stop the dancer?

$$F\Delta t = m\Delta v = m(v_f - v_i)$$

To stop the dancer, $v_f = 0$. Thus,

$$F\Delta t = -mv_f = -p = -1.5\times10^2\ \text{kg·m/s up}$$

c. As the dancer lands, his knees bend, lengthening the stopping time to 0.050 s. Find the average force exerted on the dancer's body.

$$F\Delta t = m\Delta v = m\sqrt{2dg}$$

$$\text{so, } F = \frac{m\sqrt{2dg}}{\Delta t}$$

$$= \frac{(60.0\ \text{kg})\sqrt{(2)(0.32\ \text{m})(9.80\ \text{m/s}^2)}}{0.050\ \text{s}}$$

$$= 3.0\times10^3\ \text{N}$$

d. Compare the stopping force with his weight.

$$F_g = mg = (60.0\ \text{kg})(9.80\ \text{m/s}^2) = 5.98\times10^2\ \text{N}$$

The force is about five times the weight.

Thinking Critically

page 254

90. Apply Concepts A 92-kg fullback, running at 5.0 m/s, attempts to dive directly across the goal line for a touchdown. Just as he reaches the line, he is met head-on in midair by two 75-kg linebackers, both moving in the direction opposite the fullback. One is moving at 2.0 m/s and the other at 4.0 m/s. They all become entangled as one mass.

a. Sketch the event, identifying the "before" and "after" situations.

Before: $m_A = 92$ kg

$m_B = 75$ kg

$m_C = 75$ kg

$v_{Ai} = 5.0$ m/s

$v_{Bi} = -2.0$ m/s

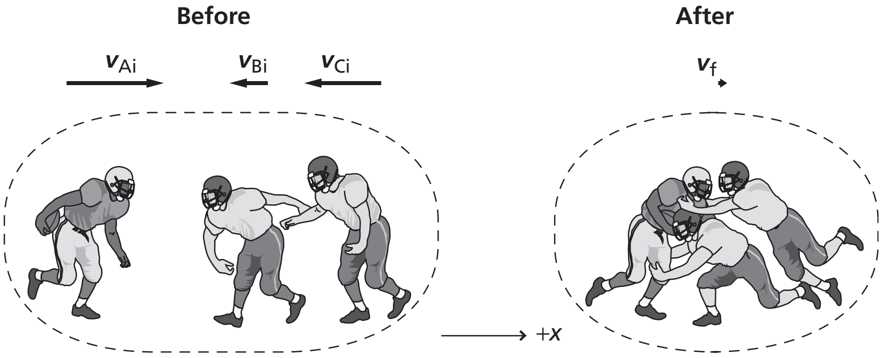
$v_{Ci} = -4.0$ m/s

After: $m_A = 92$ kg

$m_B = 75$ kg

$m_C = 75$ kg

$v_f = ?$



b. What is the velocity of the football players after the collision?

$$p_{Ai} + p_{Bi} + p_{Ci} = p_{Af} + p_{Bf} + p_{Cf}$$

$$m_A v_{Ai} + m_B v_{Bi} + m_C v_{Ci} = m_A v_{Af} + m_B v_{Bf} + m_C v_{Cf}$$

$$= (m_A + m_B + m_C)v_f$$

$$v_f = \frac{m_A v_{Ai} + m_B v_{Bi} + m_{Ci} v_{Ci}}{m_A + m_B + m_C}$$

$$= \frac{(92\text{ kg})(5.0\text{ m/s}) + (75\text{ kg})(-2.0\text{ m/s}) + (75\text{ kg})(-4.0\text{ m/s})}{92\text{ kg} + 75\text{ kg} + 75\text{ kg}}$$

$$= 0.041\text{ m/s}$$

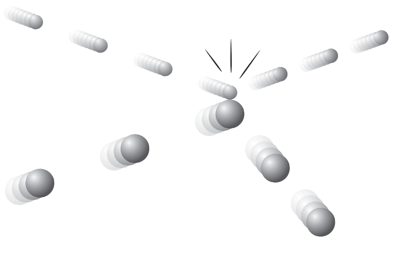
c. Does the fullback score a touchdown?

Yes. The velocity is positive, so the football crosses the goal line for a touchdown.

91. Analyze and Conclude A student, holding a bicycle wheel with its axis vertical, sits on a stool that can rotate without friction. She uses her hand to get the wheel spinning. Would you expect the student and stool to turn? If so, in which direction? Explain.

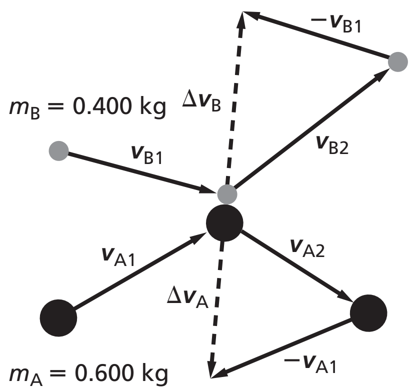
The student and the stool would spin slowly in the direction opposite to that of the wheel. Without friction there are no external torques. Thus, the angular momentum of the system is not changed. The angular momentum of the student and stool must be equal and opposite to the angular momentum of the spinning wheel.

92. Analyze and Conclude Two balls during a collision are shown in **Figure 9-22,** which is drawn to scale. The balls enter from the left, collide, and then bounce away. The heavier ball, at the bottom of the diagram, has a mass of 0.600 kg, and the other has a mass of 0.400 kg. Using a vector diagram, determine whether momentum is conserved in this collision. Explain any difference in the momentum of the system before and after the collision.



■ **Figure 9-22**

Dotted lines show that the changes of momentum for each ball are equal and opposite: $\Delta(m_A v_A) = \Delta(m_B v_B)$. Because the masses have a 3:2 ratio, a 2:3 ratio of velocity changes will compensate.



Writing in Physics

page 254

93. How can highway barriers be designed to be more effective in saving people's lives? Research this issue and describe how impulse and change in momentum can be used to analyze barrier designs.

The change in a car's momentum does not depend on how it is brought to a stop. Thus, the impulse also does not change. To reduce the force, the time over which a car is stopped must be increased. Using barriers that can extend the time it takes to stop a car will reduce the force. Flexible, plastic containers filled with sand often are used.

94. While air bags save many lives, they also have caused injuries and even death. Research the arguments and responses of automobile makers to this statement. Determine whether the problems involve impulse and momentum or other issues.

There are two ways an air bag reduces injury. First, an air bag extends the time over which the impulse acts, thereby reducing the force. Second, an air bag spreads the force over a larger area, thereby reducing the pressure. Thus, the injuries due to forces from small objects are reduced. The dangers of air bags mostly center on the fact that air bags must be inflated very rapidly. The surface of an air bag can approach the passenger at speeds of up to 322 km/h (200 mph). Injuries can occur when the moving bag collides with the person. Systems are being developed that will adjust the rate at which gases fill the air bags to match the size of the person.

Cumulative Review

page 254

95. A 0.72-kg ball is swung vertically from a 0.60-m string in uniform circular motion at a speed of 3.3 m/s. What is the tension in the cord at the top of the ball's motion? (Chapter 6)

The tension is the gravitational force minus the centripetal force.

$$F_T = F_g - F_c$$

$$= mg - \frac{mv^2}{r} = m\left(g - \frac{v^2}{r}\right)$$

$$= (0.72\text{ kg})\left((9.80\text{ m/s}^2) - \frac{(3.3\text{ m/s})^2}{0.60\text{ m}}\right)$$

$$= -6.0\text{ N}$$

96. You wish to launch a satellite that will remain above the same spot on Earth's surface. This means the satellite must have a period of exactly one day. Calculate the radius of the circular orbit this satellite must have. *Hint: The Moon also circles Earth and both the Moon and the satellite will obey Kepler's third law. The Moon is 3.9×10⁸ m from Earth and its period is 27.33 days.* (Chapter 7)

$$\left(\frac{T_s}{T_m}\right)^2 = \left(\frac{r_s}{r_m}\right)^3$$

$$\text{so } r_s = \left(\left(\frac{T_s}{T_m}\right)^2 r_m{}^3\right)^{\frac{1}{3}}$$

$$= \left(\left(\frac{1.000\text{ day}}{27.33\text{ days}}\right)^2 (3.9\times10^8\text{ m})^3\right)^{\frac{1}{3}}$$

$$= 4.3\times10^7\text{ m}$$

97. A rope is wrapped around a drum that is 0.600 m in diameter. A machine pulls with a constant 40.0 N force for a total of 2.00 s. In that time, 5.00 m of rope is unwound. Find α, ω at 2.00 s, and I. (Chapter 8)

The angular acceleration is the ratio of the linear acceleration of the drum's edge and drum's radius.

$$\alpha = \frac{a}{r}$$

The linear acceleration is found from the equation of motion.

$$x = \frac{1}{2}at^2$$

$$a = \frac{2x}{t^2}$$

Thus, the angular acceleration is

$$\alpha = \frac{a}{r} = \frac{2x}{rt^2}$$

$$= \frac{(2)(5.00\ \text{m})}{\left(\frac{0.600\ \text{m}}{2}\right)(2.00\ \text{s})^2}$$

$$= 8.33\ \text{rad/s}^2$$

At the end of 2.00 s, the angular velocity is

$$\omega = \alpha t$$

$$= \frac{2xt}{rt^2}$$

$$= \frac{2x}{rt}$$

$$= \frac{(2)(5.00\ \text{m})}{\left(\frac{0.600\ \text{m}}{2}\right)(2.00\ \text{s})}$$

$$= 16.7\ \text{rad/s}$$

The moment of inertia is

$$I = \frac{\tau}{\alpha}$$

$$= \frac{Fr \sin \theta}{\left(\frac{2x}{rt^2}\right)} = \frac{Fr^2t^2 \sin \theta}{2x}$$

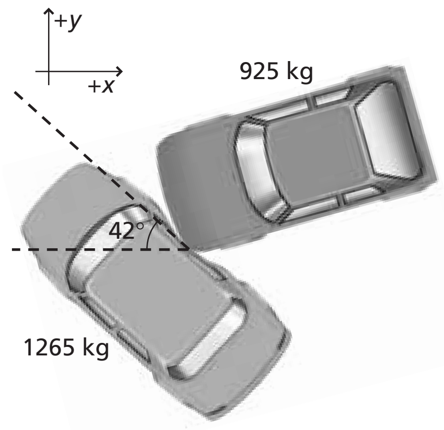
$$= \frac{(40.0\ \text{N})\left(\frac{0.600\ \text{m}}{2}\right)^2(2.00\ \text{s})^2(\sin 90.0°)}{(2)(5.00\ \text{m})}$$

$$= 1.44\ \text{kg·m}^2$$

Challenge Problem

page 244

Your friend was driving her 1265-kg car north on Oak Street when she was hit by a 925-kg compact car going west on Maple Street. The cars stuck together and slid 23.1 m at 42° north of west. The speed limit on both streets is 22 m/s (50 mph). Assume that momentum was conserved during the collision and that acceleration was constant during the skid. The coefficient of kinetic friction between the tires and the pavement is 0.65.



1. Your friend claims that she wasn't speeding, but that the driver of other car was. How fast was your friend driving before the crash?

The vector diagram provides a momentum equation for the friend's car.

$p_{Ci} = p_f \sin 42°$

The friend's initial velocity, then, is

$v_{Ci} = \frac{p_{Ci}}{m_C} = \frac{(m_C + m_D)v_f \sin 42°}{m_C}$

We can find v_f first by finding the acceleration and time of the skid. The acceleration is

$a = \frac{F}{m} = \frac{\mu F_g}{m} = \frac{\mu(m_C + m_D)g}{m_C + m_D} = \mu g$

The time can be derived from the distance equation.

$d = \frac{1}{2}at^2$

$t = \sqrt{\frac{2d}{a}} = \sqrt{\frac{2d}{\mu g}}$

The final velocity, then, is

$v_f = at = \mu g\sqrt{\frac{2d}{\mu g}} = \sqrt{2d\mu g}$

Using this, we now can find the friend's initial velocity.

$v_{Ci} = \frac{(m_C + m_D)v_f \sin 42°}{m_C}$

$= \frac{(m_C + m_D)\sqrt{2d\mu g} \sin 42°}{m_C}$

$= \frac{(1265 \text{ kg} + 925 \text{ kg})\left(\sqrt{(2)(23.1 \text{ m})(0.65)(9.80 \text{ m/s}^2)}\right)(\sin 42°)}{1265 \text{ kg}}$

$= 2.0\times10^1$ m/s

2. How fast was the other car moving before the crash? Can you support your friend's case in court?

From the vector diagram, the momentum equation for the other car is

$$p_{Di} = p_f \cos 42°$$
$$= (m_C + m_D)v_f \cos 42°$$
$$= (m_C + m_D)\sqrt{2d\mu g}\,(\cos 42°)$$

The other car's initial velocity, then, is,

$$v_{Di} = \frac{p_{Di}}{m_D}$$
$$= \frac{(m_C + m_D)\sqrt{2d\mu g}\,(\sin 42°)}{m_D}$$
$$= \frac{(1265\text{ kg} + 925\text{ kg})\left(\sqrt{(2)(23.1\text{ m})(0.65)(9.80\text{ m/s}^2)}\right)(\cos 42°)}{925\text{ kg}}$$
$$= 3.0\times10^{1}\text{ m/s}$$

The friend was not exceeding the 22 m/s speed limit. The other car was exceeding the speed limit.

CHAPTER 10

Energy, Work, and Simple Machines

Practice Problems

10.1 Energy and Work pages 257–265

page 261

1. Refer to Example Problem 1 to solve the following problem.

a. If the hockey player exerted twice as much force, 9.00 N, on the puck, how would the puck's change in kinetic energy be affected?

Because $W = Fd$ and $\Delta KE = W$, doubling the force would double the work, which would double the change in kinetic energy to 1.35 J.

b. If the player exerted a 9.00 N-force, but the stick was in contact with the puck for only half the distance, 0.075 m, what would be the change in kinetic energy?

Because $W = Fd$, halving the distance would cut the work in half, which also would cut the change in kinetic energy in half, to 0.68 J.

2. Together, two students exert a force of 825 N in pushing a car a distance of 35 m.

a. How much work do the students do on the car?

$$W = Fd = (825\text{ N})(35\text{ m}) = 2.9\times10^4\text{ J}$$

b. If the force was doubled, how much work would they do pushing the car the same distance?

$$W = Fd = (2)(825\text{ N})(35\text{ m}) = 5.8\times10^4\text{ J}$$ **which is twice as much work**

3. A rock climber wears a 7.5-kg backpack while scaling a cliff. After 30.0 min, the climber is 8.2 m above the starting point.

a. How much work does the climber do on the backpack?

$$W = Fd = mgd = (7.5\text{ kg})(9.80\text{ m/s}^2)(8.2\text{ m}) = 6.0\times10^2\text{ J}$$

b. If the climber weighs 645 N, how much work does she do lifting herself and the backpack?

$$W = Fd + 6.0\times10^2\text{ J} = (645\text{ N})(8.2\text{ m}) + 6.0\times10^2\text{ J} = 5.9\times10^3\text{ J}$$

c. What is the average power developed by the climber?

$$P = \frac{W}{t} = \left(\frac{5.9\times10^3\text{ J}}{30.0\text{ min}}\right)\left(\frac{1\text{ min}}{60\text{ s}}\right) = 3.3\text{ W}$$

page 262

4. If the sailor in Example Problem 2 pulled with the same force, and along the same distance, but at an angle of 50.0°, how much work would he do?

$$W = Fd\cos\theta = (255\text{ N})(30.0\text{ m})(\cos 50.0°) = 4.92\times10^3\text{ J}$$

5. Two people lift a heavy box a distance of 15 m. They use ropes, each of which makes an angle of 15° with the vertical. Each person exerts a force of 225 N. How much work do they do?

$$W = Fd\cos\theta = (2)(225\text{ N})(15\text{ m})(\cos 15°) = 6.5\times10^3\text{ J}$$

6. An airplane passenger carries a 215-N suitcase up the stairs, a displacement of 4.20 m vertically, and 4.60 m horizontally.

a. How much work does the passenger do?

Since gravity acts vertically, only the vertical displacement needs to be considered.

$W = Fd = (215\ \text{N})(4.20\ \text{m}) = 903\ \text{J}$

b. The same passenger carries the same suitcase back down the same set of stairs. How much work does the passenger do now?

Force is upward, but vertical displacement is downward, so

$W = Fd\cos\theta$

$= (215\ \text{N})(4.20\ \text{m})(\cos 180.0°)$

$= -903\ \text{J}$

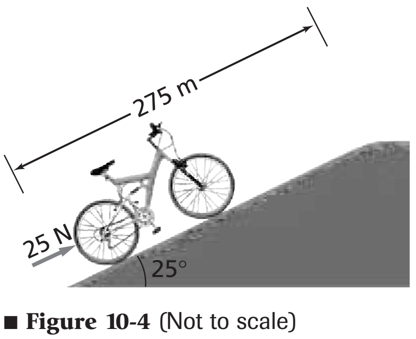
7. A rope is used to pull a metal box a distance of 15.0 m across the floor. The rope is held at an angle of 46.0° with the floor, and a force of 628 N is applied to the rope. How much work does the force on the rope do?

$W = Fd\cos\theta$

$= (628\ \text{N})(15.0\ \text{m})(\cos 46.0°)$

$= 6.54\times10^3\ \text{J}$

8. A bicycle rider pushes a bicycle that has a mass of 13 kg up a steep hill. The incline is 25° and the road is 275 m long, as shown in **Figure 10-4.** The rider pushes the bike parallel to the road with a force of 25 N.



■ **Figure 10-4** (Not to scale)

a. How much work does the rider do on the bike?

Force and displacement are in the same direction.

$W = Fd$

$= (25\ \text{N})(275\ \text{m})$

$= 6.9\times10^3\ \text{J}$

b. How much work is done by the force of gravity on the bike?

The force is downward (−90°), and the displacement is 25° above the horizontal or 115° from the force.

$W = Fd\cos\theta$

$= mgd\cos\theta$

$= (13\ \text{kg})(9.80\ \text{m/s}^2)(275\ \text{m})(\cos 115°)$

$= -1.5\times10^4\ \text{J}$

page 264

9. A box that weighs 575 N is lifted a distance of 20.0 m straight up by a cable attached to a motor. The job is done in 10.0 s. What power is developed by the motor in W and kW?

$$P = \frac{W}{t} = \frac{Fd}{t} = \frac{(575\ \text{N})(20.0\ \text{m})}{10.0\ \text{s}}$$

$= 1.15\times10^3\ \text{W} = 1.15\ \text{kW}$

10. You push a wheelbarrow a distance of 60.0 m at a constant speed for 25.0 s, by exerting a 145-N force horizontally.

a. What power do you develop?

$$P = \frac{W}{t} = \frac{Fd}{t} = \frac{(145\ \text{N})(60.0\ \text{m})}{25.0\ \text{s}} = 348\ \text{W}$$

b. If you move the wheelbarrow twice as fast, how much power is developed?

t is halved, so P is doubled to 696 W.

11. What power does a pump develop to lift 35 L of water per minute from a depth of 110 m? (1 L of water has a mass of 1.00 kg.)

$$P = \frac{W}{t} = \frac{mgd}{t} = \left(\frac{m}{t}\right)gd$$

where $\frac{m}{t} = (35\ \text{L/min})(1.00\ \text{kg/L})$

Thus,

$P = \left(\frac{m}{t}\right)gd$

$= (35\ \text{L/min})(1.00\ \text{kg/L})(9.80\ \text{m/s}^2)(110\ \text{m})(1\ \text{min}/60\text{s})$

$= 0.63\ \text{kW}$

12. An electric motor develops 65 kW of power as it lifts a loaded elevator 17.5 m in 35 s. How much force does the motor exert?

$$P = \frac{W}{t} = \frac{Fd}{t}$$

$$F = \frac{Pt}{d} = \frac{(65\times10^3\ \text{W})(35\ \text{s})}{17.5\ \text{m}}$$

$$= 1.3\times10^5\ \text{N}$$

13. A winch designed to be mounted on a truck, as shown in **Figure 10-7,** is advertised as being able to exert a 6.8×10^3-N force and to develop a power of 0.30 kW. How long would it take the truck and the winch to pull an object 15 m?

■ **Figure 10-7**

$$P = \frac{W}{t} = \frac{Fd}{t}$$

$$t = \frac{Fd}{P}$$

$$= \frac{(6.8\times10^3\ \text{N})(15\ \text{m})}{(0.30\times10^3\ \text{W})} = 340\ \text{s}$$

$$= 5.7\ \text{min}$$

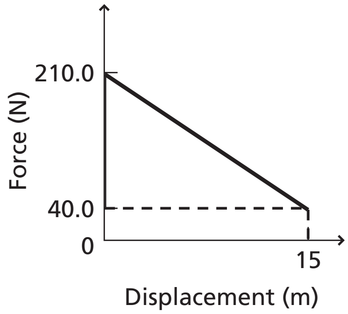
14. Your car has stalled and you need to push it. You notice as the car gets going that you need less and less force to keep it going. Suppose that for the first 15 m, your force decreased at a constant rate from 210.0 N to 40.0 N. How much work did you do on the car? Draw a force-displacement graph to represent the work done during this period.

The work done is the area of the trapezoid under the solid line:

$$W = \frac{1}{2}d(F_1 + F_2)$$

$$= \frac{1}{2}(15\ \text{m})(210.0\ \text{N} + 40.0\ \text{N})$$

$$= 1.9\times10^3\ \text{J}$$



Section Review

10.1 Energy and Work pages 257–265

page 265

15. Work Murimi pushes a 20-kg mass 10 m across a floor with a horizontal force of 80 N. Calculate the amount of work done by Murimi.

$W = Fd = (80\ \text{N})(10\ \text{m}) = 8\times10^2\ \text{J}$

The mass is not important to this problem.

16. Work A mover loads a 185-kg refrigerator into a moving van by pushing it up a 10.0-m, friction-free ramp at an angle of inclination of 11.0°. How much work is done by the mover?

$y = (10.0\ \text{m})(\sin 11.0°)$

$= 1.91\ \text{m}$

$W = Fd = mgd \sin \theta$

$= (185\ \text{kg})(9.80\ \text{m/s}^2)(10.0\ \text{m})(\sin 11.0°)$

$= 3.46\times10^3\ \text{J}$

17. Work and Power Does the work required to lift a book to a high shelf depend on how fast you raise it? Does the power required to lift the book depend on how fast you raise it? Explain.

No, work is not a function of time. However, power is a function of time, so the power required to lift the book does depend on how fast you raise it.

18. Power An elevator lifts a total mass of 1.1×10^3 kg a distance of 40.0 m in 12.5 s. How much power does the elevator generate?

$$P = \frac{W}{t} = \frac{Fd}{t} = \frac{mgd}{t}$$

$$= \frac{(1.1\times10^3\text{ kg})(9.80\text{ m/s}^2)(40.0\text{ m})}{12.5\text{ s}}$$

$$= 3.4\times10^4\text{ W}$$

19. Work A 0.180-kg ball falls 2.5 m. How much work does the force of gravity do on the ball?

$$W = F_g d = mgd$$

$$= (0.180\text{ kg})(9.80\text{ m/s}^2)(2.5\text{ m})$$

$$= 4.4\text{ J}$$

20. Mass A forklift raises a box 1.2 m and does 7.0 kJ of work on it. What is the mass of the box?

$$W = Fd = mgd$$

$$\text{so } m = \frac{W}{gd} = \frac{7.0\times10^3\text{ J}}{(9.80\text{ m/s}^2)(1.2\text{ m})}$$

$$= 6.0\times10^2\text{ kg}$$

21. Work You and a friend each carry identical boxes from the first floor of a building to a room located on the second floor, farther down the hall. You choose to carry the box first up the stairs, and then down the hall to the room. Your friend carries it down the hall on the first floor, then up a different stairwell to the second floor. Who does more work?

Both do the same amount of work. Only the height lifted and the vertical force exerted count.

22. Work and Kinetic Energy If the work done on an object doubles its kinetic energy, does it double its velocity? If not, by what ratio does it change the velocity?

Kinetic energy is proportional to the square of the velocity, so doubling the energy doubles the square of the velocity. The velocity increases by a factor of the square root of 2, or 1.4.

23. Critical Thinking Explain how to find the change in energy of a system if three agents exert forces on the system at once.

Since work is the change in kinetic energy, calculate the work done by each force. The work can be positive, negative, or zero, depending on the relative angles of the force and displacement of the object. The sum of the three works is the change in energy of the system.

Practice Problems

10.2 Machines pages 266–273

page 272

24. If the gear radius in the bicycle in Example Problem 4 is doubled, while the force exerted on the chain and the distance the wheel rim moves remain the same, what quantities change, and by how much?

$$IMA = \frac{r_e}{r_r} = \frac{8.00\text{ cm}}{35.6\text{ cm}} = 0.225\text{ (doubled)}$$

$$MA = \left(\frac{e}{100}\right)IMA = \frac{95.0}{100}(0.225)$$

$$= 0.214\text{ (doubled)}$$

$$MA = \frac{F_r}{F_e}\text{ so } F_r = (MA)(F_e)$$

$$= (0.214)(155\text{ N})$$

$$= 33.2\text{ N}$$

$$IMA = \frac{d_e}{d_r}$$

$$\text{so } d_e = (IMA)(d_r)$$

$$= (0.225)(14.0\text{ cm})$$

$$= 3.15\text{ cm}$$

25. A sledgehammer is used to drive a wedge into a log to split it. When the wedge is driven 0.20 m into the log, the log is separated a distance of 5.0 cm. A force of 1.7×10^4 N is needed to split the log, and the sledgehammer exerts a force of 1.1×10^4 N.

a. What is the *IMA* of the wedge?

$$IMA = \frac{d_e}{d_r} = \frac{(0.20\text{ m})}{(0.050\text{ m})} = 4.0$$

b. What is the *MA* of the wedge?

$$MA = \frac{F_r}{F_e}$$

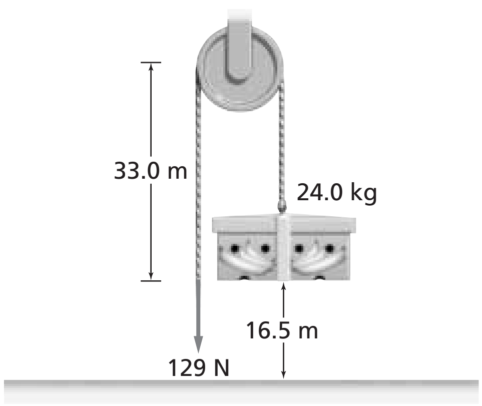
$$= \frac{(1.7\times10^4\ \text{N})}{(1.1\times10^4\ \text{N})} = 1.5$$

c. Calculate the efficiency of the wedge as a machine.

$$e = \frac{MA}{IMA} \times 100$$

$$= \frac{1.5}{4.0} \times 100 = 38\%$$

26. A worker uses a pulley system to raise a 24.0-kg carton 16.5 m, as shown in **Figure 10-14.** A force of 129 N is exerted, and the rope is pulled 33.0 m.



■ **Figure 10-14**

a. What is the *MA* of the pulley system?

$$MA = \frac{F_r}{F_e} = \frac{mg}{F_e}$$

$$= \frac{(24.0\ \text{kg})(9.80\ \text{m/s}^2)}{129\ \text{N}}$$

$$= 1.82$$

b. What is the efficiency of the system?

$$\text{efficiency} = \left(\frac{MA}{IMA}\right) \times 100$$

$$= \frac{(MA)(100)}{\frac{d_e}{d_r}}$$

$$= \frac{(MA)(d_r)(100)}{d_e}$$

$$= \frac{(1.82)(16.5\ \text{m})(100)}{33.0\ \text{m}}$$

$$= 91.0\%$$

27. You exert a force of 225 N on a lever to raise a 1.25×10^3-N rock a distance of 13 cm. If the efficiency of the lever is 88.7 percent, how far did you move your end of the lever?

$$\text{efficiency} = \frac{W_o}{W_i} \times 100$$

$$= \frac{F_r d_r}{F_e d_e} \times 100$$

$$\text{So } d_e = \frac{F_r d_r (100)}{F_e(\text{efficiency})}$$

$$= \frac{(1.25\times10^3\ \text{N})(0.13\ \text{m})(100)}{(225\ \text{N})(88.7)}$$

$$= 0.81\ \text{m}$$

28. A winch has a crank with a 45-cm radius. A rope is wrapped around a drum with a 7.5-cm radius. One revolution of the crank turns the drum one revolution.

a. What is the ideal mechanical advantage of this machine?

Compare effort and resistance distances for 1 rev:

$$IMA = \frac{d_e}{d_r} = \frac{(2\pi)45\ \text{cm}}{(2\pi)7.5\ \text{cm}} = 6.0$$

b. If, due to friction, the machine is only 75 percent efficient, how much force would have to be exerted on the handle of the crank to exert 750 N of force on the rope?

$$\text{efficiency} = \left(\frac{MA}{IMA}\right) \times 100$$

$$= \frac{F_r}{(F_e)(IMA)} \times 100$$

$$\text{so } F_e = \frac{(F_r)(100)}{(\text{efficiency})(IMA)}$$

$$= \frac{(750\ \text{N})(100)}{(75)(6.0)}$$

$$= 1.7\times10^2\ \text{N}$$

Section Review

10.2 Machines pages 266–273

page 273

29. Simple Machines Classify the tools below as a lever, a wheel and axle, an inclined plane, a wedge, or a pulley.

a. screwdriver

wheel and axle

b. pliers

lever

c. chisel

wedge

d. nail puller

lever

30. *IMA* A worker is testing a multiple pulley system to estimate the heaviest object that he could lift. The largest downward force he could exert is equal to his weight, 875 N. When the worker moves the rope 1.5 m, the object moves 0.25 m. What is the heaviest object that he could lift?

$$MA = \frac{F_r}{F_e}$$

so $F_r = (MA)(F_e)$

Assuming the efficiency is 100%,

$$MA = IMA = \left(\frac{d_e}{d_r}\right)(F_e)$$

$$= \frac{(1.5\text{ m})}{(0.25\text{ m})}(875\text{ N})$$

$$= 5.2\times10^3\text{ N}$$

31. Compound Machines A winch has a crank on a 45-cm arm that turns a drum with a 7.5-cm radius through a set of gears. It takes three revolutions of the crank to rotate the drum through one revolution. What is the *IMA* of this compound machine?

The *IMA* of the system is the product of the *IMA* of each machine. For the crank and drum, the ratio of distances is

$$\frac{2\pi(45\text{ cm})}{2\pi(7.5\text{ cm})} = 6.0.$$

$$IMA = \frac{d_e}{d_r} = \frac{(3)(2\pi r)}{2\pi r}$$

$$= \frac{(3)(2\pi)(45\text{ cm})}{(2\pi)(7.5\text{ cm})}$$

$$= 18$$

32. Efficiency Suppose you increase the efficiency of a simple machine. Do the *MA* and *IMA* increase, decrease, or remain the same?

Either *MA* increases while *IMA* remains the same, or *IMA* decreases while *MA* remains the same, or *MA* increases while *IMA* decreases.

33. Critical Thinking The mechanical advantage of a multi-gear bicycle is changed by moving the chain to a suitable rear gear.

a. To start out, you must accelerate the bicycle, so you want to have the bicycle exert the greatest possible force. Should you choose a small or large gear?

large, to increase $IMA = \frac{r_{gear}}{r_{wheel}}$

b. As you reach your traveling speed, you want to rotate the pedals as few times as possible. Should you choose a small or large gear?

Small, because less chain travel, hence few pedal revolutions, will be required per wheel revolution.

c. Many bicycles also let you choose the size of the front gear. If you want even more force to accelerate while climbing a hill, would you move to a larger or smaller front gear?

smaller, to increase pedal-front gear *IMA* because

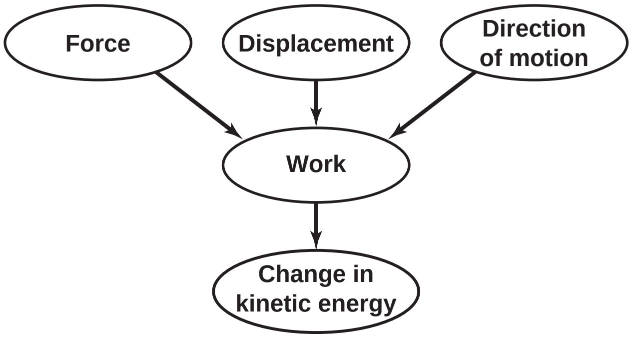
$$IMA = \frac{r_{pedal}}{r_{front\ gear}}$$

Chapter Assessment

Concept Mapping

page 278

34. Create a concept map using the following terms: *force, displacement, direction of motion, work, change in kinetic energy.*



Mastering Concepts

page 278

35. In what units is work measured? (10.1)

joules

36. Suppose a satellite revolves around Earth in a circular orbit. Does Earth's gravity do any work on the satellite? (10.1)

No, the force of gravity is directed toward Earth and is perpendicular to the direction of displacement of the satellite.

37. An object slides at constant speed on a frictionless surface. What forces act on the object? What work is done by each force? (10.1)

Only gravity and an upward, normal force act on the object. No work is done because the displacement is perpendicular to these forces. There is no force in the direction of displacement because the object is sliding at a constant speed.

38. Define *work* and *power.* (10.1)

Work is the product of force and the distance over which an object is moved in the direction of the force. Power is the time rate at which work is done.

39. What is a watt equivalent to in terms of kilograms, meters, and seconds? (10.1)

$$\mathrm{W = J/s = N\cdot m/s = (kg\cdot m/s^2)\cdot m/s = kg\cdot m^2/s^3}$$

40. Is it possible to get more work out of a machine than you put into it? (10.2)

no, $e \leq 100\%$

41. Explain how the pedals of a bicycle are a simple machine. (10.2)

Pedals transfer force from the rider to the bike through a wheel and axle.

Applying Concepts

page 278

42. Which requires more work, carrying a 420-N backpack up a 200-m-high hill or carrying a 210-N backpack up a 400-m-high hill? Why?

Each requires the same amount of work because force times distance is the same.

43. Lifting You slowly lift a box of books from the floor and put it on a table. Earth's gravity exerts a force, magnitude *mg,* downward, and you exert a force, magnitude *mg,* upward. The two forces have equal magnitudes and opposite directions. It appears that no work is done, but you know that you did work. Explain what work was done.

You do positive work on the box because the force and motion are in the same direction. Gravity does negative work on the box because the force of gravity is opposite to the direction of motion. The work done by you and by gravity are separate and do not cancel each other.

44. You have an after-school job carrying cartons of new copy paper up a flight of stairs, and then carrying recycled paper back down the stairs. The mass of the paper does not change. Your physics teacher says that you do not work all day, so you should not be paid. In what sense is the physics teacher correct? What arrangement of payments might you make to ensure that you are properly compensated?

The net work is zero. Carrying the carton upstairs requires positive work; carrying it back down is negative work. The work done in both cases is equal and opposite because the distances are equal and opposite. The student might arrange the payments on the basis of the time it takes to carry paper, whether up or down, not on the basis of work done.

45. You carry the cartons of copy paper down the stairs, and then along a 15-m-long hallway. Are you working now? Explain.

No, the force on the box is up and the displacement is down the hall. They are perpendicular and no work is done.

46. **Climbing Stairs** Two people of the same mass climb the same flight of stairs. The first person climbs the stairs in 25 s; the second person does so in 35 s.

a. Which person does more work? Explain your answer.

Both people are doing the same amount of work because they both are climbing the same flight of stairs and they have the same mass.

b. Which person produces more power? Explain your answer.

The person who climbs in 25 s expends more power, as less time is needed to cover the distance.

47. Show that power delivered can be written as $P = Fv \cos \theta$.

$P = \frac{W}{t}$, **but** $W = Fd \cos \theta$

so, $P = \frac{Fd \cos \theta}{t}$

because $v = \frac{d}{t}$,

$P = Fv \cos \theta$

48. How can you increase the ideal mechanical advantage of a machine?

Increase the ratio of d_e/d_r to increase the *IMA* of a machine.

49. **Wedge** How can you increase the mechanical advantage of a wedge without changing its ideal mechanical advantage?

Reduce friction as much as possible to reduce the resistance force.

50. **Orbits** Explain why a planet orbiting the Sun does not violate the work-energy theorem.

Assuming a circular orbit, the force due to gravity is perpendicular to the direction of motion. This means the work done is zero. Hence, there is no change in kinetic energy of the planet, so it does not speed up or slow down. This is true for a circular orbit.

51. **Claw Hammer** A claw hammer is used to pull a nail from a piece of wood, as shown in **Figure 10-16.** Where should you place your hand on the handle and where should the nail be located in the claw to make the effort force as small as possible?

■ **Figure 10-16**

Your hand should be as far from the head as possible to make d_e as large as possible. The nail should be as close to the head as possible to make d_r as small as possible.

Mastering Problems

10.1 Energy and Work

pages 278–280

Level 1

52. The third floor of a house is 8 m above street level. How much work is needed to move a 150-kg refrigerator to the third floor?

$W = Fd = mgd$

$= (150\ \text{kg})(9.80\ \text{m/s}^2)(8\ \text{m})$

$= 1\times10^4\ \text{J}$

53. Haloke does 176 J of work lifting himself 0.300 m. What is Haloke's mass?

$W = Fd = mgd$; therefore,

$m = \frac{W}{gd} = \frac{176\ \text{J}}{(9.80\ \text{m/s}^2)(0.300\ \text{m})}$

$= 59.9\ \text{kg}$

54. Football After scoring a touchdown, an 84.0-kg wide receiver celebrates by leaping 1.20 m off the ground. How much work was done by the wide receiver in the celebration?

$W = Fd = mgd$

$= (84.0\ \text{kg})(9.80\ \text{m/s}^2)(1.20\ \text{m})$

$= 988\ \text{J}$

55. Tug-of-War During a tug-of-war, team A does 2.20×10^5 J of work in pulling team B 8.00 m. What force was team A exerting?

$W = Fd$, so

$F = \frac{W}{d} = \frac{2.20\times10^5\ \text{J}}{8.00\ \text{m}} = 2.75\times10^4\ \text{N}$

56. To keep a car traveling at a constant velocity, a 551-N force is needed to balance frictional forces. How much work is done against friction by the car as it travels from Columbus to Cincinnati, a distance of 161 km?

$W = Fd = (551\ \text{N})(1.61\times10^5\ \text{m})$

$= 8.87\times10^7\ \text{J}$

57. Cycling A cyclist exerts a force of 15.0 N as he rides a bike 251 m in 30.0 s. How much power does the cyclist develop?

$P = \frac{W}{t} = \frac{Fd}{t}$

$= \frac{(15.0\ \text{N})(2.51\ \text{m})}{30.0\ \text{s}}$

$= 126\ \text{W}$

58. A student librarian lifts a 2.2-kg book from the floor to a height of 1.25 m. He carries the book 8.0 m to the stacks and places the book on a shelf that is 0.35 m above the floor. How much work does he do on the book?

Only the net vertical displacement counts.

$W = Fd = mgd$

$= (2.2\ \text{kg})(9.80\ \text{m/s}^2)(0.35\ \text{m})$

$= 7.5\ \text{J}$

59. A force of 300.0 N is used to push a 145-kg mass 30.0 m horizontally in 3.00 s.

a. Calculate the work done on the mass.

$W = Fd = (300.0\ \text{N})(30.0\ \text{m})$

$= 9.00\times10^3\ \text{J}$

$= 9.00\ \text{kJ}$

b. Calculate the power developed.

$P = \frac{W}{t} = \frac{9.00\times10^3\ \text{J}}{3.00\ \text{s}}$

$= 3.00\times10^3\ \text{W}$

$= 3.00\ \text{kW}$

Level 2

60. Wagon A wagon is pulled by a force of 38.0 N exerted on the handle at an angle of 42.0° with the horizontal. If the wagon is pulled in a circle of radius 25.0 m, how much work is done?

$W = Fd \cos \theta$

$= (F)(2\pi r) \cos \theta$

$= (38.0\ \text{N})(2\pi)(25.0\ \text{m})(\cos 42.0°)$

$= 4.44\times10^3\ \text{J}$

61. Lawn Mower Shani is pushing a lawn mower with a force of 88.0 N along a handle that makes an angle of 41.0° with the horizontal. How much work is done by

Shani in moving the lawn mower 1.2 km to mow the yard?

$W = Fd\cos\theta$

$= (88.0\ \text{N})(1.2\times10^3\ \text{m})(\cos 41.0°)$

$= 8.0\times10^4\ \text{J}$

62. A 17.0-kg crate is to be pulled a distance of 20.0 m, requiring 1210 J of work to be done. If the job is done by attaching a rope and pulling with a force of 75.0 N, at what angle is the rope held?

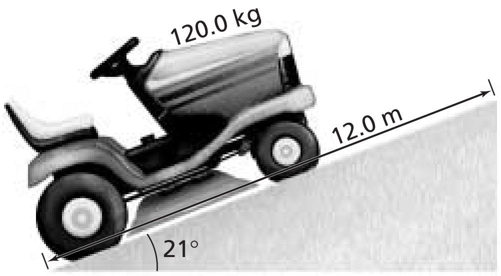
$W = Fd\cos\theta$

$\theta = \cos^{-1}\left(\frac{W}{Fd}\right)$

$= \cos^{-1}\left(\frac{1210\ \text{J}}{(75.0\ \text{N})(20.0\ \text{m})}\right)$

$= 36.2°$

63. Lawn Tractor A 120-kg lawn tractor, shown in **Figure 10-17,** goes up a 21° incline that is 12.0 m long in 2.5 s. Calculate the power that is developed by the tractor.



■ **Figure 10-17**

$P = \frac{W}{t} = \frac{Fd\sin\theta}{t} = \frac{mgd\sin\theta}{t}$

$= \frac{(120\ \text{kg})(9.80\ \text{m/s}^2)(12.0\ \text{m})(\sin 21°)}{2.5\ \text{s}}$

$= 2.0\times10^3\ \text{W} = 2.0\ \text{kW}$

64. You slide a crate up a ramp at an angle of 30.0° by exerting a 225-N force parallel to the ramp. The crate moves at a constant speed. The coefficient of friction is 0.28. How much work did you do on the crate as it was raised a vertical distance of 1.15 m?

***F* and *d* are parallel so**

$W = Fd = F\left(\frac{h}{\sin\theta}\right)$

$= \frac{(225\ \text{N})(1.15\ \text{m})}{\sin 30.0°}$

$= 518\ \text{J}$

65. Piano A 4.2×10^3-N piano is to be slid up a 3.5-m frictionless plank at a constant speed. The plank makes an angle of 30.0° with the horizontal. Calculate the work done by the person sliding the piano up the plank.

The force parallel to the plane is given by

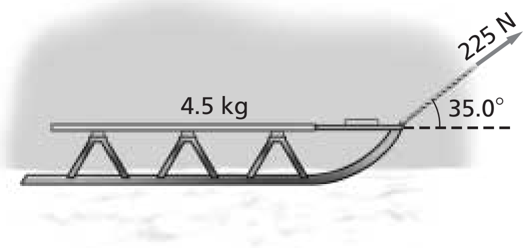
$F_{\parallel} = F\sin\theta$

so $W = F_{\parallel}d = Fd\sin\theta$

$W = (4200\ \text{N})(3.5\ \text{m})(\sin 30.0°)$

$= 7.4\times10^3\ \text{J}$

66. Sled Diego pulls a 4.5-kg sled across level snow with a force of 225 N on a rope that is 35.0° above the horizontal, as shown in **Figure 10-18.** If the sled moves a distance of 65.3 m, how much work does Diego do?



■ **Figure 10-18**

$W = Fd\cos\theta$

$= (225\ \text{N})(65.3\ \text{m})(\cos 35.0°)$

$= 1.20\times10^4\ \text{J}$

67. Escalator Sau-Lan has a mass of 52 kg. She rides up the escalator at Ocean Park in Hong Kong. This is the world's longest escalator, with a length of 227 m and an average inclination of 31°. How much work does the escalator do on Sau-Lan?

$W = Fd\sin\theta = mgd\sin\theta$

$= (52\ \text{kg})(9.80\ \text{m/s}^2)(227\ \text{m})(\sin 31°)$

$= 6.0\times10^4\ \text{J}$

68. Lawn Roller A lawn roller is pushed across a lawn by a force of 115 N along the direction of the handle, which is 22.5°

above the horizontal. If 64.6 W of power is developed for 90.0 s, what distance is the roller pushed?

$$P = \frac{W}{t} = \frac{Fd\cos\theta}{t} \text{ so,}$$

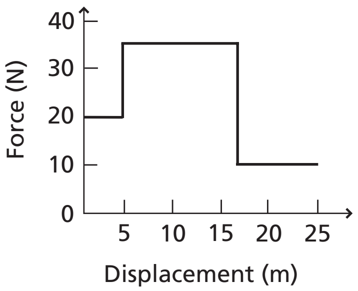
$$d = \frac{Pt}{F\cos\theta}$$

$$= \frac{(64.6\ \text{W})(90.0\ \text{s})}{(115\ \text{N})(\cos 22.5°)}$$

$$= 54.7\ \text{m}$$

69. John pushes a crate across the floor of a factory with a horizontal force. The roughness of the floor changes, and John must exert a force of 20 N for 5 m, then 35 N for 12 m, and then 10 N for 8 m.

a. Draw a graph of force as a function of distance.



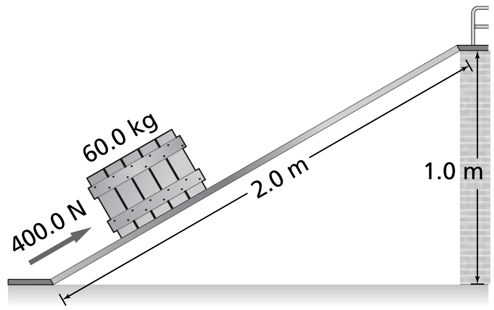
b. Find the work John does pushing the crate.

$$W = F_1d_1 + F_2d_2 + F_3d_3$$

$$= (20\ \text{N})(5\ \text{m}) + (35\ \text{N})(12\ \text{m}) + (10\ \text{N})(8\ \text{m})$$

$$= 600\ \text{J}$$

70. Maricruz slides a 60.0-kg crate up an inclined ramp that is 2.0-m long and attached to a platform 1.0 m above floor level, as shown in **Figure 10-19.** A 400.0-N force, parallel to the ramp, is needed to slide the crate up the ramp at a constant speed.



■ **Figure 10-19**

a. How much work does Maricruz do in sliding the crate up the ramp?

$W = Fd = (400.0\ \text{N})(2.0\ \text{m}) = 8.0\times10^2\ \text{J}$

b. How much work would be done if Maricruz simply lifted the crate straight up from the floor to the platform?

$$W = Fd = mgd$$

$$= (60.0\ \text{kg})(9.80\ \text{m/s}^2)(1.0\ \text{m})$$

$$= 5.9\times10^2\ \text{J}$$

71. Boat Engine An engine moves a boat through the water at a constant speed of 15 m/s. The engine must exert a force of 6.0 kN to balance the force that the water exerts against the hull. What power does the engine develop?

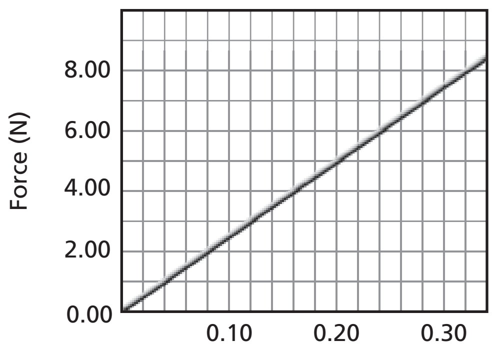
$$P = \frac{W}{t} = \frac{Fd}{t} = Fv$$

$$= (6.0\times10^3\ \text{N})(15\ \text{m/s})$$

$$= 9.0\times10^4\ \text{W} = 9.0\times10^1\ \text{kW}$$

Level 3

72. In **Figure 10-20,** the magnitude of the force necessary to stretch a spring is plotted against the distance the spring is stretched.



■ **Figure 10-20**

a. Calculate the slope of the graph, k, and show that $F = kd$, where $k = 25$ N/m.

$$k = \frac{\Delta y}{\Delta x} = \frac{5.00\text{ N} - 0.00\text{ N}}{0.20\text{ m} - 0.00\text{ m}}$$

$F_1 = kd_1$

Let $d_1 = 0.20$ m

From the graph, F_1 is 5.00 N.

$$\text{So } k = \frac{F_1}{d_1} = \frac{5.00\text{ N}}{0.20\text{ m}} = 25\text{ N/m}$$

b. Find the amount of work done in stretching the spring from 0.00 m to 0.20 m by calculating the area under the graph from 0.00 m to 0.20 m.

$$A = \frac{1}{2}(\text{base})(\text{height}) = \left(\frac{1}{2}\right)(0.20\text{ m})(5.00\text{ N}) = 0.50\text{ J}$$

c. Show that the answer to part **b** can be calculated using the formula $W = \frac{1}{2}kd^2$, where W is the work, $k = 25$ N/m (the slope of the graph), and d is the distance the spring is stretched (0.20 m).

$$W = \frac{1}{2}kd^2 = \left(\frac{1}{2}\right)(25\text{ N/m})(0.20\text{ m})^2 = 0.50\text{ J}$$

73. Use the graph in Figure 10-20 to find the work needed to stretch the spring from 0.12 m to 0.28 m.

Add the areas of the triangle and rectangle. The area of the triangle is:

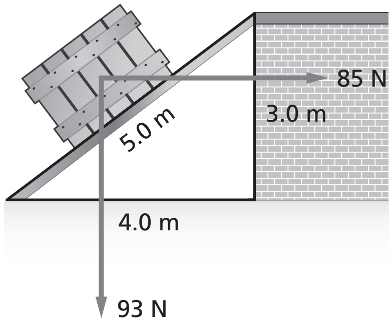
$$\frac{1}{2}bh = \frac{1}{2}(0.28\text{ m} - 0.12\text{ m})(7.00\text{ N} - 3.00\text{ N}) = 0.32\text{ J}$$

The area of the rectangle is:

$$bh = (0.28\text{ m} - 0.12\text{ m})(3.00\text{ N} - 0.00\text{ N}) = 0.48\text{ J}$$

Total work is 0.32 J + 0.48 J = 0.80 J

74. A worker pushes a crate weighing 93 N up an inclined plane. The worker pushes the crate horizontally, parallel to the ground, as illustrated in **Figure 10-21.**



■ **Figure 10-21**

a. The worker exerts a force of 85 N. How much work does he do?

Displacement in direction of force is 4.0 m,

$$\text{so } W = Fd = (85\text{ N})(4.0\text{ m}) = 3.4\times10^2\text{ J}$$

b. How much work is done by gravity? (Be careful with the signs you use.)

Displacement in direction of force is −3.0 m,

$$\text{so } W = Fd = (93\text{ N})(-3.0\text{ m}) = -2.8\times10^2\text{ J}$$

c. The coefficient of friction is $\mu = 0.20$. How much work is done by friction? (Be careful with the signs you use.)

$$W = \mu F_N d = \mu(F_{you,\perp} + F_{g,\perp})d$$

$$= 0.20(85\text{ N})(\sin\theta) + (93\text{ N})(\cos\theta)(-5.0\text{ m})$$

$$= 0.20(85\text{ N})\left(\frac{3.0}{5.0}\right) + (93\text{ N})\left(\frac{4.0}{5.0}\right)(-5.0\text{ m})$$

$$= -1.3\times10^2\text{ J (work done against friction)}$$

75. Oil Pump In 35.0 s, a pump delivers 0.550 m^3 of oil into barrels on a platform 25.0 m above the intake pipe. The oil's density is 0.820 g/cm^3.

a. Calculate the work done by the pump.

The work done is

$$W = F_g d = mgh$$

$$= (\text{volume})(\text{density})gh$$

$$= (0.550\ \text{m}^3)(0.820\ \text{g/cm}^3)\left(\frac{1\ \text{kg}}{1000\ \text{g}}\right)(1.00\times10^6\ \text{cm}^3/\text{m}^3)(9.80\ \text{m/s}^2)(25.0\ \text{m})$$

$$= 1.10\times10^5\ \text{J}$$

b. Calculate the power produced by the pump.

$$P = \frac{W}{t} = \frac{1.10\times10^5\ \text{J}}{35.0\ \text{s}}$$

$$= 3.14\times10^3\ \text{W} = 3.14\ \text{kW}$$

76. Conveyor Belt A 12.0-m-long conveyor belt, inclined at 30.0°, is used to transport bundles of newspapers from the mail room up to the cargo bay to be loaded onto delivery trucks. Each newspaper has a mass of 1.0 kg, and there are 25 newspapers per bundle. Determine the power that the conveyor develops if it delivers 15 bundles per minute.

$$P = \frac{W}{t} = \frac{Fd}{t} = \frac{mgd}{t}$$

$$= (25\ \text{newspapers})(15\ \text{bundles/min})(1.0\ \text{kg/newspaper})(9.80\ \text{m/s}^2)(12.0\ \text{m})(\sin 30.0°)(1\ \text{min}/60\ \text{s})$$

$$= 3.7\times10^2\ \text{W}$$

77. A car is driven at a constant speed of 76 km/h down a road. The car's engine delivers 48 kW of power. Calculate the average force that is resisting the motion of the car.

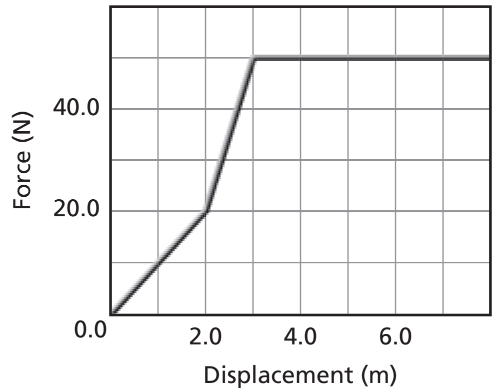
$$P = \frac{W}{t} = \frac{Fd}{t} = Fv$$

$$\text{so } F = \frac{P}{v}$$

$$= \frac{48{,}000\ \text{W}}{\left(\frac{76\ \text{km}}{1\ \text{h}}\right)\left(\frac{1000\ \text{m}}{1\ \text{km}}\right)\left(\frac{1\ \text{h}}{3600\ \text{s}}\right)}$$

$$= 2.3\times10^3\ \text{N}$$

78. The graph in **Figure 10-22** shows the force and displacement of an object being pulled.



■ **Figure 10-22**

a. Calculate the work done to pull the object 7.0 m.

Find the area under the curve (see graph):

0.0 to 2.0 m:

$$\frac{1}{2}(20.0\ \text{N})(2.0\ \text{m}) = 2.0\times10^1\ \text{J}$$

2.0 m to 3.0 m:

$$\frac{1}{2}(30.0\ \text{N})(1.0\ \text{m}) + (20\ \text{N})(1.0\ \text{m}) = 35\ \text{J}$$

3.0 m to 7.0 m:

$$(50.0\ \text{N})(4.0\ \text{m}) = 2.0\times10^2\ \text{J}$$

Total work:

$$2.0\times10^1\ \text{J} + 35\ \text{J} + 2.0\times10^2\ \text{J}$$

$$= 2.6\times10^2\ \text{J}$$

b. Calculate the power that would be developed if the work was done in 2.0 s.

$$P = \frac{W}{t} = \frac{2.6\times10^2\ \text{J}}{2.0\ \text{s}} = 1.3\times10^2\ \text{W}$$

10.2 Machines
pages 280–281
Level 1

79. Piano Takeshi raises a 1200-N piano a distance of 5.00 m using a set of pulleys. He pulls in 20.0 m of rope.

a. How much effort force would Takeshi apply if this were an ideal machine?

$$\frac{F_r}{F_e} = \frac{d_e}{d_r}$$

$$\text{so } F_e = \frac{F_r d_r}{d_e} = \frac{(1200\text{ N})(5.00\text{ m})}{20.0\text{ m}}$$

$$= 3.0\times10^2\text{ N}$$

b. What force is used to balance the friction force if the actual effort is 340 N?

$$F_e = F_f + F_{e,\text{ ideal}}$$

$$F_f = F_e - F_{e,\text{ ideal}} = 340\text{ N} - 3.0\times10^2\text{ N}$$

$$= 40\text{ N}$$

c. What is the output work?

$$W_o = F_r d_r = (1200\text{ N})(5.00\text{ m})$$

$$= 6.0\times10^3\text{ J}$$

d. What is the input work?

$$W_i = F_e d_e = (340\text{ N})(20.0\text{ m})$$

$$= 6.8\times10^3\text{ J}$$

e. What is the mechanical advantage?

$$MA = \frac{F_r}{F_e} = \frac{1200\text{ N}}{340\text{ N}} = 3.5$$

80. Lever Because there is very little friction, the lever is an extremely efficient simple machine. Using a 90.0-percent-efficient lever, what input work is required to lift an 18.0-kg mass through a distance of 0.50 m?

$$\text{efficiency} = \frac{W_o}{W_i}\times 100$$

$$W_i = \frac{(W_o)(100)}{\text{efficiency}} = \frac{(mgd)(100)}{90.0}$$

$$= \frac{(18.0\text{ kg})(9.80\text{ m/s}^2)(0.50\text{ m})(100)}{90.0}$$

$$= 98\text{ J}$$

81. A pulley system lifts a 1345-N weight a distance of 0.975 m. Paul pulls the rope a distance of 3.90 m, exerting a force of 375 N.

a. What is the ideal mechanical advantage of the system?

$$IMA = \frac{d_e}{d_r} = \frac{3.90\text{ m}}{0.975\text{ m}} = 4.00$$

b. What is the mechanical advantage?

$$MA = \frac{F_r}{F_e} = \frac{1345\text{ N}}{375\text{ N}} = 3.59$$

c. How efficient is the system?

$$\text{efficiency} = \frac{MA}{IMA}\times 100$$

$$= \frac{3.59}{4.00}\times 100$$

$$= 89.8\%$$

82. A force of 1.4 N is exerted through a distance of 40.0 cm on a rope in a pulley system to lift a 0.50-kg mass 10.0 cm. Calculate the following.

a. the *MA*

$$MA = \frac{F_r}{F_e} = \frac{mg}{F_e}$$

$$= \frac{(0.50\text{ kg})(9.80\text{ m/s}^2)}{1.4\text{ N}}$$

$$= 3.5$$

b. the *IMA*

$$IMA = \frac{d_e}{d_r} = \frac{40.0\text{ cm}}{10.0\text{ cm}} = 4.00$$

c. the efficiency

$$\text{efficiency} = \frac{MA}{IMA}\times 100$$

$$= \frac{3.5}{4.00}\times 100 = 88\%$$

83. A student exerts a force of 250 N on a lever, through a distance of 1.6 m, as he lifts a 150-kg crate. If the efficiency of the lever is 90.0 percent, how far is the crate lifted?

$$e = 90 = \frac{MA}{IMA}\times 100 = \frac{\frac{F_r}{F_e}}{\frac{d_e}{d_r}}\times 100$$

$$= \frac{F_r d_r}{F_e d_e}\times 100$$

so, $d_r = \frac{eF_e d_e}{100F_r} = \frac{eF_e d_e}{100mg}$

$= \frac{(90.0)(250\text{ N})(1.6\text{ m})}{(100)(150\text{ kg})(9.80\text{ m/s}^2)}$

$= 0.24\text{ m}$

Level 2

84. What work is required to lift a 215-kg mass a distance of 5.65 m, using a machine that is 72.5 percent efficient?

$e = \frac{W_o}{W_i} \times 100$

$= \frac{F_r d_r}{W_i} \times 100$

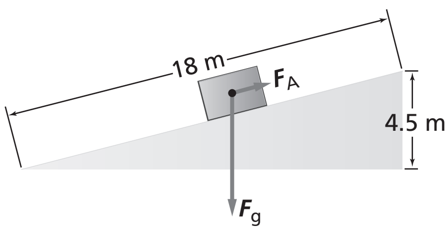
$= \frac{mgd_r}{W_i} \times 100$

$W_i = \frac{mgd_r}{e} \times 100$

$= \frac{(215\text{ kg})(9.80\text{ m/s}^2)(5.65\text{ m})(100)}{72.5}$

$= 1.64\times10^4\text{ J}$

85. The ramp in **Figure 10-23** is 18 m long and 4.5 m high.



■ **Figure 10-23**

a. What force, parallel to the ramp (F_A), is required to slide a 25-kg box at constant speed to the top of the ramp if friction is disregarded?

$W = F_g d = mgh$

so $F = F_g = \frac{mgh}{d}$

$= \frac{(25\text{ kg})(9.80\text{ m/s}^2)(4.5\text{ m})}{18\text{ m}}$

$= 61\text{ N}$

b. What is the *IMA* of the ramp?

$IMA = \frac{d_e}{d_f} = \frac{18\text{ m}}{4.5\text{ m}} = 4.0$

c. What are the real *MA* and the efficiency of the ramp if a parallel force of 75 N is actually required?

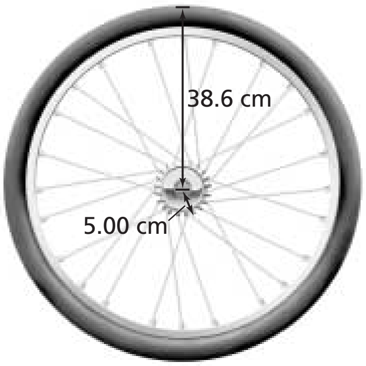
$MA = \frac{F_r}{F_e}$

$= \left(\frac{mg}{F_e}\right)\frac{(25\text{ kg})(9.80\text{ m/s}^2)}{75\text{ N}} = 3.3$

efficiency $= \frac{MA}{IMA} \times 100$

$= \frac{3.3}{4.0} \times 100 = 82\%$

86. Bicycle Luisa pedals a bicycle with a gear radius of 5.00 cm and a wheel radius of 38.6 cm, as shown in **Figure 10-24.** If the wheel revolves once, what is the length of the chain that was used?



■ **Figure 10-24**

$d = 2\pi r = 2\pi(5.00\text{ cm}) = 31.4\text{ cm}$

Level 3

87. Crane A motor with an efficiency of 88 percent operates a crane with an efficiency of 42 percent. If the power supplied to the motor is 5.5 kW, with what constant speed does the crane lift a 410-kg crate of machine parts?

Total efficiency = (88%)(42%) = 37%

Useful Power = (5.5 kW)(37%)

= 2.0 kW

$= 2.0\times10^3\text{ W}$

$$P = \frac{W}{t} = \frac{Fd}{t} = F\left(\frac{d}{t}\right) = Fv$$

$$v = \frac{P}{F_g} = \frac{P}{mg} = \frac{2.0\times10^3\ \text{W}}{(410\ \text{kg})(9.80\ \text{m/s}^2)}$$

$$= 0.50\ \text{m/s}$$

88. A compound machine is constructed by attaching a lever to a pulley system. Consider an ideal compound machine consisting of a lever with an *IMA* of 3.0 and a pulley system with an *IMA* of 2.0.

a. Show that the *IMA* of this compound machine is 6.0.

$$W_{i1} = W_{o1} = W_{i2} = W_{o2}$$

$$W_{i1} = W_{o2}$$

$$F_{e1}d_{e1} = F_{r2}d_{r2}$$

For the compound machine

$$IMA_c = \frac{d_{e1}}{d_{r2}}$$

$$\frac{d_{e1}}{d_{r1}} = IMA_1 \text{ and } \frac{d_{e2}}{d_{r2}} = IMA_2$$

$$d_{r1} = d_{e2}$$

$$\frac{d_{e1}}{IMA_1} = d_{r1} = d_{e2} = (IMA_2)(d_{r2})$$

$$d_{e1} = (IMA_1)(IMA_2)(d_{r2})$$

$$\frac{d_{e1}}{d_{r2}} = IMA_c = (IMA_1)(IMA_2)$$

$$= (3.0)(2.0) = 6.0$$

b. If the compound machine is 60.0 percent efficient, how much effort must be applied to the lever to lift a 540-N box?

$$e = \frac{MA}{IMA} \times 100 = \frac{\frac{F_r}{F_e}}{IMA} \times 100$$

$$= \frac{(F_r)(100)}{(F_e)(IMA)}$$

$$\text{so } F_e = \frac{(F_r)(100)}{(e)(IMA)}$$

$$= \frac{(540\ \text{N})(100)}{(60.0)(6.0)} = 150\ \text{N}$$

c. If you move the effort side of the lever 12.0 cm, how far is the box lifted?

$$\frac{d_{e1}}{d_{r2}} = IMA_c$$

$$d_{r2} = \frac{d_{e1}}{IMA_c} = \frac{12.0\ \text{cm}}{6.0} = 2.0\ \text{cm}$$

Mixed Review

pages 281–282

Level 1

89. Ramps Isra has to get a piano onto a 2.0-m-high platform. She can use a 3.0-m-long frictionless ramp or a 4.0-m-long frictionless ramp. Which ramp should Isra use if she wants to do the least amount of work?

Either ramp: only the vertical distance is important. If Isra used a longer ramp, she would require less force. The work done would be the same.

90. Brutus, a champion weightlifter, raises 240 kg of weights a distance of 2.35 m.

a. How much work is done by Brutus lifting the weights?

$$W = Fd = mgd$$

$$= (240\ \text{kg})(9.80\ \text{m/s}^2)(2.35\ \text{m})$$

$$= 5.5\times10^3\ \text{J}$$

b. How much work is done by Brutus holding the weights above his head?

d = 0, so no work

c. How much work is done by Brutus lowering them back to the ground?

d is opposite of motion in part a, so W is also the opposite, -5.5×10^3 J.

d. Does Brutus do work if he lets go of the weights and they fall back to the ground?

No. He exerts no force, so he does no work, positive or negative.

e. If Brutus completes the lift in 2.5 s, how much power is developed?

$$P = \frac{W}{t} = \frac{5.5\times10^3\ \text{J}}{2.5\ \text{s}} = 2.2\ \text{kW}$$

Level 2

91. A horizontal force of 805 N is needed to drag a crate across a horizontal floor with a constant speed. You drag the crate using a rope held at an angle of 32°.

a. What force do you exert on the rope?

$$F_x = F\cos\theta$$

$$\text{so } F = \frac{F_x}{\cos\theta} = \frac{805\text{ N}}{\cos 32°}$$

$$= 9.5\times10^2\text{ N}$$

b. How much work do you do on the crate if you move it 22 m?

$$W = F_x d = (805\text{ N})(22\text{ m})$$

$$= 1.8\times10^4\text{ J}$$

c. If you complete the job in 8.0 s, what power is developed?

$$P = \frac{W}{t} = \frac{1.8\times10^4\text{ J}}{8.0\text{ s}} = 2.2\text{ kW}$$

92. Dolly and Ramp A mover's dolly is used to transport a refrigerator up a ramp into a house. The refrigerator has a mass of 115 kg. The ramp is 2.10 m long and rises 0.850 m. The mover pulls the dolly with a force of 496 N up the ramp. The dolly and ramp constitute a machine.

a. What work does the mover do?

$$W_i = Fd = (496\text{ N})(2.10\text{ m})$$

$$= 1.04\times10^3\text{ J}$$

b. What is the work done on the refrigerator by the machine?

d = height raised = 0.850 m

$$W_o = F_g d = mgd$$

$$= (115\text{ kg})(9.80\text{ m/s}^2)(0.850\text{ m})$$

$$= 958\text{ J}$$

c. What is the efficiency of the machine?

$$\text{efficiency} = \frac{W_o}{W_i}\times100$$

$$= \frac{958\text{ J}}{1.04\times10^3\text{ J}}\times100$$

$$= 92.1\%$$

93. Sally does 11.4 kJ of work dragging a wooden crate 25.0 m across a floor at a constant speed. The rope makes an angle of 48.0° with the horizontal.

a. How much force does the rope exert on the crate?

$$W = Fd\cos\theta$$

$$\text{so } F = \frac{W}{d\cos\theta} = \frac{11{,}400\text{ J}}{(25.0\text{ m})(\cos 48.0°)}$$

$$= 681\text{ N}$$

b. What is the force of friction acting on the crate?

The crate moves with constant speed, so the force of friction equals the horizontal component of the force of the rope.

$$F_f = F_x = F\cos\theta$$

$$= (681\text{ N})(\cos 48.0°)$$

= 456 N, opposite to the direction of motion

c. What work is done by the floor through the force of friction between the floor and the crate?

Force and displacement are in opposite directions, so

$$W = -Fd = -(456\text{ N})(25.0\text{ m})$$

$$= -1.14\times10^4\text{ J}$$

(Because no net forces act on the crate, the work done on the crate must be equal in magnitude but opposite in sign to the energy Sally expands: -1.14×10^4 J)

94. Sledding An 845-N sled is pulled a distance of 185 m. The task requires 1.20×10^4 J of work and is done by pulling on a rope with a force of 125 N. At what angle is the rope held?

$W = Fd\cos\theta$, so

$$\theta = \cos^{-1}\left(\frac{W}{Fd}\right) = \cos^{-1}\left(\frac{1.20\times10^4\text{ J}}{(125\text{ N})(185\text{ m})}\right)$$

$$= 58.7°$$

Level 3

95. An electric winch pulls a 875-N crate up a 15° incline at 0.25 m/s. The coefficient of friction between the crate and incline is 0.45.

a. What power does the winch develop?

Work is done on the crate by the winch, gravity, and friction. Because the kinetic energy of the crate does not change, the sum of the three works is equal to zero.

Therefore,

$W_{winch} = W_{friction} + W_{gravity}$

or, $P_{winch} = P_{friction} + P_{gravity}$

$= \frac{\mu F_N d}{t} + \frac{F_g d}{t}$

$= \mu F_N\left(\frac{d}{t}\right) + F_g\left(\frac{d}{t}\right)$

$= \mu F_N v + F_g v$

$= (\mu F_g)(\cos\theta)(v) + F_g v$

$= (0.45)(875\ \text{N})(\cos 15°)(0.25\ \text{m/s}) + (875\ \text{N})(0.25\ \text{m/s})$

$= 3.1\times10^2\ \text{W}$

b. If the winch is 85 percent efficient, what is the electrical power that must be delivered to the winch?

$e = \frac{W_o}{W_i} = \frac{P_o}{P_i}$

so, $P_i = \frac{P_o}{e}$

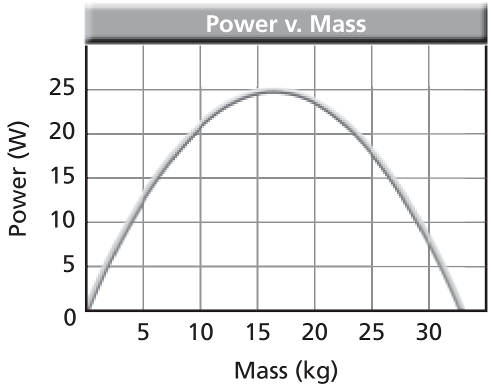
$= \frac{3.1\times10^2\ \text{W}}{0.85}$

$= 3.6\times10^2\ \text{W}$

Thinking Critically

page 282

96. Analyze and Conclude You work at a store, carrying boxes to a storage loft that is 12 m above the ground. You have 30 boxes with a total mass of 150 kg that must be moved as quickly as possible, so you consider carrying more than one up at a time. If you try to move too many at once, you know that you will go very slowly, resting often. If you carry only one box at a time, most of the energy will go into raising your own body. The power (in watts) that your body can develop over a long time depends on the mass that you carry, as shown in **Figure 10-25.** This is an example of a power curve that applies to machines as well as to people. Find the number of boxes to carry on each trip that would minimize the time required. What time would you spend doing the job? Ignore the time needed to go back down the stairs and to lift and lower each box.



■ **Figure 10-25**

The work has to be done the same,

$W = F_g d = mgd$

$= (150\ \text{kg})(9.80\ \text{m/s}^2)(12\ \text{m})$

$= 1.76\times10^4\ \text{J}.$

From the graph, the maximum power is 25 W at 15 kg. Since the mass per box is $\frac{150\ \text{kg}}{30\ \text{boxes}}$ **= 5 kg, this represents three boxes.**

$P = \frac{W}{t}$ so $t = \frac{W}{t}$

$= \frac{1.76\times10^4\ \text{J}}{25\ \text{W}}$

$= 7.0\times10^2\ \text{s}$

$= 12\ \text{min}$

97. Apply Concepts A sprinter of mass 75 kg runs the 50.0-m dash in 8.50 s. Assume that the sprinter's acceleration is constant throughout the race.

a. What is the average power of the sprinter over the 50.0 m?

Assume constant acceleration, therefore constant force

$d = d_i + v_it + \frac{1}{2}at^2$

but $d_i = v_i = 0$

$P = \frac{W}{t} = \frac{Fd}{t} = \frac{mad}{t} = \frac{m\left(\frac{2d}{t^2}\right)d}{t}$

$= \frac{2md^2}{t^3} = \frac{(2)(75\text{ kg})(50.0\text{ m})}{(8.50\text{ s})^3}$

$= 6.1\times10^2$ W

b. What is the maximum power generated by the sprinter?

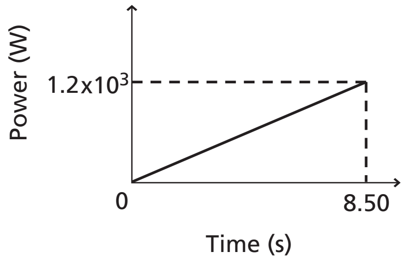
Power increases linearly from zero, since the velocity increases linearly as shown by

$P = \frac{W}{t} = \frac{Fd}{t} = F\left(\frac{d}{t}\right) = Fv.$

Therefore

$P_{max} = 2P_{ave} = 1.2\times10^3$ W

c. Make a quantitative graph of power versus time for the entire race.



98. Apply Concepts The sprinter in the previous problem runs the 50.0-m dash in the same time, 8.50 s. However, this time the sprinter accelerates in the first second and runs the rest of the race at a constant velocity.

a. Calculate the average power produced for that first second.

Distance first second + Distance rest of race = 50.0 m

$d_f = d_i + v_it + \frac{1}{2}at^2$

$d_i = v_i = 0$ so

$d_f = \frac{1}{2}a(t_1)^2 + v_f(t_2) = 50.0$ m

Final velocity:

$v_f = v_i + at$

$v_i = 0$ so

$v_f = at = a(t_1)$

Therefore,

$d_f = \frac{1}{2}at_1{}^2 + at_1t_2$

$= a\left(\frac{1}{2}t_1{}^2 + t_1t_2\right)$

$a = \frac{d_f}{\frac{1}{2}t_1{}^2 + t_1t_2}$

$= \frac{50.0\text{ m}}{\left(\frac{1}{2}\right)(1.00\text{ s})^2 + (1.00\text{ s})(7.50\text{ s})}$

$= 6.25\text{ m/s}^2$

For the first second:

$d = \frac{1}{2}at^2 = \left(\frac{1}{2}\right)(6.25\text{ m/s}^2)(1.00\text{ s})^2$

$= 3.12$ m

From Problem 97,

$P = \frac{mad}{t}$

$P_{ave} = \frac{(75\text{ kg})(6.25\text{ m/s}^2)(3.12\text{ m})}{1.00\text{ s}}$

$= 1.5\times10^3$ W

b. What is the maximum power that the sprinter now generates?

$P_{max} = 2P_{ave} = 3.0\times10^3$ W

Writing in Physics

page 282

99. Just as a bicycle is a compound machine, so is an automobile. Find the efficiencies of the component parts of the power train (engine, transmission, wheels, and tires). Explore possible improvements in each of these efficiencies.

The overall efficiency is 15–30 percent. The transmission's efficiency is about 90 percent. Rolling friction in the tires is about 1 percent (ratio of pushing force to weight moved). The largest gain is possible in the engine.

100. The terms *force, work, power,* and *energy* often mean the same thing in everyday use. Obtain examples from advertisements, print media, radio, and television that illustrate meanings for these terms that differ from those used in physics.

Answers will vary. Some examples include, the company Consumers' Power changed its name to Consumers' Energy without changing its product, natural gas. "It's not just energy, it's power!" has appeared in the popular press.

Cumulative Review

page 282

101. You are helping your grandmother with some gardening and have filled a garbage can with weeds and soil. Now you have to move the garbage can across the yard and realize it is so heavy that you will need to push it, rather than lift it. If the can has a mass of 24 kg, the coefficient of kinetic friction between the can's bottom and the muddy grass is 0.27, and the static coefficient of friction between those same surfaces is 0.35, how hard do you have to push horizontally to get the can to just start moving? (Chapter 5)

$$F_{\text{you on can}} = F_{\text{friction}} = \mu_s F_N = \mu_s mg$$

$$= (0.35)(24\text{ kg})(9.80\text{ m/s}^2)$$

$$= 82\text{ N}$$

102. Baseball If a major league pitcher throws a fastball horizontally at a speed of 40.3 m/s (90 mph) and it travels 18.4 m (60 ft, 6 in), how far has it dropped by the time it crosses home plate? (Chapter 6)

$$d_{fx} = d_{ix} + v_{x}t$$

$$\text{so } t = \frac{d_{fx} - d_{ix}}{v_x}$$

$$= \frac{18.4\text{ m} - 0.0\text{ m}}{40.3\text{ m/s}} = 0.457\text{ s}$$

$$d_{fy} = d_{iy} + v_{iy}t + \frac{1}{2}gt^2$$

$$d_{iy} = v_{iy} = 0$$

$$\text{so } d_{fy} = \frac{1}{2}gt^2$$

$$= \left(\frac{1}{2}\right)(9.80\text{ m/s}^2)(0.457\text{ s})^2$$

$$= 1.02\text{ m}$$

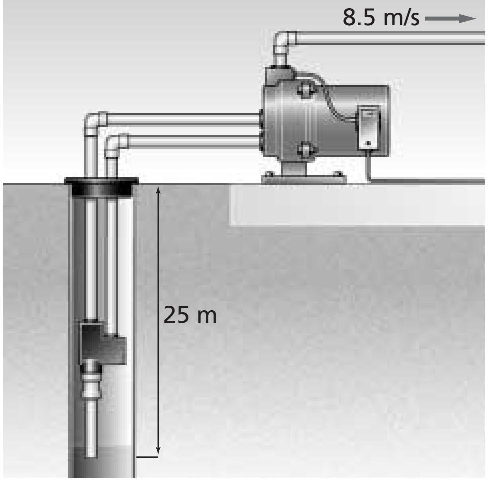
103. People sometimes say that the Moon stays in its orbit because the "centrifugal force just balances the centripetal force, giving no net force." Explain why this idea is wrong. (Chapter 8)

There is only one force on the moon, the gravitational force of Earth's mass on it. This net force gives it an acceleration which is its centripetal acceleration toward Earth's center.

Challenge Problem

page 268

An electric pump pulls water at a rate of 0.25 m^3/s from a well that is 25 m deep. The water leaves the pump at a speed of 8.5 m/s.



1. What power is needed to lift the water to the surface?

The work done in lifting is $F_g d = mgd$. Therefore, the power is

$$P_{lift} = \frac{W}{t} = \frac{F_g d}{t} = \frac{mgd}{t}$$

$$= \frac{(0.25\ m^3)(1.00\times10^3\ kg/m^3)(9.80\ m/s^2)(25\ m)}{1.0\ s}$$

$$= 6.1\times10^4\ W$$

$$= 61\ kW$$

2. What power is needed to increase the pump's kinetic energy?

The work done in increasing the pump's kinetic energy is $\frac{1}{2}mv^2$.

Therefore, $$P = \frac{W}{t} = \frac{\Delta KE}{t} = \frac{\frac{1}{2}mv^2}{t} = \frac{mv^2}{2t}$$

$$= \frac{(0.25\ m^3)(1.00\times10^3\ kg/m^3)(8.5\ m/s)^2}{(2)(1.0\ s)}$$

$$= 9.0\times10^3\ W = 9.0\ kW$$

3. If the pump's efficiency is 80 percent, how much power must be delivered to the pump?

$$e = \frac{W_o}{W_i}\times 100 = \frac{\frac{W_o}{t}}{\frac{W_i}{t}}\times 100 = \frac{P_o}{P_i}\times 100 \text{ so,}$$

$$P_i = \frac{P_o}{e}\times 100 = \frac{9.0\times10^3\ W}{80}\times 100$$

$$= 1.1\times10^4\ W$$

$$= 11\ kW$$

CHAPTER

11 Energy and Its Conservation

Practice Problems

11.1 The Many Forms of Energy pages 285–292

page 287

1. A skater with a mass of 52.0 kg moving at 2.5 m/s glides to a stop over a distance of 24.0 m. How much work did the friction of the ice do to bring the skater to a stop? How much work would the skater have to do to speed up to 2.5 m/s again?

To bring the skater to a stop:

$$W = KE_f - KE_i$$
$$= \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$
$$= \frac{1}{2}(52.0\ \text{kg})(0.00\ \text{m/s})^2 - \frac{1}{2}(52.0\ \text{kg})(2.5\ \text{m/s})^2$$
$$= -160\ \text{J}$$

To speed up again:

This is the reverse of the first question.

$$W = KE_f - KE_i$$
$$= \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$
$$= \frac{1}{2}(52.0\ \text{kg})(2.5\ \text{m/s})^2 - \frac{1}{2}(52.0\ \text{kg})(0.00\ \text{m/s})^2$$
$$= +160\ \text{J}$$

2. An 875.0-kg compact car speeds up from 22.0 m/s to 44.0 m/s while passing another car. What are its initial and final energies, and how much work is done on the car to increase its speed?

The initial kinetic energy of the car is

$$KE_i = \frac{1}{2}mv^2 = \frac{1}{2}(875.0\ \text{kg})(22.0\ \text{m/s})^2$$
$$= 2.12\times10^5\ \text{J}$$

The final kinetic energy is

$$KE_f = \frac{1}{2}mv^2 = \frac{1}{2}(875.0\ \text{kg})(44.0\ \text{m/s})^2$$
$$= 8.47\times10^5\ \text{J}$$

The work done is

$$KE_f - KE_i = 8.47\times10^5\ \text{J} - 2.12\times10^5\ \text{J}$$
$$= 6.35\times10^5\ \text{J}$$

3. A comet with a mass of 7.85×10^{11} kg strikes Earth at a speed of 25.0 km/s. Find the kinetic energy of the comet in joules, and compare the work that is done by Earth in stopping the comet to the 4.2×10^{15} J of energy that was released by the largest nuclear weapon ever built.

$$KE = \frac{1}{2}mv^2$$
$$= \frac{1}{2}(7.85\times10^{11}\ \text{kg})(2.50\times10^4\ \text{m/s})^2$$
$$= 2.45\times10^{20}\ \text{J}$$

$$\frac{KE_{comet}}{KE_{bomb}} = \frac{2.45\times10^{20}\ \text{J}}{4.2\times10^{15}\ \text{J}} = 5.8\times10^4$$

5.8×10^4 bombs would be required to produce the same amount of energy used by Earth in stopping the comet.

page 291

4. In Example Problem 1, what is the potential energy of the bowling ball relative to the rack when it is on the floor?

$$PE = mgh$$
$$= (7.30\ \text{kg})(9.80\ \text{m/s}^2)(-0.610\ \text{m})$$
$$= -43.6\ \text{J}$$

5. If you slowly lower a 20.0-kg bag of sand 1.20 m from the trunk of a car to the driveway, how much work do you do?

$$W = Fd$$
$$= mg(h_f - h_i)$$
$$= (20.0\ \text{kg})(9.80\ \text{m/s}^2)(0.00\ \text{m} - 1.20\ \text{m})$$
$$= -2.35\times10^2\ \text{J}$$

6. A boy lifts a 2.2-kg book from his desk, which is 0.80 m high, to a bookshelf that is 2.10 m high. What is the potential energy of the book relative to the desk?

$$PE = mg(h_f - h_i)$$
$$= (2.2 \text{ kg})(9.80 \text{ m/s}^2)(2.10 \text{ m} - 0.80 \text{ m})$$
$$= 28 \text{ J}$$

7. If a 1.8-kg brick falls to the ground from a chimney that is 6.7 m high, what is the change in its potential energy?

Choose the ground as the reference level.

$$\Delta PE = mg(h_f - h_i)$$
$$= (1.8 \text{ kg})(9.80 \text{ m/s}^2)(0.0 \text{ m} - 6.7 \text{ m})$$
$$= -1.2\times10^2 \text{ J}$$

8. A warehouse worker picks up a 10.1-kg box from the floor and sets it on a long, 1.1-m-high table. He slides the box 5.0 m along the table and then lowers it back to the floor. What were the changes in the energy of the box, and how did the total energy of the box change? (Ignore friction.)

To lift the box to the table:

$$W = Fd$$
$$= mg(h_f - h_i)$$
$$= \Delta PE$$
$$= (10.1 \text{ kg})(9.80 \text{ m/s}^2)(1.1 \text{ m} - 0.0 \text{ m})$$
$$= 1.1\times10^2 \text{ J}$$

To slide the box across the table, $W = 0.0$ because the height did not change and we ignored friction.

To lower the box to the floor:

$$W = Fd$$
$$= mg(h_f - h_i)$$
$$= \Delta PE$$
$$= (10.1 \text{ kg})(9.80 \text{ m/s}^2)(0.0 \text{ m} - 1.1 \text{ m})$$
$$= -1.1\times10^2 \text{ J}$$

The sum of the three energy changes is

$$1.1\times10^2 \text{ J} + 0.0 \text{ J} + (-1.1\times10^2 \text{ J}) = 0.0 \text{ J}$$

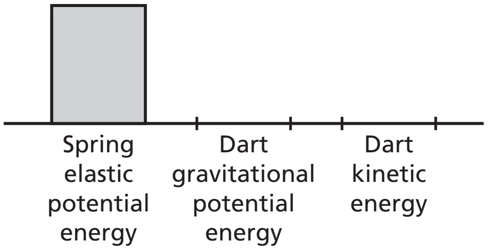
Section Review

11.1 The Many Forms of Energy pages 285–292

page 292

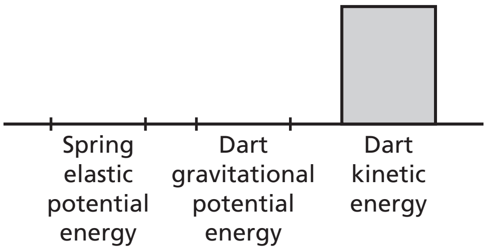
9. **Elastic Potential Energy** You get a spring-loaded toy pistol ready to fire by compressing the spring. The elastic potential energy of the spring pushes the rubber dart out of the pistol. You use the toy pistol to shoot the dart straight up. Draw bar graphs that describe the forms of energy present in the following instances.

   a. The dart is pushed into the gun barrel, thereby compressing the spring.



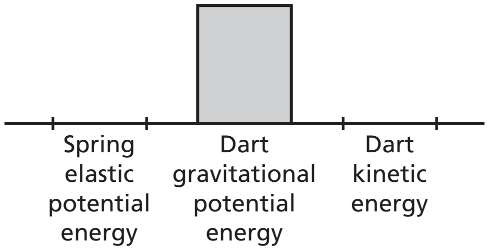
There should be three bars: one for the spring's potential energy, one for gravitational potential energy, and one for kinetic energy. The spring's potential energy is at the maximum level, and the other two are zero.

   b. The spring expands and the dart leaves the gun barrel after the trigger is pulled.



The kinetic energy is at the maximum level, and the other two are zero.

c. The dart reaches the top of its flight.



The gravitational potential energy is at the maximum level, and the other two are zero.

10. Potential Energy A 25.0-kg shell is shot from a cannon at Earth's surface. The reference level is Earth's surface. What is the gravitational potential energy of the system when the shell is at 425 m? What is the change in potential energy when the shell falls to a height of 225 m?

a. $PE = mgh$

$= (25.0 \text{ kg})(9.80 \text{ m/s}^2)(425 \text{ m})$

$= 1.04\times10^5 \text{ J}$

b. $PE = mgh$

$= (25.0 \text{ kg})(9.80 \text{ m/s}^2)(225 \text{ m})$

$= 5.51\times10^4 \text{ J}$

The change in energy is

$(1.04\times10^5 \text{ J}) - (5.51\times10^4 \text{ J})$
$= 4.89\times10^4 \text{ J}$

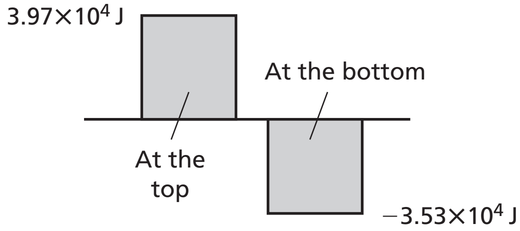
11. Rotational Kinetic Energy Suppose some children push a merry-go-round so that it turns twice as fast as it did before they pushed it. What are the relative changes in angular momentum and rotational kinetic energy?

The angular momentum is doubled because it is proportional to the angular velocity. The rotational kinetic energy is quadrupled because it is proportional to the square of the angular velocity. The children did work in rotating the merry-go-round.

12. Work-Energy Theorem How can you apply the work-energy theorem to lifting a bowling ball from a storage rack to your shoulder?

The bowling ball has zero kinetic energy when it is resting on the rack or when it is held near your shoulder. Therefore, the total work done on the ball by you and by gravity must equal zero.

13. Potential Energy A 90.0-kg rock climber first climbs 45.0 m up to the top of a quarry, then descends 85.0 m from the top to the bottom of the quarry. If the initial height is the reference level, find the potential energy of the system (the climber and Earth) at the top and at the bottom. Draw bar graphs for both situations.



$PE = mgh$

At the top,

$PE = (90.0 \text{ kg})(9.80 \text{ m/s}^2)(+45.0 \text{ m})$

$= 3.97\times10^4 \text{ J}$

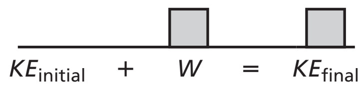
At the bottom,

$PE = (90.0 \text{ kg})(9.80 \text{ m/s}^2)$
$(+45.0 \text{ m} - 85.0 \text{ m})$

$= -3.53\times10^4 \text{ J}$

14. Critical Thinking Karl uses an air hose to exert a constant horizontal force on a puck, which is on a frictionless air table. He keeps the hose aimed at the puck, thereby creating a constant force as the puck moves a fixed distance.

a. Explain what happens in terms of work and energy. Draw bar graphs.



Karl exerted a constant force *F* over a distance *d* and did an amount of work *W* = *Fd* on the puck. This work changed the kinetic energy of the puck.

$$W = (KE_f - KE_i)$$
$$= \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$
$$= \frac{1}{2}mv_f^2$$

b. Suppose Karl uses a different puck with half the mass of the first one. All other conditions remain the same. How will the kinetic energy and work differ from those in the first situation?

If the puck has half the mass, it still receives the same amount of work and has the same change in kinetic energy. However, the smaller mass will move faster by a factor of 1.414.

c. Explain what happened in parts **a** and **b** in terms of impulse and momentum.

The two pucks do not have the same final momentum.

Momentum of the first puck:

$$p_1 = m_1v_1$$

Momentum of the second puck:

$$p_2 = m_2v_2$$
$$= \left(\frac{1}{2}m_1\right)(1.414v_1)$$
$$= 0.707\ p_1$$

Thus, the second puck has less momentum than the first puck does. Because the change in momentum is equal to the impulse provided by the air hose, the second puck receives a smaller impulse.

Practice Problems

11.2 Conservation of Energy pages 293–301

page 297

15. A bike rider approaches a hill at a speed of 8.5 m/s. The combined mass of the bike and the rider is 85.0 kg. Choose a suitable system. Find the initial kinetic energy of the system. The rider coasts up the hill. Assuming there is no friction, at what height will the bike come to rest?

The system is the bike + rider + Earth. There are no external forces, so total energy is conserved.

$$KE = \frac{1}{2}mv^2$$
$$= \frac{1}{2}(85.0\ \text{kg})(8.5\ \text{m/s})^2$$
$$= 3.1\times10^3\ \text{J}$$

$$KE_i + PE_i = KE_f + PE_f$$
$$\frac{1}{2}mv^2 + 0 = 0 + mgh$$
$$h = \frac{v^2}{2g} = \frac{(8.5\ \text{m/s})^2}{(2)(9.80\ \text{m/s}^2)}$$
$$= 3.7\ \text{m}$$

16. Suppose that the bike rider in problem 15 pedaled up the hill and never came to a stop. In what system is energy conserved? From what form of energy did the bike gain mechanical energy?

The system of Earth, bike, and rider remains the same, but now the energy involved is not mechanical energy alone. The rider must be considered as having stored energy, some of which is converted to mechanical energy.

Energy came from the chemical potential energy stored in the rider's body.

17. A skier starts from rest at the top of a 45.0-m-high hill, skis down a 30° incline into a valley, and continues up a 40.0-m-high hill. The heights of both hills are measured from the valley floor. Assume that you can neglect friction and the effect of the ski poles. How fast is the skier moving at the bottom of the valley? What is the skier's speed at the top of the next hill? Do the angles of the hills affect your answers?

Bottom of valley:

$$KE_i + PE_i = KE_f + PE_f$$
$$0 + mgh = \frac{1}{2}mv^2 + 0$$
$$v^2 = 2gh$$
$$v = \sqrt{2gh}$$
$$= \sqrt{(2)(9.80\ \text{m/s}^2)(45.0\ \text{m})}$$

$= 29.7\ \text{m/s}$

Top of next hill:

$KE_i + PE_i = KE_f + PE_f$

$0 + mgh_i = \frac{1}{2}mv^2 + mgh_f$

$v^2 = 2g(h_i - h_f)$

$= \sqrt{2g(h_i - h_f)}$

$= \sqrt{(2)(9.80\ \text{m/s}^2)(45.0\ \text{m} - 40.0\ \text{m})}$

$= 9.90\ \text{m/s}$

No, the angles do not have any impact.

18. In a belly-flop diving contest, the winner is the diver who makes the biggest splash upon hitting the water. The size of the splash depends not only on the diver's style, but also on the amount of kinetic energy that the diver has. Consider a contest in which each diver jumps from a 3.00-m platform. One diver has a mass of 136 kg and simply steps off the platform. Another diver has a mass of 102 kg and leaps upward from the platform. How high would the second diver have to leap to make a competitive splash?

Using the water as a reference level, the kinetic energy on entry is equal to the potential energy of the diver at the top of his flight. The large diver has $PE = mgh = (136\ \text{kg})(9.80\ \text{m/s}^2)(3.00\ \text{m}) = 4.00\times10^3\ \text{J}$

To equal this, the smaller diver would have to jump to

$h = \frac{4.00\times10^3\ \text{J}}{(102\ \text{kg})(9.80\ \text{m/s}^2)} = 4.00\ \text{m}$

Thus, the smaller diver would have to leap 1.00 m above the platform.

page 300

19. An 8.00-g bullet is fired horizontally into a 9.00-kg block of wood on an air table and is embedded in it. After the collision, the block and bullet slide along the frictionless surface together with a speed of 10.0 cm/s. What was the initial speed of the bullet?

Conservation of momentum:

$mv = (m + M)V$, **or**

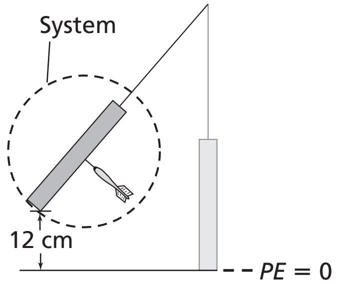
$v = \frac{(m + M)V}{m}$

$= \frac{(0.00800\ \text{kg} + 9.00\ \text{kg})(0.100\ \text{m/s})}{0.00800\ \text{kg}}$

$= 1.13\times10^2\ \text{m/s}$

20. A 0.73-kg magnetic target is suspended on a string. A 0.025-kg magnetic dart, shot horizontally, strikes the target head-on. The dart and the target together, acting like a pendulum, swing 12.0 cm above the initial level before instantaneously coming to rest.

a. Sketch the situation and choose a system.



The system includes the suspended target and the dart.

b. Decide what is conserved in each part and explain your decision.

Only momentum is conserved in the inelastic dart-target collision, so

$mv_i + MV_i = (m + M)V_f$

where $V_i = 0$ **since the target is initially at rest and** V_f **is the common velocity just after impact. As the dart-target combination swings upward, energy is conserved, so** $\Delta PE = \Delta KE$ **or, at the top of the swing,**

$(m + M)gh_f = \frac{1}{2}(m + M)(V_f)^2$

c. What was the initial velocity of the dart?

Solve for V_f.

$V_f = \sqrt{2gh_f}$

Substitute v_f into the momentum equation and solve for v_i.

$$v_i = \left(\frac{m + M}{m}\right)\sqrt{2gh_f}$$

$$= \left(\frac{0.025\ \text{kg} + 0.73\ \text{kg}}{0.025\ \text{kg}}\right)\left(\sqrt{(2)(9.80\ \text{m/s}^2)(0.120\ \text{m})}\right)$$

$$= 46\ \text{m/s}$$

21. A 91.0-kg hockey player is skating on ice at 5.50 m/s. Another hockey player of equal mass, moving at 8.1 m/s in the same direction, hits him from behind. They slide off together.

a. What are the total energy and momentum in the system before the collision?

$$KE_i = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2$$

$$= \frac{1}{2}(91.0\ \text{kg})(5.50\ \text{m/s})^2 + \frac{1}{2}(91.0\ \text{kg})(8.1\ \text{m/s})^2$$

$$= 4.4\times10^3\ \text{J}$$

$$p_i = m_1v_1 + m_2v_2$$

$$= (91.0\ \text{kg})(5.5\ \text{m/s}) + (91.0\ \text{kg})(8.1\ \text{m/s})$$

$$= 1.2\times10^3\ \text{kg·m/s}$$

b. What is the velocity of the two hockey players after the collision?

After the collision:

$$p_i = p_f$$

$$m_1v_1 + m_2v_2 = (m_1 + m_2)v_f$$

$$v_f = \frac{m_1v_1 + m_2v_2}{m_1 + m_2}$$

$$= \frac{(91.0\ \text{kg})(5.50\ \text{m/s}) + (91.0\ \text{kg})(8.1\ \text{m/s})}{91.0\ \text{kg} + 91.0\ \text{kg}}$$

$$= 6.8\ \text{m/s}$$

c. How much energy was lost in the collision?

The final kinetic energy is

$$KE_f = \frac{1}{2}(m_i + m_f)v_f^2$$

$$= \frac{1}{2}(91.0\ \text{kg} + 91.0\ \text{kg})(6.8\ \text{m/s})^2$$

$$= 4.2\times10^3\ \text{J}$$

Thus, the energy lost in the collision is

$$KE_i - KE_f = 4.4\times10^3\ \text{J} - 4.2\times10^3\ \text{J}$$

$$= 2\times10^2\ \text{J}$$

Section Review

11.2 Conservation of Energy pages 293–301

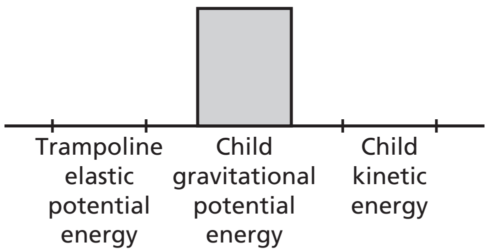
page 301

22. Closed Systems Is Earth a closed, isolated system? Support your answer.

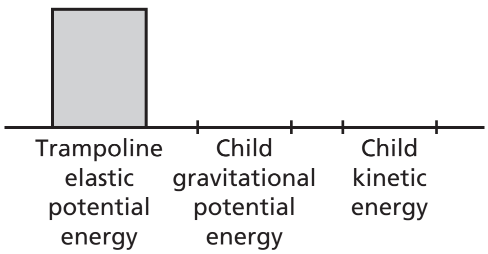
To simplify problems that take place over a short time, Earth is considered a closed system. It is not actually isolated, however, because it is acted upon by the gravitational forces from the planets, the Sun, and other stars. In addition, Earth is the recipient of continuous electromagnetic energy, primarily from the Sun.

23. Energy A child jumps on a trampoline. Draw bar graphs to show the forms of energy present in the following situations.

a. The child is at the highest point.



b. The child is at the lowest point.



24. Kinetic Energy Suppose a glob of chewing gum and a small, rubber ball collide head-on in midair and then rebound apart. Would you expect kinetic energy to be conserved? If not, what happens to the energy?

Even though the rubber ball rebounds with little energy loss, kinetic energy would not be conserved in this case because the glob of chewing gum probably was deformed in the collision.

25. Kinetic Energy In table tennis, a very light but hard ball is hit with a hard rubber or wooden paddle. In tennis, a much softer ball is hit with a racket. Why are the two sets of equipment designed in this way? Can you think of other ball-paddle pairs in sports? How are they designed?

The balls and the paddle and racket are designed to match so that the maximum amount of kinetic energy is passed from the paddle or racket to the ball. A softer ball receives energy with less loss from a softer paddle or racket. Other combinations are a golf ball and club (both hard) and a baseball and bat (also both hard).

26. Potential Energy A rubber ball is dropped from a height of 8.0 m onto a hard concrete floor. It hits the floor and bounces repeatedly. Each time it hits the floor, it loses $\frac{1}{5}$ of its total energy. How many times will it bounce before it bounces back up to a height of only about 4 m?

$E_{total} = mgh$

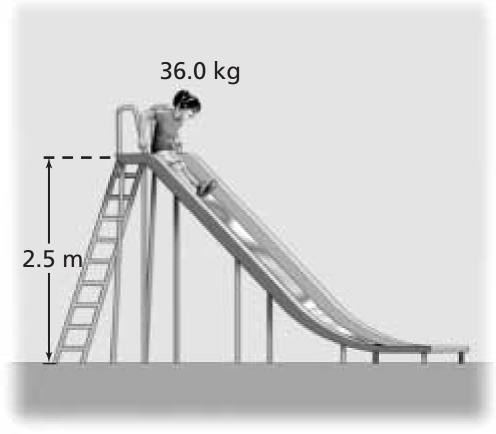
Since the rebound height is proportional to energy, each bounce will rebound to $\frac{4}{5}$ the height of the previous bounce.

After one bounce: $h = \left(\frac{4}{5}\right)(8\ \text{m}) = 6.4\ \text{m}$

After two bounces: $h = \left(\frac{4}{5}\right)(6.4\ \text{m}) = 5.12\ \text{m}$

After three bounces: $h = \left(\frac{4}{5}\right)(5.12\ \text{m}) = 4.1\ \text{m}$

27. **Energy** As shown in **Figure 11-15,** a 36.0-kg child slides down a playground slide that is 2.5 m high. At the bottom of the slide, she is moving at 3.0 m/s. How much energy was lost as she slid down the slide?



■ **Figure 11-15**

$$E_i = mgh$$
$$= (36.0 \text{ kg})(9.80 \text{ m/s}^2)(2.5 \text{ m})$$
$$= 880 \text{ J}$$
$$E_f = \frac{1}{2}mv^2$$
$$= \frac{1}{2}(36.0 \text{ kg})(3.0 \text{ m/s})^2$$
$$= 160 \text{ J}$$
$$\text{Energy loss} = 880 \text{ J} - 160 \text{ J}$$
$$= 720 \text{ J}$$

28. **Critical Thinking** A ball drops 20 m. When it has fallen half the distance, or 10 m, half of its energy is potential and half is kinetic. When the ball has fallen for half the amount of time it takes to fall, will more, less, or exactly half of its energy be potential energy?

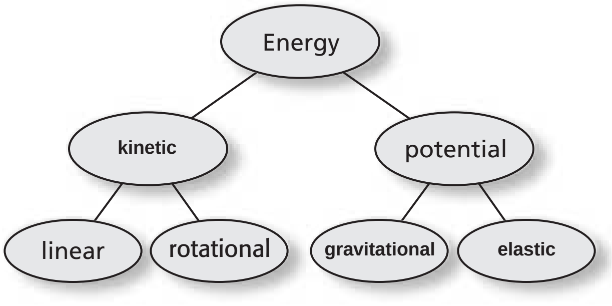
The ball falls more slowly during the beginning part of its drop. Therefore, in the first half of the time that it falls, it will not have traveled half of the distance that it will fall. Therefore, the ball will have more potential energy than kinetic energy.

Chapter Assessment

Concept Mapping

page 306

29. Complete the concept map using the following terms: *gravitational potential energy, elastic potential energy, kinetic energy.*



Mastering Concepts

page 306

Unless otherwise directed, assume that air resistance is negligible.

30. Explain how work and a change in energy are related. (11.1)

The work done on an object causes a change in the object's energy. This is the work-energy theorem.

31. What form of energy does a wound-up watch spring have? What form of energy does a functioning mechanical watch have? When a watch runs down, what has happened to the energy? (11.1)

The wound-up watch spring has elastic potential energy. The functioning watch has elastic potential energy and rotational kinetic energy. The watch runs down when all of the energy has been converted to heat by friction in the gears and bearings.

32. Explain how energy change and force are related. (11.1)

A force exerted over a distance does work, which produces a change in energy.

33. A ball is dropped from the top of a building. You choose the top of the building to be the reference level, while your friend chooses the bottom. Explain whether the energy calculated using these two reference levels is the same or different for the following situations. (11.1)

a. the ball's potential energy at any point

The potential energies are different due to the different reference levels.

b. the change in the ball's potential energy as a result of the fall

The changes in the potential energies as a result of the fall are equal because the change in *h* is the same for both reference levels.

c. the kinetic energy of the ball at any point

The kinetic energies of the ball at any point are equal because the velocities are the same.

34. Can the kinetic energy of a baseball ever be negative? (11.1)

The kinetic energy of a baseball can never be negative because the kinetic energy depends on the square of the velocity, which is always positive.

35. Can the gravitational potential energy of a baseball ever be negative? Explain without using a formula. (11.1)

The gravitational potential energy of a baseball can be negative if the height of the ball is lower than the reference level.

36. If a sprinter's velocity increases to three times the original velocity, by what factor does the kinetic energy increase? (11.1)

The sprinter's kinetic energy increases by a factor of 9, because the velocity is squared.

37. What energy transformations take place when an athlete is pole-vaulting? (11.2)

The pole-vaulter runs (kinetic energy) and bends the pole, thereby adding elastic potential energy to the pole. As he/she lifts his/her body, that kinetic and elastic potential energy is transferred into kinetic and gravitational potential energy. When he/she releases the pole, all of his/her energy is kinetic and gravitational potential energy.

38. The sport of pole-vaulting was drastically changed when the stiff, wooden poles were replaced by flexible, fiberglass poles. Explain why. (11.2)

A flexible, fiberglass pole can store elastic potential energy because it can be bent easily. This energy can be released to push the pole-vaulter higher vertically. By contrast, the wooden pole does not store elastic potential energy, and the pole-vaulter's maximum height is limited by the direct conversion of kinetic energy to gravitational potential energy.

39. You throw a clay ball at a hockey puck on ice. The smashed clay ball and the hockey puck stick together and move slowly. (11.2)

a. Is momentum conserved in the collision? Explain.

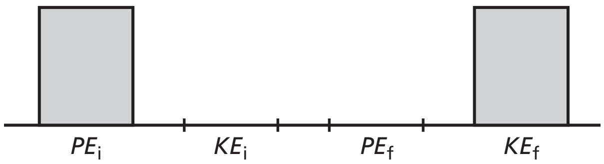
The total momentum of the ball and the puck together is conserved in the collision because there are no unbalanced forces on this system.

b. Is kinetic energy conserved? Explain.

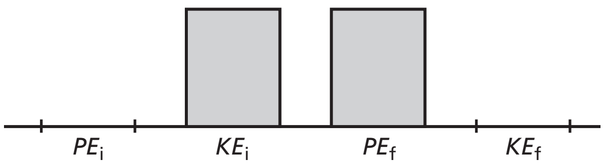
The total kinetic energy is not conserved. Part of it is lost in the smashing of the clay ball and the adhesion of the ball to the puck.

40. Draw energy bar graphs for the following processes. (11.2)

a. An ice cube, initially at rest, slides down a frictionless slope.



b. An ice cube, initially moving, slides up a frictionless slope and instantaneously comes to rest.



41. Describe the transformations from kinetic energy to potential energy and vice versa for a roller-coaster ride. (11.2)

On a roller-coaster ride, the car has mostly potential energy at the tops of the hills and mostly kinetic energy at the bottoms of the hills.

42. Describe how the kinetic energy and elastic potential energy are lost in a bouncing rubber ball. Describe what happens to the motion of the ball. (11.2)

On each bounce, some, but not all, of the ball's kinetic energy is stored as elastic potential energy; the ball's deformation dissipates the rest of the energy as thermal energy and sound. After the bounce, the stored elastic potential energy is released as kinetic energy. Due to the energy losses in the deformation, each subsequent bounce begins with a smaller amount of kinetic energy, and results in the ball reaching a lower height. Eventually, all of the ball's energy is dissipated, and the ball comes to rest.

Applying Concepts

pages 306–307

43. The driver of a speeding car applies the brakes and the car comes to a stop. The system includes the car but not the road. Apply the work-energy theorem to the following situations.

a. The car's wheels do not skid.

If the car wheels do not skid, the brake surfaces rub against each other and do work that stops the car. The work that the brakes do is equal to the change in kinetic energy of the car. The brake surfaces heat up because the kinetic energy is transformed to thermal energy.

b. The brakes lock and the car's wheels skid.

If the brakes lock and the car wheels skid, the wheels rubbing on the road are doing the work that stops the car. The tire surfaces heat up, not the brakes. This is not an efficient way to stop a car, and it ruins the tires.

44. A compact car and a trailer truck are both traveling at the same velocity. Did the car engine or the truck engine do more work in accelerating its vehicle?

The trailer truck has more kinetic energy, $KE = \frac{1}{2}mv^2$, because it has greater mass than the compact car. Thus, according to the work-energy theorem, the truck's engine must have done more work.

45. **Catapults** Medieval warriors used catapults to assault castles. Some catapults worked by using a tightly wound rope to turn the catapult arm. What forms of energy are involved in catapulting a rock to the castle wall?

Elastic potential energy is stored in the wound rope, which does work on the rock. The rock has kinetic and potential energy as it flies through the air. When it hits the wall, the inelastic collision causes most of the mechanical energy to be converted to thermal and sound energy and to do work breaking apart the wall structure. Some of the mechanical energy appears in the fragments thrown from the collision.

46. Two cars collide and come to a complete stop. Where did all of their energy go?

The energy went into bending sheet metal on the cars. Energy also was lost due to frictional forces between the cars and the tires, and in the form of thermal energy and sound.

47. During a process, positive work is done on a system, and the potential energy decreases. Can you determine anything about the change in kinetic energy of the system? Explain.

The work equals the change in the total mechanical energy, $W = \Delta(KE + PE)$. If W is positive and ΔPE is negative, then ΔKE must be positive and greater than W.

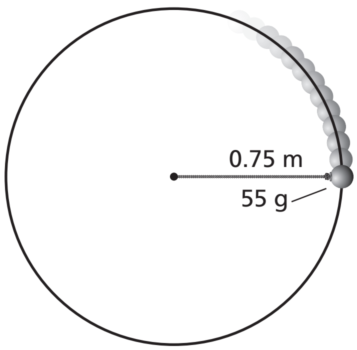
48. During a process, positive work is done on a system, and the potential energy increases. Can you tell whether the kinetic energy increased, decreased, or remained the same? Explain.

The work equals the change in the total mechanical energy, $W = \Delta(KE + PE)$. If W is positive and ΔPE is positive, then you cannot say anything conclusive about ΔKE.

49. **Skating** Two skaters of unequal mass have the same speed and are moving in the same direction. If the ice exerts the same frictional force on each skater, how will the stopping distances of their bodies compare?

The larger skater will have more kinetic energy. The kinetic energy of each skater will be dissipated by the negative work, $W = Fd$, done by the friction of the ice. Since the frictional forces are equal, the larger skater will go farther before stopping.

50. You swing a 55-g mass on the end of a 0.75-m string around your head in a nearly horizontal circle at constant speed, as shown in **Figure 11-16.**



■ **Figure 11-16**

a. How much work is done on the mass by the tension of the string in one revolution?

No work is done by the tension force on the mass because the tension is pulling perpendicular to the motion of the mass.

b. Is your answer to part a in agreement with the work-energy theorem? Explain.

This does not violate the work-energy theorem because the kinetic energy of the mass is constant; it is moving at a constant speed.

51. Give specific examples that illustrate the following processes.

a. Work is done on a system, thereby increasing kinetic energy with no change in potential energy.

pushing a hockey puck horizontally across ice; system consists of hockey puck only

b. Potential energy is changed to kinetic energy with no work done on the system.

dropping a ball; system consists of ball and Earth

c. Work is done on a system, increasing potential energy with no change in kinetic energy.

compressing the spring in a toy pistol; system consists of spring only

d. Kinetic energy is reduced, but potential energy is unchanged. Work is done by the system.

A car, speeding on a level track, brakes and reduces its speed.

52. **Roller Coaster** You have been hired to make a roller coaster more exciting. The owners want the speed at the bottom of the first hill doubled. How much higher must the first hill be built?

The hill must be made higher by a factor of 4.

53. Two identical balls are thrown from the top of a cliff, each with the same speed. One is thrown straight up, the other straight down. How do the kinetic energies and speeds of the balls compare as they strike the ground?

Even though the balls are moving in opposite directions, they have the same kinetic energy and potential energy when they are thrown. Therefore, they will have the same mechanical energy and speed when they hit the ground.

Mastering Problems

Unless otherwise directed, assume that air resistance is negligible.

11.1 The Many Forms of Energy
pages 307–308

Level 1

54. A 1600-kg car travels at a speed of 12.5 m/s. What is its kinetic energy?

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}(1600\ \text{kg})(12.5\ \text{m/s})^2$$

$$= 1.3\times10^5\ \text{J}$$

55. A racing car has a mass of 1525 kg. What is its kinetic energy if it has a speed of 108 km/h?

$$KE = \frac{1}{2}mv^2$$

$$= \frac{1}{2}(1525\ \text{kg})\left(\frac{(108\ \text{km/h})(1000\ \text{m/km})}{3600\ \text{s/h}}\right)^2$$

$$= 6.86\times10^5\ \text{J}$$

56. Shawn and his bike have a combined mass of 45.0 kg. Shawn rides his bike 1.80 km in 10.0 min at a constant velocity. What is Shawn's kinetic energy?

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{d}{t}\right)^2$$

$$= \frac{1}{2}(45\ \text{kg})\left(\frac{(1.80\ \text{km})(1000\ \text{m/km})}{(10.0\ \text{min})(60\ \text{s/min})}\right)^2$$

$$= 203\ \text{J}$$

57. Tony has a mass of 45 kg and is moving with a speed of 10.0 m/s.

a. Find Tony's kinetic energy.

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}(45\ \text{kg})(10.0\ \text{m/s})^2$$

$$= 2.3\times10^3\ \text{J}$$

b. Tony's speed changes to 5.0 m/s. Now what is his kinetic energy?

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}(45\ \text{kg})(5.0\ \text{m/s})^2$$

$$= 5.6\times10^2\ \text{J}$$

c. What is the ratio of the kinetic energies in parts **a** and **b?** Explain.

$$\frac{\frac{1}{2}(mv_1^2)}{\frac{1}{2}(mv_2^2)} = \frac{v_1^2}{v_2^2} = \frac{(10.0)^2}{(5.0)^2} = \frac{4}{1}$$

Twice the velocity gives four times the kinetic energy. The kinetic energy is proportional to the square of the velocity.

58. Katia and Angela each have a mass of 45 kg, and they are moving together with a speed of 10.0 m/s.

a. What is their combined kinetic energy?

$$KE_c = \frac{1}{2}mv^2 = \frac{1}{2}(m_K + m_A)v^2$$

$$= \frac{1}{2}(45\ \text{kg} + 45\ \text{kg})(10.0\ \text{m/s})^2$$

$$= 4.5\times10^3\ \text{J}$$

b. What is the ratio of their combined mass to Katia's mass?

$$\frac{m_K + m_A}{m_K} = \frac{45\ \text{kg} + 45\ \text{kg}}{45\ \text{kg}}$$

$$= \frac{2}{1}$$

c. What is the ratio of their combined kinetic energy to Katia's kinetic energy? Explain.

$$KE_K = \frac{1}{2}m_Kv^2 = \frac{1}{2}(45\ \text{kg})(10.0\ \text{m/s})^2$$

$$= 2.3\times10^3\ \text{J}$$

$$\frac{KE_C}{KE_K} = \frac{\frac{1}{2}(m_K + m_A)v^2}{\frac{1}{2}m_Kv^2} = \frac{m_K + m_A}{m_K}$$

$$= \frac{2}{1}$$

The ratio of their combined kinetic energy to Katia's kinetic energy is the same as the ratio of their combined mass to Katia's mass. Kinetic energy is proportional to mass.

59. **Train** In the 1950s, an experimental train, which had a mass of 2.50×10^4 kg, was powered across a level track by a jet engine that produced a thrust of 5.00×10^5 N for a distance of 509 m.

a. Find the work done on the train.

$$W = Fd = (5.00\times10^5 \text{ N})(509 \text{ m})$$
$$= 2.55\times10^8 \text{ J}$$

b. Find the change in kinetic energy.

$$\Delta KE = W = 2.55\times10^8 \text{ J}$$

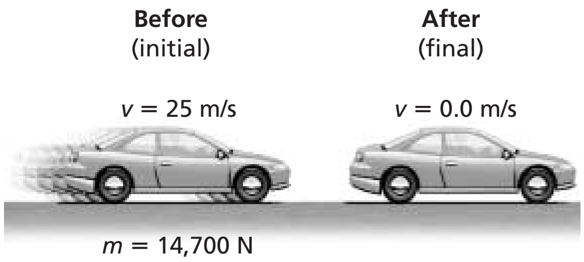
c. Find the final kinetic energy of the train if it started from rest.

$$\Delta KE = KE_f - KE_i$$
$$\text{so } KE_f = \Delta KE + KE_i$$
$$= 2.55\times10^8 \text{ J} + 0.00 \text{ J}$$
$$= 2.55\times10^8 \text{ J}$$

d. Find the final speed of the train if there had been no friction.

$$KE_f = \frac{1}{2}mv_f^2$$
$$\text{So } v_f^2 = \frac{KE_f}{\frac{1}{2}m}$$
$$= \frac{2.55\times10^8 \text{ J}}{\frac{1}{2}(2.50\times10^4 \text{ kg})}$$
$$\text{So } v_f = \sqrt{2.04\times10^4 \text{ m}^2/\text{s}^2} = 143 \text{ m/s}$$

60. **Car Brakes** A 14,700-N car is traveling at 25 m/s. The brakes are applied suddenly, and the car slides to a stop, as shown in **Figure 11-17.** The average braking force between the tires and the road is 7100 N. How far will the car slide once the brakes are applied?



■ **Figure 11-17**

$$W = Fd = \frac{1}{2}mv^2$$

$$\text{Now } m = \frac{F_g}{g}$$
$$\text{So } d = \frac{\frac{1}{2}mv^2}{F}$$
$$= \frac{\frac{1}{2}\left(\frac{F_g}{g}\right)v^2}{F}$$
$$= \frac{\frac{1}{2}\left(\frac{14{,}700 \text{ N}}{9.80 \text{ m/s}^2}\right)(25.0 \text{ m/s})^2}{7100 \text{ N}}$$
$$= 66 \text{ m}$$

61. A 15.0-kg cart is moving with a velocity of 7.50 m/s down a level hallway. A constant force of 10.0 N acts on the cart, and its velocity becomes 3.20 m/s.

a. What is the change in kinetic energy of the cart?

$$\Delta KE = KE_f - KE_i = \frac{1}{2}m(v_f^2 - v_i^2)$$
$$= \frac{1}{2}(15.0 \text{ kg})((3.20 \text{ m/s})^2 - (7.50 \text{ m/s})^2)$$
$$= -345 \text{ J}$$

b. How much work was done on the cart?

$$W = \Delta KE = -345 \text{ J}$$

c. How far did the cart move while the force acted?

$$W = Fd$$
$$\text{so } d = \frac{W}{F} = \frac{-345 \text{ J}}{-10.0 \text{ N}} = 34.5 \text{ m}$$

62. How much potential energy does DeAnna with a mass of 60.0 kg, gain when she climbs a gymnasium rope a distance of 3.5 m?

$$PE = mgh$$
$$= (60.0 \text{ kg})(9.80 \text{ m/s}^2)(3.5 \text{ m})$$
$$= 2.1\times10^3 \text{ J}$$

63. **Bowling** A 6.4-kg bowling ball is lifted 2.1 m into a storage rack. Calculate the increase in the ball's potential energy.

$$PE = mgh$$
$$= (6.4 \text{ kg})(9.80 \text{ m/s}^2)(2.1 \text{ m})$$
$$= 1.3\times10^2 \text{ J}$$

64. Mary weighs 505 N. She walks down a flight of stairs to a level 5.50 m below her starting point. What is the change in Mary's potential energy?

$PE = mg\Delta h = F_g\Delta h$

$= (505\ \text{N})(-5.50\ \text{m})$

$= -2.78\times10^3\ \text{J}$

65. Weightlifting A weightlifter raises a 180-kg barbell to a height of 1.95 m. What is the increase in the potential energy of the barbell?

$PE = mgh$

$= (180\ \text{kg})(9.80\ \text{m/s}^2)(1.95\ \text{m})$

$= 3.4\times10^3\ \text{J}$

66. A 10.0-kg test rocket is fired vertically from Cape Canaveral. Its fuel gives it a kinetic energy of 1960 J by the time the rocket engine burns all of the fuel. What additional height will the rocket rise?

$PE = mgh = KE$

$h = \frac{KE}{mg} = \frac{1960}{(10.0\ \text{kg})(9.80\ \text{m/s}^2)}$

$= 20.0\ \text{m}$

67. Antwan raised a 12.0-N physics book from a table 75 cm above the floor to a shelf 2.15 m above the floor. What was the change in the potential energy of the system?

$PE = mg\Delta h = F_g\Delta h = F_g(h_f - \text{h}_i)$

$= (12.0\ \text{N})(2.15\ \text{m} - 0.75\ \text{m})$

$= 17\ \text{J}$

68. A hallway display of energy is constructed in which several people pull on a rope that lifts a block 1.00 m. The display indicates that 1.00 J of work is done. What is the mass of the block?

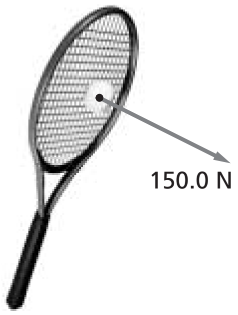
$W = PE = mgh$

$m = \frac{W}{gh} = \frac{1.00\ \text{J}}{(9.80\ \text{m/s}^2)(1.00\ \text{m})}$

$= 0.102\ \text{kg}$

Level 2

69. Tennis It is not uncommon during the serve of a professional tennis player for the racket to exert an average force of 150.0 N on the ball. If the ball has a mass of 0.060 kg and is in contact with the strings of the racket, as shown in **Figure 11-18,** for 0.030 s, what is the kinetic energy of the ball as it leaves the racket? Assume that the ball starts from rest.



■ **Figure 11-18**

$Ft = m\Delta v = mv_f - mv_i$ and $v_i = 0$

so $v_f = \frac{Ft}{m} = \frac{(150.0\ \text{N})(3.0\times10^{-2}\ \text{s})}{6.0\times10^{-2}\ \text{kg}}$

$= 75\ \text{m/s}$

$KE = \frac{1}{2}mv^2$

$= \frac{1}{2}(6.0\times10^{-2}\ \text{kg})(75\ \text{m/s})^2$

$= 1.7\times10^2\ \text{J}$

70. Pam, wearing a rocket pack, stands on frictionless ice. She has a mass of 45 kg. The rocket supplies a constant force for 22.0 m, and Pam acquires a speed of 62.0 m/s.

a. What is the magnitude of the force?

$\Delta KE_f = \frac{1}{2}mv_f^2$

$= \frac{1}{2}(45\ \text{kg})(62.0\ \text{m/s})^2$

$= 8.6\times10^4\ \text{J}$

b. What is Pam's final kinetic energy?

Work done on Pam equals her change in kinetic energy.

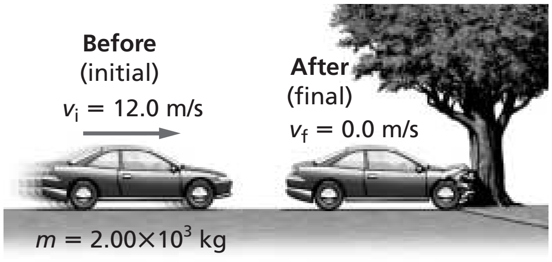
$W = Fd = \Delta KE = KE_f - KE_i$

$KE_i = 0\ \text{J}$

So, $F = \frac{KE_f}{d} = \frac{8.6\times10^4\ \text{J}}{22.0\ \text{m}}$

$= 3.9\times10^3\ \text{N}$

71. Collision A 2.00×10^3-kg car has a speed of 12.0 m/s. The car then hits a tree. The tree doesn't move, and the car comes to rest, as shown in **Figure 11-19.**



■ Figure 11-19

a. Find the change in kinetic energy of the car.

$$\Delta KE = KE_f - KE_i = \frac{1}{2}m(v_f^2 - v_i^2)$$
$$= \frac{1}{2}(2.00\times10^3\ \text{kg})((0.0\ \text{m/s})^2 - (12.0\ \text{m/s})^2)$$
$$= -1.44\times10^5\ \text{J}$$

b. Find the amount of work done as the front of the car crashes into the tree.

$$W = \Delta KE = -1.44\times10^5\ \text{J}$$

c. Find the size of the force that pushed in the front of the car by 50.0 cm.

$$W = Fd$$
$$\text{so } F = \frac{W}{d}$$
$$= \frac{-1.44\times10^5\ \text{J}}{0.500\ \text{m}}$$
$$= -2.88\times10^5\ \text{N}$$

72. A constant net force of 410 N is applied upward to a stone that weighs 32 N. The upward force is applied through a distance of 2.0 m, and the stone is then released. To what height, from the point of release, will the stone rise?

$$W = Fd = (410\ \text{N})(2.0\ \text{m}) = 8.2\times10^2\ \text{J}$$
But $W = \Delta PE = mg\Delta h$, so
$$\Delta h = \frac{W}{mg} = \frac{8.2\times10^2\ \text{J}}{32\ \text{N}} = 26\ \text{m}$$

11.2 Conservation of Energy
pages 308–309
Level 1

73. A 98.0-N sack of grain is hoisted to a storage room 50.0 m above the ground floor of a grain elevator.

a. How much work was done?

$$W = \Delta PE = mg\Delta h = F_g\Delta h$$
$$= (98.0\ \text{N})(50.0\ \text{m})$$
$$= 4.90\times10^3\ \text{J}$$

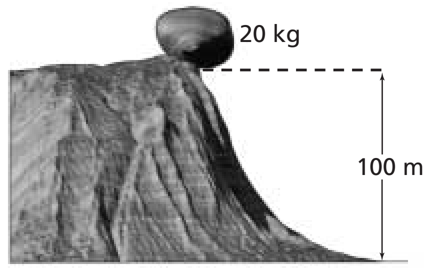
b. What is the increase in potential energy of the sack of grain at this height?

$$\Delta PE = W = 4.90\times10^3\ \text{J}$$

c. The rope being used to lift the sack of grain breaks just as the sack reaches the storage room. What kinetic energy does the sack have just before it strikes the ground floor?

$$KE = \Delta PE = 4.90\times10^3\ \text{J}$$

74. A 20-kg rock is on the edge of a 100-m cliff, as shown in **Figure 11-20.**



■ Figure 11-20

a. What potential energy does the rock possess relative to the base of the cliff?

$$PE = mgh = (20\ \text{kg})(9.80\ \text{m/s}^2)(100\ \text{m})$$
$$= 2\times10^4\ \text{J}$$

b. The rock falls from the cliff. What is its kinetic energy just before it strikes the ground?

$$KE = \Delta PE = 2\times10^4\ \text{J}$$

c. What speed does the rock have as it strikes the ground?

$$KE = \frac{1}{2}mv^2$$
$$v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{(2)(2\times10^4\ \text{J})}{20\ \text{kg}}}$$
$$= 40\ \text{m/s}$$

75. Archery An archer puts a 0.30-kg arrow to the bowstring. An average force of 201 N is exerted to draw the string back 1.3 m.

a. Assuming that all the energy goes into the arrow, with what speed does the arrow leave the bow?

Work done on the string increases the string's elastic potential energy.

$W = \Delta PE = Fd$

All of the stored potential energy is transformed to the arrow's kinetic energy.

$KE = \frac{1}{2}mv^2 = \Delta PE = Fd$

$v^2 = \frac{2Fd}{m}$

$v = \sqrt{\frac{2Fd}{m}} = \sqrt{\frac{(2)(201\ \text{N})(1.3\ \text{m})}{0.30\ \text{kg}}}$

$= 42\ \text{m/s}$

b. If the arrow is shot straight up, how high does it rise?

The change in the arrow's potential energy equals the work done to pull the string.

$\Delta PE = mg\Delta h = Fd$

$\Delta h = \frac{Fd}{mg} = \frac{(201\ \text{N})(1.3\ \text{m})}{(0.30\ \text{kg})(9.80\ \text{m/s}^2)}$

$= 89\ \text{m}$

76. A 2.0-kg rock that is initially at rest loses 407 J of potential energy while falling to the ground. Calculate the kinetic energy that the rock gains while falling. What is the rock's speed just before it strikes the ground?

$PE_i + KE_i = PE_f + KE_f$

$KE_i = 0$

So,

$KE_f = PE_i - PE_f = 407\ \text{J}$

$KE_f = \frac{1}{2}mv_f^2$

$v_f^2 = \frac{2KE_f}{m}$

$v_f = \sqrt{\frac{2KE_f}{m}} = \sqrt{\frac{(2)(407\ \text{J})}{(2.0\ \text{kg})}}$

$= 2.0\times10^1\ \text{m/s}$

77. A physics book of unknown mass is dropped 4.50 m. What speed does the book have just before it hits the ground?

$KE = PE$

$\frac{1}{2}mv^2 = mgh$

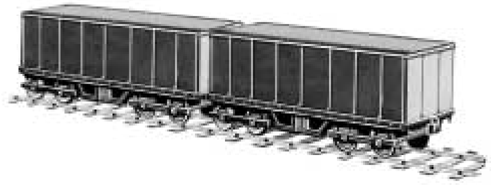
The mass of the book divides out, so

$\frac{1}{2}v^2 = gh$

$v = \sqrt{2gh} = \sqrt{2(9.80\ \text{m/s}^2)(4.50\ \text{m})}$

$= 9.39\ \text{m/s}$

78. Railroad Car A railroad car with a mass of 5.0×10^5 kg collides with a stationary railroad car of equal mass. After the collision, the two cars lock together and move off at 4.0 m/s, as shown in **Figure 11-21.**



■ **Figure 11-21**

a. Before the collision, the first railroad car was moving at 8.0 m/s. What was its momentum?

$mv = (5.0\times10^5\ \text{kg})(8.0\ \text{m/s})$

$= 4.0\times10^6\ \text{kg·m/s}$

b. What was the total momentum of the two cars after the collision?

Because momentum is conserved, it must be 4.0×10^6 kg·m/s

c. What were the kinetic energies of the two cars before and after the collision?

Before the collision:

$KE_i = \frac{1}{2}mv^2$

$= \frac{1}{2}(5.0\times10^5\ \text{kg})(8.0\ \text{m/s})^2$

$= 1.6\times10^7\ \text{J}$

After the collision:

$KE_f = \frac{1}{2}mv^2$

$= \frac{1}{2}(5.0\times10^5 \text{ kg} + 5.0\times10^5 \text{ kg})(4.0 \text{ m/s})^2$

$= 8.0\times10^6 \text{ J}$

d. Account for the loss of kinetic energy.

While momentum was conserved during the collision, kinetic energy was not. The amount not conserved was turned into thermal energy and sound energy.

79. From what height would a compact car have to be dropped to have the same kinetic energy that it has when being driven at 1.00×10^2 km/h?

$v = \left(1.00\times10^2 \frac{\text{km}}{\text{h}}\right)\left(\frac{1000 \text{ m}}{1 \text{ km}}\right)\left(\frac{1 \text{ h}}{3600 \text{ s}}\right)$

$= 27.8 \text{ m/s}$

$KE = PE$

$\frac{1}{2}mv^2 = mgh$

$\frac{1}{2}v^2 = gh$

$h = \frac{v^2}{2g} = \frac{(27.8 \text{ m/s})^2}{2(9.80 \text{ m/s}^2)}$

$= 39.4 \text{ m}$

Level 2

80. Kelli weighs 420 N, and she is sitting on a playground swing that hangs 0.40 m above the ground. Her mom pulls the swing back and releases it when the seat is 1.00 m above the ground.

a. How fast is Kelli moving when the swing passes through its lowest position?

$\Delta PE = mg\Delta h = mg(h_f - h_i)$

$\Delta KE = \frac{1}{2}m(v_f^2 - v_i^2) = \frac{1}{2}mv_f^2$

By conservation of mechanical energy:

$\Delta PE + \Delta KE = 0$

$mg(h_f - h_i) + \frac{1}{2}mv_f^2 = 0$

$v_f = \sqrt{2g(h_i - h_f)}$

$= \sqrt{(2)(9.80 \text{ m/s}^2)(1.00 \text{ m} - 0.40 \text{ m})}$

$= 3.4 \text{ m/s}$

b. If Kelli moves through the lowest point at 2.0 m/s, how much work was done on the swing by friction?

The work done by friction equals the change in mechanical energy.

$W = \Delta PE - \Delta KE$

$= mg(h_f - h_i) + \frac{1}{2}mv_f^2$

$= (420 \text{ N})(0.40 \text{ m} - 1.00 \text{ m}) + \frac{1}{2}\left(\frac{420 \text{ N}}{9.80 \text{ m/s}^2}\right)(2.0 \text{ m/s})^2$

$= -1.7\times10^2 \text{ J}$

81. Hakeem throws a 10.0-g ball straight down from a height of 2.0 m. The ball strikes the floor at a speed of 7.5 m/s. What was the initial speed of the ball?

$KE_f = KE_i + PE_i$

$\frac{1}{2}mv_f^2 = \frac{1}{2}mv_i^2 + mgh$

the mass of the ball divides out, so

$v_i^2 = v_f^2 - 2gh,$

$v_i = \sqrt{v_f^2 - 2gh}$

$= \sqrt{(7.5 \text{ m/s})^2 - (2)(9.80 \text{ m/s}^2)(2.0 \text{ m})}$

$= 4.1 \text{ m/s}$

82. **Slide** Lorena's mass is 28 kg. She climbs the 4.8-m ladder of a slide and reaches a velocity of 3.2 m/s at the bottom of the slide. How much work was done by friction on Lorena?

The work done by friction on Lorena equals the change in her mechanical energy.

$W = \Delta PE + \Delta KE$

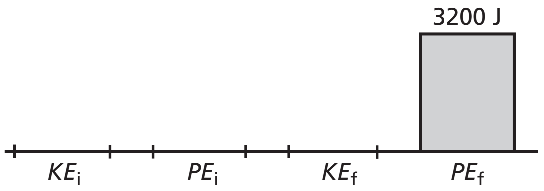
$= mg(h_f - h_i) + \frac{1}{2}m(v_f^2 - v_i^2)$

$= (28 \text{ kg})(9.80 \text{ m/s}^2)(0.0 \text{ m} - 4.8 \text{ m}) + \frac{1}{2}(28 \text{ kg})((3.2 \text{ m/s})^2 - (0.0 \text{ m/s})^2)$

$= -1.2\times10^3 \text{ J}$

83. A person weighing 635 N climbs up a ladder to a height of 5.0 m. Use the person and Earth as the system.

a. Draw energy bar graphs of the system before the person starts to climb the ladder and after the person stops at the top. Has the mechanical energy changed? If so, by how much?



Yes. The mechanical energy has changed, increase in potential energy of (635 N)(5.0 m) = 3200 J.

b. Where did this energy come from?

from the internal energy of the person

Mixed Review

pages 309–310

Level 1

84. Suppose a chimpanzee swings through the jungle on vines. If it swings from a tree on a 13-m-long vine that starts at an angle of 45°, what is the chimp's velocity when it reaches the ground?

The chimpanzee's initial height is

$h = (13\text{ m})(1 - \cos 45°) = 3.8\text{ m}$

Conservation of mechanical energy:

$\Delta PE + \Delta KE = 0$

$mg(h_f - h_i) + \frac{1}{2}m(v_f^2 - v_i^2) = 0$

$-mgh_i + \frac{1}{2}mv_f^2 = 0$

$v_f = \sqrt{2gh_i} = \sqrt{2(9.80\text{ m/s}^2)(3.8\text{ m})}$

$= 8.6\text{ m/s}$

85. An 0.80-kg cart rolls down a frictionless hill of height 0.32 m. At the bottom of the hill, the cart rolls on a flat surface, which exerts a frictional force of 2.0 N on the cart. How far does the cart roll on the flat surface before it comes to a stop?

$E = mgh = W = Fd$

$d = \frac{mgh}{F} = \frac{(0.80\text{ kg})(9.80\text{ m/s}^2)(0.32\text{ m})}{2.0\text{ N}}$

$= 1.3\text{ m}$

86. High Jump The world record for the men's high jump is about 2.45 m. To reach that height, what is the minimum amount of work that a 73.0-kg jumper must exert in pushing off the ground?

$W = \Delta E = mgh$

$= (73.0\text{ kg})(9.80\text{ m/s}^2)(2.45\text{ m})$

$= 1.75\text{ kJ}$

87. A stuntwoman finds that she can safely break her fall from a one-story building by landing in a box filled to a 1-m depth with foam peanuts. In her next movie, the script calls for her to jump from a five-story building. How deep a box of foam peanuts should she prepare?

Assume that the foam peanuts exert a constant force to slow him down, $W = Fd = E = mgh$. If the height is increased five times, then the depth of the foam peanuts also should be increased five times to 5 m.

Level 2

88. Football A 110-kg football linebacker has a head-on collision with a 150-kg defensive end. After they collide, they come to a complete stop. Before the collision, which player had the greater momentum and which player had the greater kinetic energy?

The momentum after the collision is zero; therefore, the two players had equal and opposite momenta before the collision. That is, $p_{linebacker} = m_{linebacker}v_{linebacker} = p_{end} = m_{end}v_{end}$. After the collision, each had zero energy. The energy loss for each player was $\frac{1}{2}mv^2 = \frac{1}{2}\left(\frac{m^2v^2}{m}\right) = \frac{p^2}{2m}$.

Because the momenta were equal but $m_{linebacker} < m_{end}$ the linebacker lost more energy.

89. A 2.0-kg lab cart and a 1.0-kg lab cart are held together by a compressed spring. The lab carts move at 2.1 m/s in one direction. The spring suddenly becomes uncompressed and pushes the two lab carts apart. The 2-kg lab cart comes to a stop, and the 1.0-kg lab cart moves ahead. How much energy did the spring add to the lab carts?

$$E_i = \frac{1}{2}mv^2 = \frac{1}{2}(2.0\text{ kg} + 1.0\text{ kg})(2.1\text{ m/s})^2$$

$$= 6.6\text{ J}$$

$$p_i = mv = (2.0\text{ kg} + 1.0\text{ kg})(2.1\text{ m/s})$$

$$= 6.3\text{ kg·m/s} = p_f = (1.0\text{ kg})v_f$$

so, $v_f = 6.3$ m/s

$$E_f = \frac{1}{2}mv_f^2 = \frac{1}{2}(1.0\text{ kg})(6.3\text{ m/s})^2 = 19.8\text{ J}$$

$$\Delta E = 19.8\text{ J} - 6.6\text{ J} = 13.2\text{ J}$$

13.2 J was added by the spring.

90. A 55.0-kg scientist roping through the top of a tree in the jungle sees a lion about to attack a tiny antelope. She quickly swings down from her 12.0-m-high perch and grabs the antelope (21.0 kg) as she swings. They barely swing back up to a tree limb out of reach of the lion. How high is this tree limb?

$$E_i = m_B gh$$

The velocity of the botanist when she reaches the ground is

$$E_i = \frac{1}{2}m_B v^2 = m_B gh$$

$$v = \sqrt{\frac{2E_i}{m}} = \sqrt{\frac{2m_B gh}{m_B}} = \sqrt{2gh}$$

Momentum is conserved when the botanist grabs the antelope.

$$m_B v = (m_B + m_A)v_f$$

so, $v_f = \dfrac{m_B v}{(m_B + m_A)} = \left(\dfrac{m_B}{m_B + m_A}\right)\sqrt{2gh}$

The final energy of the two is

$$E_f = \frac{1}{2}(m_B + m_A)v_f^2$$

$$= \frac{1}{2}(m_B + m_A)\left(\frac{m_B}{m_B + m_A}\right)^2(2gh)$$

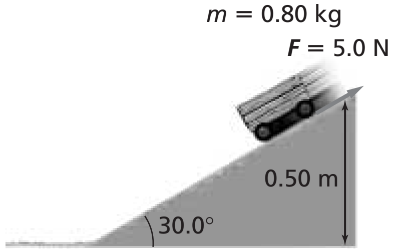
$$= (m_B + m_A)gh_f$$

So, $h_f = \left(\dfrac{m_B}{m_B + m_A}\right)^2 h$

$$= \left(\frac{55.0\text{ kg}}{55.0\text{ kg} + 21.0\text{ kg}}\right)^2(12.0\text{ m})$$

$$= 6.28\text{ m}$$

91. An 0.80-kg cart rolls down a 30.0° hill from a vertical height of 0.50 m as shown in **Figure 11-22.** The distance that the cart must roll to the bottom of the hill is 0.50 m/sin 30.0° = 1.0 m. The surface of the hill exerts a frictional force of 5.0 N on the cart. Does the cart roll to the bottom of the hill?



■ **Figure 11-22**

$$E_i = mgh = (0.80\text{ kg})(9.80\text{ m/s}^2)(0.50\text{ m})$$

$$= 3.9\text{ J}$$

The work done by friction over 1.0 m would be

$W = Fd = (5.0\text{ N})(1.0\text{ m}) = 5.0$ J.

The work done by friction is greater than the energy of the cart. The cart would not reach the bottom of the hill.

Level 3

92. Object A, sliding on a frictionless surface at 3.2 m/s, hits a 2.0-kg object, B, which is motionless. The collision of A and B is completely elastic. After the collision, A and B move away from each other at equal and opposite speeds. What is the mass of object A?

$$p_i = m_A v_1 + 0$$

$$p_f = m_A(-v_2) + m_B v_2$$

$p_i = p_f$ (conservation of momentum)

therefore, $m_A v_1 = m_A(-v_2) + m_B v^2$

$$(m_B - m_A)v_2 = m_A v_1$$

$$v_2 = \frac{(m_A v_1)}{(m_B - m_A)}$$

$$E_i = \frac{1}{2}m_A v_1^2$$

$$E_f = \frac{1}{2}m_A v_2^2 + \frac{1}{2}m_B v_2^2$$

$$E_f = \frac{1}{2}(m_A + m_B)v_2^2$$

$$= \frac{1}{2}(m_A + m_B)\left(\frac{(m_A v_1)}{(m_B - m_A)}\right)^2$$

$E_i = E_f$ (conservation of energy in elastic collision)
therefore,

$$\frac{1}{2}m_A v_1^2 = \frac{1}{2}(m_A + m_B)\left(\frac{(m_A v_1)}{(m_B - m_A)}\right)^2$$

After cancelling out common factors,

$$(m_A + m_B)m_A = (m_B - m_A)^2 = m_B^2 - 2m_A m_B + m_A^2$$

$$m_A = \frac{m_B}{3} = \frac{2.00 \text{ kg}}{3} = 0.67 \text{ kg}$$

93. **Hockey** A 90.0-kg hockey player moving at 5.0 m/s collides head-on with a 110-kg hockey player moving at 3.0 m/s in the opposite direction. After the collision, they move off together at 1.0 m/s. How much energy was lost in the collision?

Before: $E = \frac{1}{2}mv_1^2 + \frac{1}{2}mv_2^2$

$$= \frac{1}{2}(90.0 \text{ kg})(5.0 \text{ m/s})^2 + \frac{1}{2}(110 \text{ kg})(3.0 \text{ m/s})^2$$

$$= 1.6\times10^3 \text{ J}$$

After: $E = \frac{1}{2}(m + m)v_f^2$

$$= \frac{1}{2}(200.0 \text{ kg})(1.0 \text{ m/s})^2$$

$$= 1.0\times10^2 \text{ J}$$

Energy loss $= 1.6\times10^3 \text{ J} - 1.0\times10^2 \text{ J}$

$$= 1.5\times10^3 \text{ J}$$

Thinking Critically

page 310

94. **Apply Concepts** A golf ball with a mass of 0.046 kg rests on a tee. It is struck by a golf club with an effective mass of 0.220 kg and a speed of 44 m/s. Assuming that the collision is elastic, find the speed of the ball when it leaves the tee.

From the conservation of momentum,

$$m_c v_{c1} = m_c v_{c2} + m_b v_{b2}$$

Solve for v_{c2}, $v_{c2} = v_{c1} - \frac{m_b v_{b2}}{m_c}$

From conservation of energy,

$$\frac{1}{2}m_c v_{c1}^2 = \frac{1}{2}m_c v_{c2}^2 + \frac{1}{2}m_b v_{b2}^2$$

Multiply by two and substitute to get:

$$m_c v_{c1}^2 = m_c\left(v_{c1} - \frac{m_b v_{b2}}{m_c}\right)^2 + m_b v_{b2}^2$$

or $m_c v_{c1}^2 = m_c v_{c1}^2 - 2m_b v_{c2} v_{c1} + \frac{m_b^2 v_{b2}^2}{m_c} + m_b v_{b2}^2$

Simplify and factor:

$$0 = (m_b v_{b2})\left(-2v_{c1} + \frac{m_b^2 v_{b2}}{m_c} + v_{b2}\right)$$

$m_b v_{b2} = 0$ or

$$-2v_{c1} + \left(\frac{m_b}{m_c} + 1\right)v_{b2} = 0$$

Ignoring the solution $v_{b2} = 0$, then

$$v_{b2} = \frac{2v_{c1}}{\left(\frac{m_b}{m_c} + 1\right)}$$

$$= \frac{2(44 \text{ m/s})}{\left(\frac{0.046 \text{ kg}}{0.220 \text{ kg}} + 1\right)} = 73 \text{ m/s}$$

95. **Apply Concepts** A fly hitting the windshield of a moving pickup truck is an example of a collision in which the mass of one of the objects is many times larger than the other. On the other hand, the collision of two billiard balls is one in which the masses of both objects are the same. How is energy transferred in these collisions? Consider an elastic collision in which billiard ball m_1 has velocity v_1 and ball m_2 is motionless.

a. If $m_1 = m_2$, what fraction of the initial energy is transferred to m_2?

If $m_1 = m_2$, we know that m_1 will be at rest after the collision and m_2 will move with velocity v_1. All of the energy will be transferred to m_2.

b. If $m_1 >> m_2$, what fraction of the initial energy is transferred to m_2?

If $m_1 >> m_2$, we know that the motion of m_1 will be unaffected by the collision and that the energy transfer to m_2 will be minimal.

c. In a nuclear reactor, neutrons must be slowed down by causing them to collide with atoms. (A neutron is about as massive as a proton.) Would hydrogen, carbon, or iron atoms be more desirable to use for this purpose?

The best way to stop a neutron is to have it hit a hydrogen atom, which has about the same mass as the neutron.

96. Analyze and Conclude In a perfectly elastic collision, both momentum and mechanical energy are conserved. Two balls, with masses m_A and m_B, are moving toward each other with speeds v_A and v_B, respectively. Solve the appropriate equations to find the speeds of the two balls after the collision.

conservation of momentum

(1) $m_A v_{A1} + m_B v_{B1} = m_A v_{A2} + m_B v_{B2}$

$$m_A v_{A1} - m_A v_{A2} = -m_B v_{B1} + m_B v_{B2}$$

(2) $m_A(v_{A1} - v_{A2}) = -m_B(v_{B1} - v_{B2})$

conservation of energy

$$\frac{1}{2}m_A v_{A1}^2 + \frac{1}{2}m_B v_{B1}^2 = \frac{1}{2}m_A v_{A2}^2 + \frac{1}{2}m_B v_{B2}^2$$

$$m_A v_{A1}^2 - m_A v_{A2}^2 = -m_B v_{B1}^2 + m_B v_{B2}^2$$

$$m_A(v_{A1}^2 - v_{A2}^2) = -m_B(v_{B1}^2 - v_{B2}^2)$$

(3) $m_A(v_{A1} + v_{A2})(v_{A1} - v_{A2}) = -m_B(v_{B1} + v_{B2})(v_{B1} - v_{B2})$

Divide equation (3) by (2) to obtain

(4) $v_{A1} + v_{A2} = v_{B1} + v_{B2}$

Solve equation (1) for v_{A2} and v_{B2}

$$v_{A2} = v_{A1} + \frac{m_B}{m_A}(v_{B1} - v_{B2})$$

$$v_{B2} = v_{B1} + \frac{m_A}{m_B}(v_{A1} - v_{A2})$$

Substitute into (4) and solve for v_{B2} and v_{A2}

$$v_{A1} + v_{A1} + \frac{m_B}{m_A}(v_{B1} - v_{B2}) = v_{B1} + v_{B2}$$

$$2m_A v_{A1} + m_B v_{B1} - m_B v_{B2} = m_A v_{B1} + m_A v_{B2}$$

$$v_{B2} = \left(\frac{2m_A}{m_A + m_B}\right)v_{A1} + \left(\frac{m_B - m_A}{m_A + m_B}\right)v_{B1}$$

$$v_{A1} + v_{A2} = v_{B1} + v_{B1} + \frac{m_A}{m_B}(v_{A1} - v_{A2})$$

$$m_B v_{A1} + m_B v_{A2} = 2m_B v_{B1} + m_A v_{A1} - m_A v_{A2}$$

$$v_{A2} = \left(\frac{m_A - m_B}{m_A + m_B}\right)v_{A1} + \left(\frac{2m_B}{m_A + m_B}\right)v_{B1}$$

97. Analyze and Conclude A 25-g ball is fired with an initial speed of v_1 toward a 125-g ball that is hanging motionless from a 1.25-m string. The balls have a perfectly elastic collision. As a result, the 125-g ball swings out until the string makes an angle of 37.0° with the vertical. What is v_1?

Object 1 is the incoming ball. Object 2 is the one attached to the string. In the collision, momentum is conserved.

$p_{1i} = p_{1f} + p_{2f}$ **or**

$m_1v_{1i} = m_1v_{1f} + m_2v_{2f}$

In the collision, kinetic energy is conserved.

$$\frac{1}{2}m_1v_{1i}^2 = \frac{1}{2}m_1v_{1f}^2 + \frac{1}{2}m_2v_{2f}^2$$

$$m_1v_{1i}^2 = m_1v_{1f}^2 + m_2v_{2f}^2$$

$$(m_1v_{1i}^2)\left(\frac{m_1}{m_1}\right) = (m_1v_{1f}^2)\left(\frac{m_1}{m_1}\right) + (m_2v_{2f}^2)\left(\frac{m_2}{m_2}\right)$$

$$\frac{m_1^2v_{1i}^2}{m_1} = \frac{m_1^2v_{1f}^2}{m_1} + \frac{m_2^2v_{2f}^2}{m_2}$$

$$\frac{p_{1i}^2}{m_1} = \frac{p_{1f}^2}{m_1} + \frac{p_{2f}^2}{m_2}$$

$$p_{1i}^2 = p_{1f}^2 + \left(\frac{m_1}{m_2}\right)p_{2f}^2$$

We don't care about v_{1f}, so get rid of p_{1f} using $p_{1f} = p_{1i} - p_{2f}$

$$p_{1i}^2 = (p_{1i} - p_{2f})^2 + \frac{m_1}{m_2}p_{2f}^2$$

$$p_{1i}^2 = p_{1i}^2 - 2p_{1i}p_{2f} + p_{2f}^2 + \frac{m_1}{m_2}p_{2f}^2$$

$$2p_{1i}p_{2f} = \left(1 + \frac{m_1}{m_2}\right)p_{2f}^2$$

$$p_{1i} = \left(\frac{1}{2}\right)\left(1 + \frac{m_1}{m_2}\right)p_{2f}$$

$$m_1v_{1i} = \left(\frac{1}{2}\right)(m_2 + m_1)v_{2f}$$

$$v_{1i} = \left(\frac{1}{2}\right)\left(\frac{m_2}{m_1} + 1\right)v_{2f}$$

Now consider the pendulum.

$$\frac{1}{2}m_2v_{2f}^2 = m_2gh$$

or $v_{2f} = \sqrt{2gh}$

where $h = L(1 - \cos\theta)$

Thus, $v_{2f} = \sqrt{2gL(1 - \cos\theta)}$

$$v_{2f} = \sqrt{(2)(9.80\ \text{m/s}^2)(1.25\ \text{m})(1 - \cos 37.0°)}$$

$$= 2.22\ \text{m/s}$$

$$v_{1i} = \frac{1}{2}\left(\frac{125\text{ g}}{25\text{ g}} + 1\right)(2.22\text{ m/s})$$

$$= 6.7\text{ m/s}$$

Writing in Physics

page 310

98. All energy comes from the Sun. In what forms has this solar energy come to us to allow us to live and to operate our society? Research the ways that the Sun's energy is turned into a form that we can use. After we use the Sun's energy, where does it go? Explain.

The Sun produces energy through nuclear fusion and releases that energy in the form of electromagnetic radiation, which is transferred through the vacuum of space to Earth. Earth absorbs that electromagnetic radiation in its atmosphere, land, and oceans in the form of thermal energy or heat. Part of the visible radiation also is converted by plants into chemical energy through photosynthesis. There are several other chemical reactions mediated by sunlight, such as ozone production. The energy then is transferred into various forms, some of which are the chemical processes that allow us to digest food and turn it into chemical energy to build tissues, to move, and to think. In the end, after we have used the energy, the remainder is dispersed as electromagnetic radiation back into the universe.

99. All forms of energy can be classified as either kinetic or potential energy. How would you describe nuclear, electric, chemical, biological, solar, and light energy, and why? For each of these types of energy, research what objects are moving and how energy is stored in those objects.

Potential energy is stored in the binding of the protons and neutrons in the nucleus. The energy is released when a heavy nucleus is broken into smaller pieces (fission) or when very small nuclei are combined to make bigger nuclei (fusion). In the same way, chemical potential energy is stored when atoms are combined to make molecules and released when the molecules are broken up or rearranged. Separation of electric charges produces electric potential energy, as in a battery. Electric potential energy is converted to kinetic energy in the motion of electric charges in an electric current when a conductive path, or circuit, is provided. Biological processes are all chemical, and thus, biological energy is just a form of chemical energy. Solar energy is fusion energy converted to to electromagnetic radiation. (See the answer to the previous question.) Light is a wave form of electromagnetic energy whose frequency is in a range detectible by the human eye.

Cumulative Review

page 310

100. A satellite is placed in a circular orbit with a radius of 1.0×10^7 m and a period of 9.9×10^3 s. Calculate the mass of Earth. *Hint: Gravity is the net force on such a satellite. Scientists have actually measured the mass of Earth this way.* (Chapter 7)

$$F_{net} = \frac{m_s v^2}{r} = \frac{G m_s m_e}{r^2}$$

Since, $v = \frac{2\pi r}{T}$

$$\left(\frac{m_s}{r}\right)\left(\frac{4\pi^2 r^2}{T^2}\right) = \frac{G m_s m_e}{r^2}$$

$$m_e = \frac{4\pi^2 r^2}{GT^2}$$

$$= \frac{4\pi^2(1.0\times10^7\text{ m})^3}{(6.67\times10^{-11}\text{ N·m}^2/\text{kg}^2)(9.9\times10\text{ s})^2}$$

$$= 6.0\times10^{24}\text{ kg}$$

101. A 5.00-g bullet is fired with a velocity of 100.0 m/s toward a 10.00-kg stationary solid block resting on a frictionless surface. (Chapter 9)

a. What is the change in momentum of the bullet if it is embedded in the block?

$$m_b v_{b1} = m_b v_2 - m_w v_2$$

$$= (m_b + m_w)v_2$$

so $v_2 = \frac{m_b v_{b1}}{m_b + m_w}$

Then,

$$\Delta pv = m_b(v_2 - v_{b1})$$

$$= m_b\left(\frac{m_b v_{b1}}{m_b + m_w} - v_{b1}\right)$$

$$= m_b v_{b1}\left(\frac{m_b}{m_b + m_w} - 1\right)$$

$$= -\frac{m_b m_w}{m_b + m_w} v_{b1}$$

$$= -\frac{(5.00\times10^{-3}\text{ kg})(10.00\text{ kg})}{5.00\times10^{-3}\text{ kg} + 10.00\text{ kg}}(100.0\text{ m/s})$$

$$= -0.500\text{ kg·m/s}$$

b. What is the change in momentum of the bullet if it ricochets in the opposite direction with a speed of 99 m/s?

$$\Delta pv = m_b(v_2 - v_{b1})$$

$$= (5.00\times10^{-3}\text{ kg})(-99.0\text{ m/s} - 100.0\text{ m/s})$$

$$= -0.995\text{ kg·m/s}$$

c. In which case does the block end up with a greater speed?

When the bullet ricochets, its change in momentum is larger in magnitude, and so is the block's change in momentum, so the block ends up with a greater speed.

102. An automobile jack must exert a lifting force of at least 15 kN.

a. If you want to limit the effort force to 0.10 kN, what mechanical advantage is needed?

$$MA = \frac{15\text{ kN}}{0.10\text{ kN}} = 150$$

b. If the jack is 75% efficient, over what distance must the effort force be exerted in order to raise the auto 33 cm?

$$IMA = \frac{MA}{e} = 2.0\times10^2.$$

Since $\frac{d_e}{d_r} = IMA$,

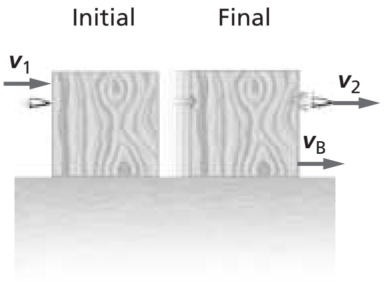
$$d_e = \frac{IMA}{d_r} = (2.0\times10^2)(33\text{ cm})$$

$$= 66\text{ m}$$

Challenge Problem

page 300

A bullet of mass m, moving at speed v_1, goes through a motionless wooden block and exits with speed v_2. After the collision, the block, which has mass m_B, is moving.



1. What is the final speed v_B, of the block?

Conservation of momentum:

$$mv_1 = mv_2 + m_B v_B$$

$$m_B v_B = m(v_1 - v_2)$$

$$v_B = \frac{m(v_1 - v_2)}{m_B}$$

2. How much energy was lost to the bullet?

For the bullet alone:

$$KE_1 = \frac{1}{2}mv_1^2$$

$$KE_2 = \frac{1}{2}mv_2^2$$

$$\Delta KE = \frac{1}{2}m(v_1^2 - v_2^2)$$

3. How much energy was lost to friction inside the block?

Energy lost to friction $= KE_1 - KE_2 - KE_{block}$

$$E_{lost} = \frac{1}{2}mv_1^2 - \frac{1}{2}mv_2^2 - \frac{1}{2}m_B v_B^2$$

CHAPTER
12 Thermal Energy

Practice Problems

12.1 Temperature and Thermal Energy pages 313–322

page 317

1. Convert the following Kelvin temperatures to Celsius temperatures.

a. 115 K

$\mathbf{T_C = T_K - 273 = 115 - 273 = -158°C}$

b. 172 K

$\mathbf{T_C = T_K - 273 = 172 - 273 = -101°C}$

c. 125 K

$\mathbf{T_C = T_K - 273 = 125 - 273 = -148°C}$

d. 402 K

$\mathbf{T_C = T_K - 273 = 402 - 273 = 129°C}$

e. 425 K

$\mathbf{T_C = T_K - 273 = 425 - 273 = 152°C}$

f. 212 K

$\mathbf{T_C = T_K - 273 = 212 - 273 = -61°C}$

2. Find the Celsius and Kelvin temperatures for the following.

a. room temperature

Room temperature is about 72°F, 22°C.

$\mathbf{T_K = T_C + 273 = 22 + 273 = 295\ K}$

b. a typical refrigerator

A refrigerator is kept at about 4°C.

$\mathbf{T_K = T_C + 273 = 4 + 273 = 277\ K}$

c. a hot summer day in North Carolina

A hot summer day is about 95°F, 35°C.

$\mathbf{T_K = T_C + 273 = 35 + 273 = 308\ K}$

d. a winter night in Minnesota

A typical winter night in Minnesota is about 14°F, −10°C.

$\mathbf{T_K = T_C + 273 = -10 + 273 = 263\ K}$

page 319

3. When you turn on the hot water to wash dishes, the water pipes have to heat up. How much heat is absorbed by a copper water pipe with a mass of 2.3 kg when its temperature is raised from 20.0°C to 80.0°C?

$$Q = mC\Delta T = (2.3\ \text{kg})(385\ \text{J/kg·K})(80.0°\text{C} - 20.0°\text{C}) = 5.3\times10^4\ \text{J}$$

4. The cooling system of a car engine contains 20.0 L of water (1 L of water has a mass of 1 kg).

a. What is the change in the temperature of the water if the engine operates until 836.0 kJ of heat is added?

$$Q = mC\Delta T$$

$$\Delta T = \frac{Q}{mC} = \frac{(8.36\times10^5\ \text{J})}{(20.0\ \text{kg})(4180\ \text{J/kg·K})} = 10.0\ \text{K}$$

b. Suppose that it is winter, and the car's cooling system is filled with methanol. The density of methanol is 0.80 g/cm^3. What would be the increase in temperature of the methanol if it absorbed 836.0 kJ of heat?

The mass of methanol would be 0.80 times the mass of 20.0 L of water, or 16 kg.

$$Q = mC\Delta T$$

$$\Delta T = \frac{Q}{mC} = \frac{8.36\times10^5\ \text{J}}{(16\ \text{kg})(2450\ \text{J/kg·K})} = 21\ \text{K}$$

c. Which is the better coolant, water or methanol? Explain.

For temperatures above 0°C, water is the better coolant because it can absorb heat without changing its temperature as much as methanol does.

5. Electric power companies sell electricity by the kWh, where 1 kWh = 3.6×10^{6} J. Suppose that it costs \$0.08 per kWh to run an electric water heater in your neighborhood. How much does it cost to heat 75 kg of water from 15°C to 43°C to fill a bathtub?

$$Q = mC\Delta T$$
$$= (75\ \text{kg})(4180\ \text{J/kg·K})(43°\text{C} - 15°\text{C})$$
$$= 8.8\times10^{6}\ \text{J}$$

$$\frac{8.8\times10^{6}\ \text{J}}{3.6\times10^{6}\ \text{J/kWh}} = 2.4\ \text{kWh}$$

(2.4 kWh)(\$0.15 per kWh) = \$0.36

page 321

6. A 2.00×10^{2}-g sample of water at 80.0°C is mixed with 2.00×10^{2} g of water at 10.0°C. Assume that there is no heat loss to the surroundings. What is the final temperature of the mixture?

$$m_A C_A(T_f - T_{Ai}) + m_B C_B(T_f - T_{Bi}) = 0$$

Since $m_A = m_B$ and $C_A = C_B$,

there is cancellation in this particular case so that

$$T_f = \frac{T_{Ai} + T_{Bi}}{2} = \frac{80.0°\text{C} + 10.0°\text{C}}{2} = 45.0°\text{C}$$

7. A 4.00×10^{2}-g sample of methanol at 16.0°C is mixed with 4.00×10^{2} g of water at 85.0°C. Assume that there is no heat loss to the surroundings. What is the final temperature of the mixture?

$$m_A C_A(T_f - T_{Ai}) + m_W C_W(T_f - T_{Wi}) = 0$$

Since in this particular case, $m_A = m_W$, the masses cancel and

$$T_f = \frac{C_A T_{Ai} + C_W T_{Wi}}{C_A + C_W}$$
$$= \frac{(2450\ \text{J/kg·K})(16.0°\text{C}) + (4180\ \text{J/kg·K})(85.0°\text{C})}{2450\ \text{J/kg·K} + 4180\ \text{J/kg·K}} = 59.5°\text{C}$$

8. Three lead fishing weights, each with a mass of 1.00×10^{2} g and at a temperature of 100.0°C, are placed in 1.00×10^{2} g of water at 35.0°C. The final temperature of the mixture is 45.0°C. What is the specific heat of the lead in the weights?

Heat gained by the water:

$$Q = mC\Delta T = (0.100\ \text{kg})(4180\ \text{J/kg·°C})(10.0°\text{C}) = 4.18\ \text{kJ}$$

Thus, heat lost by the weights = −4.18 kJ = $m_{weights}C_{weights}\Delta T$

$$\text{hence, } C_{weights} = \frac{(-4.184\ \text{kJ})(1000\ \text{J/kJ})}{(0.100\ \text{kg})(-55.0°\text{C})}$$
$$= 2.53\times10^{2}\ \text{J/kg·°C}$$

9. A 1.00×10^2-g aluminum block at 100.0°C is placed in 1.00×10^2 g of water at 10.0°C. The final temperature of the mixture is 25.0°C. What is the specific heat of the aluminum?

Heat gained by the water:

$$Q = mC\Delta T$$
$$= (0.100\text{ kg})(4180\text{ J/kg·°C})(15.0\text{°C})$$
$$= 6.27\text{ kJ}$$

Thus, heat lost by the aluminum block $= -6.27\text{ kJ} = m_{\text{Aluminum}}C_{\text{Aluminum}}\Delta T$

hence, $C_{\text{Aluminum}} = \frac{Q}{m_{\text{Aluminum}}\Delta T}$

$$= \frac{-6.27\text{ kJ}}{(0.100\text{ kg})(-75.0\text{°C})}$$
$$= 8.36\times10^2\text{ J/kg·°C}$$

Section Review

12.1 Temperature and Thermal Energy pages 313–322

page 322

10. Temperature Make the following conversions.

a. 5°C to kelvins

278 K

b. 34 K to degrees Celsius

−239°C

c. 212°C to kelvins

485 K

d. 316 K to degrees Celsius

43°C

11. Conversions Convert the following Celsius temperatures to Kelvin temperatures.

a. 28°C

301 K

b. 154°C

427 K

c. 568°C

841 K

d. −55°C

218 K

e. −184°C

89 K

12. Thermal Energy Could the thermal energy of a bowl of hot water equal that of a bowl of cold water? Explain your answer.

Thermal energy is the measure of the total energy of all the molecules in an object. The temperature (hot or cold) measures the amount of energy per molecule. If the bowls are identical and contain the same amount of water, they have the same number of molecules, but the bowl of hot water has more total thermal energy. However, if the cold water mass is slightly more than that of the hot water, the two energies could be equal.

13. Heat Flow On a dinner plate, a baked potato always stays hot longer than any other food. Why?

A potato has a large specific heat and conducts heat poorly, so it loses its heat energy slowly.

14. Heat The hard tile floor of a bathroom always feels cold to bare feet even though the rest of the room is warm. Is the floor colder than the rest of the room?

The floor is usually at the same temperature as the rest of the room, but the tile conducts heat more efficiently than most materials, so it conducts heat from a person's feet, making them feel cold.

15. Specific Heat If you take a plastic spoon out of a cup of hot cocoa and put it in your mouth, you are not likely to burn your tongue. However, you could very easily burn your tongue if you put the hot cocoa in your mouth. Why?

The plastic spoon has a lower specific heat than the cocoa, so it does not transmit much heat to your tongue as it cools.

16. **Heat** Chefs often use cooking pans made of thick aluminum. Why is thick aluminum better than thin aluminum for cooking?

Thick aluminum conducts heat better and does not have any "hot spots."

17. **Heat and Food** It takes much longer to bake a whole potato than to cook french fries. Why?

Potatoes do not conduct heat well. Increasing surface area by cutting a potato into small parts increases heat flow into the potato. Heat flow from hot oil to the potato is also more efficient than from hot air.

18. **Critical Thinking** As water heats in a pot on a stove, the water might produce some mist above its surface right before the water begins to roll. What is happening, and where is the coolest part of the water in the pot?

The heat flows from the burner (the hottest part) to the top surface of the water (coldest). The water first transfers heat from bottom to top through conduction, and then convection begins to move hot water in currents to the top.

Practice Problems

12.2 Changes of State and the Laws of Thermodynamics pages 323–331

page 325

19. How much heat is absorbed by 1.00×10^2 g of ice at -20.0°C to become water at 0.0°C?

$$Q = mC\Delta T + mH_f$$

$$= (0.100\text{ kg})(2060\text{ J/kg·°C})(20.0\text{°C}) + (0.100\text{ kg})(3.34\times10^5\text{ J/kg})$$

$$= 3.75\times10^4\text{ J}$$

20. A 2.00×10^2-g sample of water at 60.0°C is heated to steam at 140.0°C. How much heat is absorbed?

$$Q = mC_{water}\Delta T + mH_v + mC_{steam}\Delta T$$

$$= (0.200\text{ kg})(4180\text{ J/kg·°C})(100.0\text{°C} - 60.0\text{°C}) + (0.200\text{ kg})(2.26\times10^6\text{ J/kg}) + (0.200\text{ kg})(2020\text{ J/kg·°C})(140.0\text{°C} - 100.0\text{°C})$$

$$= 502\text{ kJ}$$

21. How much heat is needed to change 3.00×10^2 g of ice at -30.0°C to steam at 130.0°C?

$$Q = mC_{ice}\Delta T + mH_f + mC_{water}\Delta T + mH_v + mC_{steam}\Delta T$$

$$= (0.300\text{ kg})(2060\text{ J/kg·°C})(0.0\text{°C} - (-30.0\text{°C})) + (0.300\text{ kg})(3.34\times10^5\text{ J/kg}) + (0.300\text{ kg})(4180\text{ J/kg·°C})(100.0\text{°C} - 0.0\text{°C}) + (0.300\text{ kg})(2.26\times10^6\text{ J/kg}) + (0.300\text{ kg})(2020\text{ J/kg·°C})(130.0\text{°C} - 100.0\text{°C})$$

$$= 9.40\times10^2\text{ kJ}$$

page 328

22. A gas balloon absorbs 75 J of heat. The balloon expands but stays at the same temperature. How much work did the balloon do in expanding?

$\Delta U = Q - W$

Since the balloon did not change temperature, $\Delta U = 0$.

Therefore, $Q = W$.

Thus, the balloon did 75 J of work in expanding.

23. A drill bores a small hole in a 0.40-kg block of aluminum and heats the aluminum by 5.0°C. How much work did the drill do in boring the hole?

$\Delta U = Q - W_{block}$; **since** $W_{drill} = -W_{block}$ **and assume no heat added to drill:**

$= 0 + W_{drill} = mC\Delta T$

$= (0.40\ \text{kg})(897\ \text{J/kg·°C})(5.0\text{°C})$

$= 1.8\times10^3\ \text{J}$

24. How many times would you have to drop a 0.50-kg bag of lead shot from a height of 1.5 m to heat the shot by 1.0°C?

$\Delta U = mC\Delta T$

$= (0.50\ \text{kg})(130\ \text{J/kg·°C})(1.0\text{°C})$

$= 65\ \text{J}$

Each time the bag is raised its potential energy is

$PE = mgh$

$= (0.50\ \text{kg})(9.80\ \text{m/s}^2)(1.5\ \text{m})$

$= 7.4\ \text{J}$

When the bag hits the ground this energy is (mostly) transmitted as work on the lead shot. The number of drops is $\frac{65\ \text{J}}{7.4\ \text{J}} = 9$ **drops**

25. When you stir a cup of tea, you do about 0.050 J of work each time you circle the spoon in the cup. How many times would you have to stir the spoon to heat a 0.15-kg cup of tea by 2.0°C?

$\Delta U = mC\Delta T$

$= (0.15\ \text{kg})(4180\ \text{J/kg·°C})(2.0\text{°C})$

$= 1.3\times10^3\ \text{J}$.

The number of stirs is

$\frac{1.3\times10^3\ \text{J}}{0.050\ \text{J}} = 2.6\times10^4$ **stirs**

26. How can the first law of thermodynamics be used to explain how to reduce the temperature of an object?

Since $\Delta U = Q - W$, it is possible to have a negative ΔU and therefore, cool an object if $Q = 0$ and the object does work, for instance, by expanding. Alternatively, have $W = 0$ and Q negative by having it transfer heat to its surroundings. Any combination of these will work well.

Section Review

12.2 Changes of State and the Laws of Thermodynamics pages 323–331

page 331

27. Heat of Vaporization Old-fashioned heating systems sent steam into radiators in each room of a house. In the radiators, the steam condensed back to water. Analyze this process and explain how it heated a room.

The condensing steam released its heat of vaporization into the room and was then circulated back to the boiler to receive the heat of vaporization again.

28. Heat of Vaporization How much heat is needed to change 50.0 g of water at 80.0°C to steam at 110.0°C?

$Q = mC_{water}\Delta T + mH_v + mC_{steam}\Delta T$

$= (0.500\ \text{kg})(4180\ \text{J/kg·°C})(100.0\text{°C} - 80.0\text{°C}) + (0.500\ \text{kg})(2.26\times10^6\ \text{J/kg}) + (0.500\ \text{kg})(2020\ \text{J/kg·°C})(110.0\text{°C} - 100.0\text{°C})$

$= 1.18\times10^5\ \text{J}$

29. Heat of Vaporization The specific heat of mercury is 140 J/kg·°C. Its heat of vaporization is 3.06×10^5 J/kg. How much energy is needed to heat 1.0 kg of mercury metal from 10.0°C to its boiling point and vaporize it completely? The boiling point of mercury is 357°C.

$$Q = mC_{Hg}\Delta T + mH_v$$
$$= (1.0\ \text{kg})(140\ \text{J/kg·°C})(357°\text{C} - 10.0°\text{C}) + (1.0\ \text{kg})(3.06\times10^5\ \text{J/kg})$$
$$= 3.5\times10^5\ \text{J}$$

30. Mechanical Energy and Thermal Energy James Joule carefully measured the difference in temperature of water at the top and bottom of a waterfall. Why did he expect a difference?

The water at the top has gravitational potential energy that is dissipated into thermal energy when the water splashes at the bottom. The water should be hotter at the bottom, but not by much.

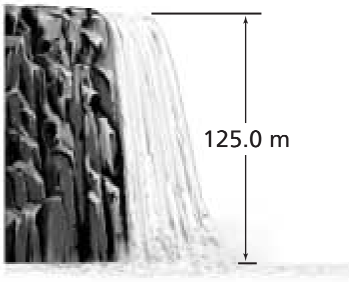
31. Mechanical Energy and Thermal Energy A man uses a 320-kg hammer moving at 5.0 m/s to smash a 3.0-kg block of lead against a 450-kg rock. When he measured the temperature he found that it had increased by 5.0°C. Explain how this happened.

Part of the kinetic energy of the hammer is absorbed as thermal energy by the lead block. The hammer's energy is $\frac{1}{2}mv^2 = \frac{1}{2}(320\ \text{kg})(5.0\ \text{m/s})^2 = 4.0$ kJ. The change in thermal energy of the block is

$$\Delta U = mC\Delta T$$
$$= (3.0\ \text{kg})(130\ \text{J/kg·K})(5.0°\text{C})$$
$$= 2.0\ \text{kJ}$$

Hence, about half of the hammer's energy went to the lead block.

32. Mechanical Energy and Thermal Energy Water flows over a fall that is 125.0 m high, as shown in **Figure 12-17.** If the potential energy of the water is all converted to thermal energy, calculate the temperature difference between the water at the top and the bottom of the fall.



■ **Figure 12-17**

$$PE_{\text{gravity}} = Q_{\text{absorbed by water}}$$
$$mgh = mC\Delta T$$
$$\Delta T = \frac{gh}{C}$$
$$= \frac{(9.80\ \text{m/s}^2)(125.0\ \text{m})}{4180\ \text{J/kg·°C}}$$
$$= 0.293°\text{C rise in temperature at the bottom}$$

33. Entropy Evaluate why heating a home with natural gas results in an increased amount of disorder.

The gas releases heat, *Q*, at its combustion temperature, *T*. The natural gas molecules break up and combust with oxygen. The heat is distributed in many new ways, and the natural gas molecules cannot readily be reassembled.

34. Critical Thinking A new deck of cards has all the suits (clubs, diamonds, hearts, and spades) in order, and the cards are ordered by number within the suits. If you shuffle the cards many times, are you likely to return the cards to their original order? Explain. Of what physical law is this an example?

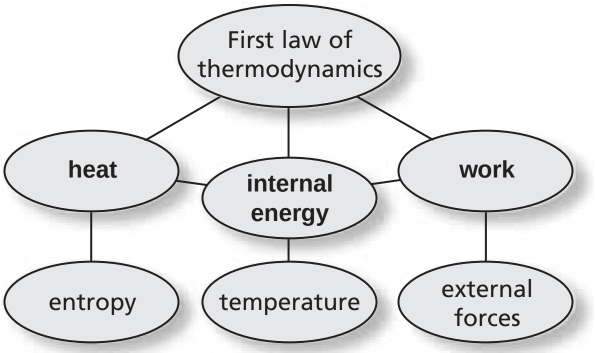
The cards are very unlikely to return to their original order. This is an example of the second law of thermodynamics, in which disorder increases.

Chapter Assessment

Concept Mapping

page 336

35. Complete the following concept map using the following terms: *heat, work, internal energy.*



Mastering Concepts

page 336

36. Explain the differences among the mechanical energy of a ball, its thermal energy, and its temperature. (12.1)

The mechanical energy is the sum of the potential and kinetic energies of the ball considered as one mass. The thermal energy is the sum of the potential and kinetic energies of the individual particles that make up the mass of the ball. The temperature is a measure of the internal energy of the ball.

37. Can temperature be assigned to a vacuum? Explain. (12.1)

No, because there are no particles that have energy in a vacuum.

38. Do all of the molecules or atoms in a liquid have the same speed? (12.1)

No. There is a distribution of velocities of the atoms or molecules.

39. Is your body a good judge of temperature? On a cold winter day, a metal doorknob feels much colder to your hand than a wooden door does. Explain why this is true. (12.1)

Your skin measures heat flow to or from itself. The metal doorknob absorbs heat from your skin faster than the wooden door, so it feels colder.

40. When heat flows from a warmer object in contact with a colder object, do the two have the same temperature changes? (12.1)

The two objects will change temperatures depending on their masses and specific heats. The temperature changes are not necessarily the same for each.

41. Can you add thermal energy to an object without increasing its temperature? Explain. (12.2)

When you melt a solid or boil a liquid, you add thermal energy without changing the temperature.

42. When wax freezes, does it absorb or release energy? (12.2)

When wax freezes, it releases energy.

43. Explain why water in a canteen that is surrounded by dry air stays cooler if it has a canvas cover that is kept wet. (12.2)

When the water in the cover evaporates into the dry air, it must absorb an amount of energy proportional to its heat of fusion. In doing so, it cools off the canteen. This works only if the air is dry; if the air is humid, then the water will not evaporate.

44. Which process occurs at the coils of a running air conditioner inside a house, vaporization or condensation? Explain. (12.2)

Inside the house, the coolant is evaporating in the coils to absorb energy from the rooms.

Applying Concepts

page 336

45. Cooking Sally is cooking pasta in a pot of boiling water. Will the pasta cook faster if the water is boiling vigorously or if it is boiling gently?

It should make no difference. Either way, the water is at the same temperature.

46. Which liquid would an ice cube cool faster, water or methanol? Explain.

Methanol, because it has a lower specific heat; for a given mass and heat transfer, it generates a bigger ΔT since $Q = mC\Delta T$.

47. Equal masses of aluminum and lead are heated to the same temperature. The pieces of metal are placed on a block of ice. Which metal melts more ice? Explain.

The specific heat of aluminum is much greater than that of lead; therefore, it melts more ice.

48. Why do easily vaporized liquids, such as acetone and methanol, feel cool to the skin?

As they evaporate, they absorb their heat of vaporization from the skin.

49. Explain why fruit growers spray their trees with water when frost is expected to protect the fruit from freezing.

The water on the leaves will not freeze until it can release its heat of fusion. This process keeps the leaves warmer longer. The heat capacity of the ice slows down the cooling below 0°C.

50. Two blocks of lead have the same temperature. Block A has twice the mass of block B. They are dropped into identical cups of water of equal temperatures. Will the two cups of water have equal temperatures after equilibrium is achieved? Explain.

The cup with block A will be hotter because block A contains more thermal energy.

51. **Windows** Often, architects design most of the windows of a house on the north side. How does putting windows on the south side affect the heating and cooling of the house?

In the northern hemisphere, the sunlight comes from the south. The Sun's light would help heat the house in the winter but also would also heat the house in the summer.

Mastering Problems

12.1 Temperature and Thermal Energy
pages 336–337

Level 1

52. How much heat is needed to raise the temperature of 50.0 g of water from 4.5°C to 83.0°C?

$$Q = mC\Delta T$$
$$= (0.0500\ \text{kg})(4180\ \text{J/kg·°C})(83.0\text{°C} - 4.5\text{°C})$$
$$= 1.64\times10^{4}\ \text{J}$$

53. A 5.00×10^{2}-g block of metal absorbs 5016 J of heat when its temperature changes from 20.0°C to 30.0°C. Calculate the specific heat of the metal.

$$Q = mC\Delta T$$
$$\text{so } C = \frac{Q}{m\Delta T}$$
$$= \frac{5016\ \text{J}}{(5.00\times10^{-1}\ \text{kg})(30.0\text{°C} - 20.0\text{°C})}$$
$$= 1.00\times10^{3}\ \text{J/kg·°C}$$
$$= 1.00\times10^{3}\ \text{J/kg·K}$$

54. **Coffee Cup** A 4.00×10^{2}-g glass coffee cup is 20.0°C at room temperature. It is then plunged into hot dishwater at a temperature of 80.0°C, as shown in **Figure 12-18.** If the temperature of the cup reaches that of the dishwater, how much heat does the cup absorb? Assume that the mass of the dishwater is large enough so that its temperature does not change appreciably.

■ **Figure 12-18**

$$Q = mC\Delta T$$
$$= (4.00\times10^{-1}\ \text{kg})(840\ \text{J/kg·°C})(80.0\text{°C} - 20.0\text{°C})$$
$$= 2.02\times10^{4}\ \text{J}$$

55. A 1.00×10^2-g mass of tungsten at 100.0°C is placed in 2.00×10^2 g of water at 20.0°C. The mixture reaches equilibrium at 21.6°C. Calculate the specific heat of tungsten.

$$\Delta Q_T + \Delta Q_W = 0$$

or $m_T C_T \Delta T_T = -m_W C_W \Delta T_W$

$$C_T = \frac{-m_W C_W \Delta T_W}{m_T \Delta T_T} = \frac{-(0.200\ \text{kg})(4180\ \text{J/kg·K})(21.6°\text{C} - 20.0°\text{C})}{(0.100\ \text{kg})(21.6°\text{C} - 100.0°\text{C})}$$

$$= 171\ \text{J/kg·K}$$

56. A 6.0×10^2-g sample of water at 90.0°C is mixed with 4.00×10^2 g of water at 22.0°C. Assume that there is no heat loss to the surroundings. What is the final temperature of the mixture?

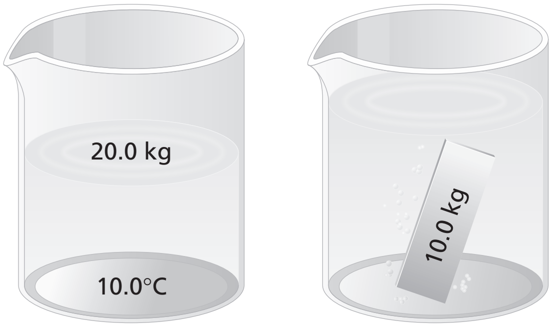
$$T_f = \frac{m_A C_A \Delta T_{Ai} + m_B C_B \Delta T_{Bi}}{m_A C_A + m_B C_B}$$

but $C_A = C_B$ because both liquids are water, and the C's will divide out.

$$T_f = \frac{m_A T_{Ai} + m_B T_{Bi}}{m_A + m_B} = \frac{(6.0\times10^2\ \text{g})(90.0°\text{C}) + (4.00\times10^2\ \text{g})(22.0°\text{C})}{6.0\times10^2\ \text{g} + 4.00\times10^2\ \text{g}}$$

$$= 63°\text{C}$$

57. A 10.0-kg piece of zinc at 71.0°C is placed in a container of water, as shown in **Figure 12-19.** The water has a mass of 20.0 kg and a temperature of 10.0°C before the zinc is added. What is the final temperature of the water and the zinc?



■ **Figure 12-19**

$$T_f = \frac{m_A C_A \Delta T_{Ai} + m_B C_B \Delta T_{Bi}}{m_A C_A + m_B C_B}$$

$$= \frac{(10.0\ \text{kg})(388\ \text{J/kg·K})(71.0°\text{C}) + (20.0\ \text{kg})(4180\ \text{J/kg·K})(10.0°\text{C})}{(10.0\ \text{kg})(388\ \text{J/kg·K}) + (20.0\ \text{kg})(4180\ \text{J/kg·K})}$$

$$= 12.7°\text{C}$$

Level 2

58. The kinetic energy of a compact car moving at 100 km/h is 2.9×10^5 J. To get a feeling for the amount of energy needed to heat water, what volume of water (in liters) would 2.9×10^5 J of energy warm from room temperature (20.0°C) to boiling (100.0°C)?

$Q = mC\Delta T = \rho VC\Delta T$ where ρ is the density of the material

so, $V = \frac{Q}{\rho C \Delta T} = \frac{2.9\times10^5\ \text{J}}{(1.00\ \text{kg/L})(4180\ \text{J/kg·°C})(100.0°\text{C} - 20.0°\text{C})}$

$$= 0.87\ \text{L}$$

59. Water Heater A 3.0×10^2-W electric immersion heater is used to heat a cup of water, as shown in **Figure 12-20.** The cup is made of glass, and its mass is 3.00×10^2 g. It contains 250 g of water at 15°C. How much time is needed to bring the water to the boiling point? Assume that the temperature of the cup is the same as the temperature of the water at all times and that no heat is lost to the air.

■ **Figure 12-20**

$Q = m_G C_G \Delta T_G + m_W C_W \Delta T_W$

but $\Delta T_G = \Delta T_W$, so

$Q = (m_G C_G + m_W C_W)\Delta T$

$= ((0.300 \text{ kg})(840 \text{ J/kg·°C}) + (0.250 \text{ kg})(4180 \text{ J/kg·°C}))(100.0°\text{C} - 15°\text{C})$

$= 1.1\times10^5$ J

Now $P = \frac{E}{t} = \frac{Q}{t}$, so

$t = \frac{Q}{P} = \frac{1.1\times10^5 \text{ J}}{3.00\times10^2 \text{ J/s}}$

$= 370$ s $= 6.1$ min

60. Car Engine A 2.50×10^2-kg cast-iron car engine contains water as a coolant. Suppose that the engine's temperature is 35.0°C when it is shut off, and the air temperature is 10.0°C. The heat given off by the engine and water in it as they cool to air temperature is 4.40×10^6 J. What mass of water is used to cool the engine?

$Q = m_W C_W \Delta T + m_i C_i \Delta T$

$m_W = \frac{Q - m_i C_i \Delta T}{C_W \Delta T} = \frac{(4.4\times10^6 \text{ J}) - ((2.50\times10^2 \text{ kg})(450 \text{ J/kg·°C})(35.0°\text{C} - 10.0°\text{C}))}{(4180 \text{ J/kg·°C})(35.0°\text{C} - 10.0°\text{C})}$

$= 15$ kg

12.2 Changes of State and the Laws of Thermodynamics

page 337

Level 1

61. Years ago, a block of ice with a mass of about 20.0 kg was used daily in a home icebox. The temperature of the ice was 0.0°C when it was delivered. As it melted, how much heat did the block of ice absorb?

$Q = mH_f = (20.0 \text{ kg})(3.34\times10^5 \text{ J/kg}) = 6.68\times10^6$ J

62. A 40.0-g sample of chloroform is condensed from a vapor at 61.6°C to a liquid at 61.6°C. It liberates 9870 J of heat. What is the heat of vaporization of chloroform?

$Q = mH_v$

$H_v = \frac{Q}{m} = \frac{9870 \text{ J}}{0.0400 \text{ kg}} = 2.47\times10^5$ J/kg

63. A 750-kg car moving at 23 m/s brakes to a stop. The brakes contain about 15 kg of iron, which absorbs the energy. What is the increase in temperature of the brakes?

During braking, the kinetic energy of the car is converted into heat energy. So,

$\Delta KE_C + Q_B = 0.0$, **and** $\Delta KE_C + m_B C_B \Delta T = 0.0$ **so,**

$$\Delta T = \frac{-\Delta KE_C}{m_B C_B} = -\frac{\frac{1}{2}m_C(v_f^2 - v_i^2)}{m_B C_B}$$

$$= -\frac{\frac{1}{2}(750\text{ kg})(0.0^2 - (23\text{ m/s})^2)}{(15\text{ kg})(450\text{ J/kg}\cdot°\text{C})}$$

$$= 29°\text{C}$$

Level 2

64. How much heat is added to 10.0 g of ice at −20.0°C to convert it to steam at 120.0°C?

Amount of heat needed to heat ice to 0.0°C:

$$Q = mC\Delta T$$
$$= (0.0100\text{ kg})(2060\text{ J/kg}\cdot°\text{C})(0.0°\text{C} - (-20.0°\text{C}))$$
$$= 412\text{ J}$$

Amount of heat to melt ice:

$$Q = mH_f$$
$$= (0.0100\text{ kg})(3.34\times10^5\text{ J/kg})$$
$$= 3.34\times10^3\text{ J}$$

Amount of heat to heat water to 100.0°C:

$$Q = mC\Delta T$$
$$= (0.0100\text{ kg})(4180\text{ J/kg}\cdot°\text{C})(100.0°\text{C} - 0.0°\text{C})$$
$$= 4.18\times10^3\text{ J}$$

Amount of heat to boil water:

$$Q = mH_v$$
$$= (0.0100\text{ kg})(2.26\times10^6\text{ J/kg})$$
$$= 2.26\times10^4\text{ J}$$

Amount of heat to heat steam to 120.0°C:

$$Q = mC\Delta T$$
$$= (0.0100\text{ kg})(2060\text{ J/kg}\cdot°\text{C})(120.0°\text{C} - 100.0°\text{C})$$
$$= 404\text{ J}$$

The total heat is

$$412\text{ J} + 3.34\times10^3\text{ J} + 4.18\times10^3\text{ J} + 2.26\times10^4\text{ J} + 404\text{ J} = 3.09\times10^4\text{ J}$$

65. A 4.2-g lead bullet moving at 275 m/s strikes a steel plate and comes to a stop. If all its kinetic energy is converted to thermal energy and none leaves the bullet, what is its temperature change?

Because the kinetic energy is converted to thermal energy, $\Delta KE + Q = 0$. **So**

$\Delta KE = -m_B C_B \Delta T$ **and**

$$\Delta T = -\frac{\Delta KE}{m_B C_B} = \frac{-\frac{1}{2}m_B(v_f^2 - v_i^2)}{m_B C_B}$$

and the mass of the bullet divides out so

$$\Delta T = \frac{-\frac{1}{2}(v_f^2 - v_i^2)}{C_B}$$

$$= \frac{-\frac{1}{2}((0.0\text{ m/s})^2 - (275\text{ m/s})^2)}{130\text{ J/kg}\cdot°\text{C}}$$

$$= 290°\text{C}$$

66. **Soft Drink** A soft drink from Australia is labeled "Low-Joule Cola." The label says "100 mL yields 1.7 kJ." The can contains 375 mL of cola. Chandra drinks the cola and then wants to offset this input of food energy by climbing stairs. How high would Chandra have to climb if she has a mass of 65.0 kg?

Chandra gained (3.75)(1.7 kJ) = 6.4×10^3 **J of energy from the drink.**

To conserve energy, $E + \Delta PE = 0$ **or** $6.4\times10^3\text{ J} = -mg\Delta h$ **so,**

$$\Delta h = \frac{6.4\times10^3\text{ J}}{-mg} = \frac{6.4\times10^3\text{ J}}{-(65.0\text{ kg})(-9.80\text{ m/s}^2)}$$

$$= 1.0\times10^1\text{ m, or about three flights of stairs}$$

Mixed Review

pages 337–338

Level 1

67. What is the efficiency of an engine that produces 2200 J/s while burning enough gasoline to produce 5300 J/s? How much waste heat does the engine produce per second?

$$\text{Efficiency} = \frac{W}{Q_H} \times 100 = \frac{2200\text{ J}}{5300\text{ J}} \times 100$$
$$= 42\%$$

The heat loss is

5300 J − 2200 J = 2900 J

68. **Stamping Press** A metal stamping machine in a factory does 2100 J of work each time it stamps out a piece of metal. Each stamped piece is then dipped in a 32.0-kg vat of water for cooling. By how many degrees does the vat heat up each time a piece of stamped metal is dipped into it?

If we assume the 2100 J of work from the machine is absorbed as thermal energy in the stamped piece, then the vat must absorb 2100 J in the form of heat from each piece. No work is done on the water, only heat is transferred. The change in temperature of the water is given by

$\Delta U = mC\Delta T$,

therefore $\Delta T = \frac{\Delta U}{mC}$

$$= \frac{2100\text{ J}}{(32.0\text{ kg})(4180\text{ J/kg·°C})}$$
$$= 0.016\text{°C.}$$

69. A 1500-kg automobile comes to a stop from 25 m/s. All of the energy of the automobile is deposited in the brakes. Assuming that the brakes are about 45 kg of aluminum, what would be the change in temperature of the brakes?

The energy change in the car is

$\Delta KE = \frac{1}{2}(1500\text{ kg})(25\text{ m/s})^2 = 4.7\times10^5\text{ J.}$

If all of this energy is transferred as work to the brakes, then

$\Delta U = \Delta KE = mC\Delta T.$

Therefore, $\Delta T = \frac{\Delta KE}{mC}$

$$= \frac{4.7\times10^5\text{ J}}{(45\text{ kg})(897\text{ J/kg·°C})}$$
$$= 12\text{°C}$$

70. **Iced Tea** To make iced tea, you start by brewing the tea with hot water. Then you add ice. If you start with 1.0 L of 90°C tea, what is the minimum amount of ice needed to cool it to 0°C? Would it be better to let the tea cool to room temperature before adding the ice?

Heat lost by the tea

$Q = mC\Delta T$

$= (1.0\text{ kg})(4180\text{ J/kg·K})(90\text{°C})$

$= 376\text{ kJ}$

Amount of ice melted

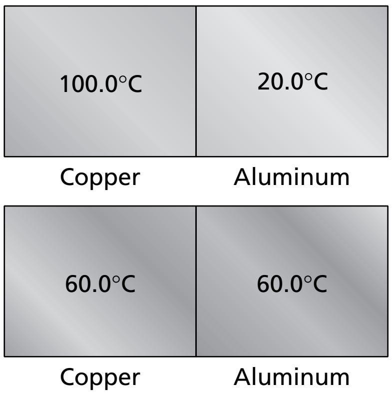
$m = \frac{Q}{H_f}$

$= \frac{376\text{ kJ}}{334\text{ kJ}} = 1.1\text{ kg}$

Thus, you need slightly more ice than tea, but this ratio would make watery tea. Let the tea cool to room temperature before adding the ice.

Level 2

71. A block of copper at 100.0°C comes in contact with a block of aluminum at 20.0°C, as shown in **Figure 12-21.** The final temperature of the blocks is 60.0°C. What are the relative masses of the blocks?



■ **Figure 12-21**

The heat lost from the copper equals the heat gained by the aluminum. The ΔT for the copper is −40.0°C and the aluminum heats by +40.0°C.

therefore,

$$m_{copper}C_{copper} = m_{aluminum}C_{aluminum}$$

$$\text{and } \frac{m_{copper}}{m_{aluminum}} = \frac{C_{aluminum}}{C_{copper}}$$

$$= \frac{897\ \text{J/kg·K}}{385\ \text{J/kg·K}} = 2.3$$

The copper block has 2.3 times as much mass as the aluminum block.

72. A 0.35-kg block of copper sliding on the floor hits an identical block moving at the same speed from the opposite direction. The two blocks come to a stop together after the collision. Their temperatures increase by 0.20°C as a result of the collision. What was their velocity before the collision?

The change in internal energy of the blocks is

$$\Delta U = mC\Delta T$$

$$= (0.70\ \text{kg})(385\ \text{J/kg·°C})(0.20°\text{C})$$

$$= 54\ \text{J}$$

Therefore, 54 J equals the kinetic energy of the blocks before the collision. $54\ \text{J} = (2)\left(\frac{1}{2}\right)mv^2$

$$v = \sqrt{\frac{54\ \text{J}}{0.35\ \text{kg}}}$$

$$= 12\ \text{m/s}$$

Level 3

73. A 2.2-kg block of ice slides across a rough floor. Its initial velocity is 2.5 m/s and its final velocity is 0.50 m/s. How much of the ice block melted as a result of the work done by friction?

The work done by friction equals the negative of the change in kinetic energy of the block, assuming not too much of the block melted.

$$\Delta KE = \frac{1}{2}(2.2\ \text{kg})(0.50\ \text{m/s})^2 - \frac{1}{2}(2.2\ \text{kg})(2.5\ \text{m/s})^2 = -6.6\ \text{J}$$

Therefore, +6.6 J is added to the ice. The amount of ice melted is given by

$$m = \frac{KE}{H_f}$$

$$= \frac{6.6\ \text{J}}{3.34\times10^5\ \text{J/kg}}$$

$$= 2.0\times10^{-5}\ \text{kg}$$

Thinking Critically

page 338

74. Analyze and Conclude A certain heat engine removes 50.0 J of thermal energy from a hot reservoir at temperature T_H = 545 K and expels 40.0 J of heat to a colder reservoir at temperature T_L = 325 K. In the process, it also transfers entropy from one reservoir to the other.

a. How does the operation of the engine change the total entropy of the reservoirs?

As the engine operates, it removes energy from the hot reservoir. Therefore, $\Delta S_H = \frac{Q_H}{T_H}$ **so that the entropy of the hot reservoir decreases.**

The entropy of the cold reservoir $\Delta S_L = \frac{Q_L}{T_L}$ **increases. The net increase in entropy of the reservoirs together is**

$$\Delta S_T = \Delta S_L - \Delta S_H$$

$$= \frac{Q_L}{T_L} - \frac{Q_H}{T_H}$$

$$\Delta S_T = \frac{40.0\ \text{J}}{325\ \text{K}} - \frac{50.0\ \text{J}}{545\ \text{K}}$$

$$= 0.0313\ \text{J/K}$$

b. What would be the total entropy change in the reservoirs if T_L = 205 K?

$$\Delta S_T = \frac{40.0\ \text{J}}{205\ \text{K}} - \frac{50.0\ \text{J}}{545\ \text{K}} = 0.103\ \text{J/K}$$

The total entropy change in the reservoirs, and in the universe, has increased approximately by a factor of three.

75. Analyze and Conclude During a game, the metabolism of basketball players often increases by as much as 30.0 W. How much perspiration must a player vaporize per hour to dissipate this extra thermal energy?

The amount of thermal energy to be dissipated in 1.00 h is

$U = (30.0\ \text{J/s})(3600\ \text{s/h}) = 1.08\times10^5\ \text{J}.$

The amount of water this energy, transmitted as heat, would vaporize is

$$m = \frac{Q}{H_V}$$

$$= \frac{1.08\times10^5\ \text{J}}{2.26\times10^6\ \text{J/kg}}$$

$$= 0.0478\ \text{kg}$$

76. Analyze and Conclude Chemists use calorimeters to measure the heat produced by chemical reactions. For instance, a chemist dissolves 1.0×10^{22} molecules of a powdered substance into a calorimeter containing 0.50 kg of water. The molecules break up and release their binding energy to the water. The water temperature increases by 2.3°C. What is the binding energy per molecule for this substance?

The amount of energy added to the water is

$$\Delta U = mC\Delta T$$

$$= (0.50\ \text{kg})(4180\ \text{J/kg·°C})(2.3\text{°C})$$

$$= 4.8\ \text{kJ}$$

The energy per molecule is therefore,

$$\frac{4.8\ \text{kJ}}{10^{22}\ \text{molecules}} = 4.8\times10^{-19}\ \text{J/molecule}$$

77. Apply Concepts All of the energy on Earth comes from the Sun. The surface temperature of the Sun is approximately 10^4 K. What would be the effect on our world if the Sun's surface temperature were 10^3 K?

Student answers will vary. Answers should reflect changing average temperature on Earth, different weather patterns, plant and animal species dying out, etc.

Writing in Physics

page 338

78. Our understanding of the relationship between heat and energy was influenced by a soldier named Benjamin Thompson, Count Rumford; and a brewer named James Prescott Joule. Both relied on experimental results to develop their ideas. Investigate what experiments they did and evaluate whether or not it is fair that the unit of energy is called the Joule and not the Thompson.

In 1799, heat was thought to be a liquid that flowed from one object to another. However, Count Rumford thought that heat was caused by the motion of particles in the metal cannon. He did not do any quantitative measurements and his ideas were not widely accepted. In 1843, Joule, doing careful measurements, measured the change in temperature caused by adding heat or doing work on a quantity of water. He proved that heat is a flavor of energy and that energy is conserved. Joule deserves the credit and the eponymic unit.

79. Water has an unusually large specific heat and large heats of fusion and vaporization. Our weather and ecosystems depend upon water in all three states. How would our world be different if water's thermodynamic properties were like other materials, such as methanol?

The large specific heat and large heats of fusion and vaporization mean that water, ice, and water vapor can store a lot of thermal energy without changing their temperatures too much. The implications are many. The oceans and large lakes moderate the temperature changes in nearby regions on a daily and seasonal basis. The day-to-night temperature variation near a lake is much smaller than the day-to-night temperature variation in the desert. The large heat of fusion of water controls the change of seasons in the far north and south. The absorption of energy by freezing water in the fall and its release

in the spring slows the temperature changes in the atmosphere. Water absorbs and stores a lot of energy as it vaporizes. This energy can be used to drive meteorological events, such as thunderstorms and hurricanes.

Cumulative Review

page 338

80. A rope is wound around a drum with a radius of 0.250 m and a moment of inertia of 2.25 kg m^2. The rope is connected to a 4.00-kg block. (Chapter 8)

a. Find the linear acceleration of the block.

Solve Newton's second law for the block: $mg - F_T = ma$, where the positive direction is downward and where F_T is the force of the rope on the drum. Newton's second law for the drum is $F_T r = I\alpha$ or $F_T r = Ia/r$. That is, $F_T = Ia/r^2$. Therefore, $mg - (I/r^2)a = ma$. That is,

$$a = mg/(m + I/r^2) = g/10.0$$
$$= 0.980 \text{ m/s}^2.$$

b. Find the angular acceleration of the drum.

$$\alpha = \frac{a}{r} = \frac{0.980 \text{ m/s}^2}{0.250 \text{ m}}$$
$$= 3.92 \text{ rad/s}^2$$

c. Find the tension, F_T, in the rope.

$$F_T = \frac{I\alpha}{r}$$
$$= \frac{(2.25 \text{ kg m}^2)(3.92 \text{ rad/s}^2)}{0.250 \text{ m}}$$
$$= 35.3 \text{ N}$$

d. Find the angular velocity of the drum after the block has fallen 5.00 m.

$$x = \frac{1}{2}at^2, \text{ so } t = \sqrt{\frac{2x}{a}} = 3.19 \text{ s}$$

Therefore, $\omega = \alpha t$

$$= (3.92 \text{ rad/s}^2)(3.19 \text{ s})$$
$$= 12.5 \text{ rad/s}$$

81. A weight lifter raises a 180-kg barbell to a height of 1.95 m. How much work is done by the weight lifter in lifting the barbell? (Chapter 10)

$$W = mgh$$
$$= (180 \text{ kg})(9.80 \text{ m/s}^2)(1.95 \text{ m})$$
$$= 3.4\times10^3 \text{ J}$$

82. In a Greek myth, the man Sisyphus is condemned by the gods to forever roll an enormous rock up a hill. Each time he reaches the top, the rock rolls back down to the bottom. If the rock has a mass of 215 kg, the hill is 33 m in height, and Sisyphus can produce an average power of 0.2 kW, how many times in 1 h can he roll the rock up the hill? (Chapter 11)

The amount of work needed to roll the rock up once is

$$W = mgh = (215 \text{ kg})(9.80 \text{ m/s}^2)(33 \text{ m})$$
$$= 70{,}000 \text{ J}$$

In one hour Sisyphus does an amount of work

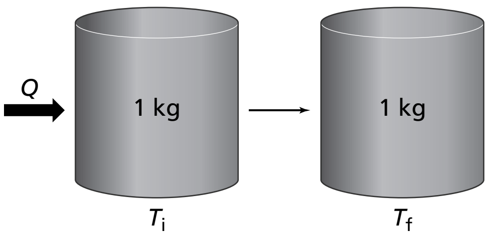
$$= (0.2\times10^3 \text{ J})(3600 \text{ s}) = 720{,}000 \text{ J}$$

He pushes the rock up the hill (720,000)/(70,000) = 10 times in one hour

Challenge Problem

page 329

Entropy has some interesting properties. Compare the following situations. Explain how and why these changes in entropy are different.



1. Heating 1.0 kg of water from 273 K to 274 K.

$$\Delta S = \frac{Q}{T} = \frac{mC\Delta T}{T}$$
$$= \frac{(1.0 \text{ kg})(4180 \text{ J/kg·K})(274 \text{ K} - 273 \text{ K})}{273 \text{ K}}$$
$$= 15 \text{ J/K}$$

2. Heating 1.0 kg of water from 353 K to 354 K.

$$\Delta S = \frac{Q}{T} = \frac{mC\Delta T}{T}$$

$$= \frac{(1.0 \text{ kg})(4180 \text{ J/kg·K})(354 \text{ K} - 353 \text{ K})}{353 \text{ K}}$$

$$= 12 \text{ J/K}$$

3. Completely melting 1.0 kg of ice at 273 K.

$$\Delta S = \frac{Q}{T} = \frac{mH_f}{T}$$

$$= \frac{(1.0 \text{ kg})(3.34\times10^5 \text{ J/kg})}{273 \text{ K}}$$

$$= 1.2\times10^3 \text{ J/K}$$

4. Heating 1.0 kg of lead from 273 K to 274 K.

$$\Delta S = \frac{Q}{T} = \frac{mC\Delta T}{T}$$

$$= \frac{(1.0 \text{ kg})(130 \text{ J/kg·K})(274 \text{ K} - 273 \text{ K})}{273 \text{ K}}$$

$$= 0.48 \text{ J/K}$$

CHAPTER

13 States of Matter

Practice Problems

13.1 Properties of Fluids pages 341–348

page 344

1. The atmospheric pressure at sea level is about 1.0×10^5 Pa. What is the force at sea level that air exerts on the top of a desk that is 152 cm long and 76 cm wide?

$$F = PA = Plw$$
$$= (1.0\times10^5\ \text{Pa})(1.52\ \text{m})(0.76\ \text{m})$$
$$= 1.2\times10^5\ \text{N}$$

2. A car tire makes contact with the ground on a rectangular area of 12 cm by 18 cm. If the car's mass is 925 kg, what pressure does the car exert on the ground as it rests on all four tires?

$$P = \frac{F}{A} = \frac{F_{g,\ car}}{A} = \frac{m_{car}g}{4lw}$$
$$= \frac{(925\ \text{kg})(9.80\ \text{m/s}^2)}{(4)(0.12\ \text{m})(0.18\ \text{m})}$$
$$= 1.0\times10^2\ \text{kPa}$$

3. A lead brick, 5.0 cm × 10.0 cm × 20.0 cm, rests on the ground on its smallest face. Lead has a density of 11.8 g/cm³. What pressure does the brick exert on the ground?

$$m_{brick} = \rho V = \rho lwh$$
$$= (11.8\ \text{g/cm}^3)(5.0\ \text{cm})(10.0\ \text{cm})(20.0\ \text{cm})$$
$$= 1.18\times10^4\ \text{g} = 11.8\ \text{kg}$$

$$P = \frac{F_{g,\ brick}}{A} = \frac{m_{brick}g}{lw}$$
$$= \frac{\rho Vg}{lw} = \frac{\rho lwhg}{lw} = \rho hg$$
$$= (11.8\ \text{g/cm}^3)(20.0\ \text{cm})(9.80\ \text{m/s}^2)\left(\frac{1\ \text{kg}}{1000\ \text{g}}\right)\left(\frac{(100\ \text{cm})^2}{(1\ \text{m})^2}\right)$$
$$= 23\ \text{kPa}$$

4. In a tornado, the pressure can be 15 percent below normal atmospheric pressure. Suppose that a tornado occurred outside a door that is 195 cm high and 91 cm wide. What net force would be exerted on the door by a sudden 15 percent drop in normal atmospheric pressure? In what direction would the force be exerted?

The pressure difference across the door is

$$P_{diff} = (15\%)(P_{atm})$$
$$= (0.15)(1.0\times10^5\ \text{Pa}) = 1.5\times10^4\ \text{Pa}$$
$$F = P_{diff}A = P_{diff}lw$$
$$= (1.5\times10^4\ \text{Pa})(1.95\ \text{m})(0.91\ \text{m})$$

$= 2.7\times10^4$ **N directed from the inside of the house outward**

5. In industrial buildings, large pieces of equipment must be placed on wide steel plates that spread the weight of the equipment over larger areas. If an engineer plans to install a 454-kg device on a floor that is rated to withstand additional pressure of 5.0×10^4 Pa, how large should the steel support plate be?

The maximum pressure $P = \frac{F_g}{A} = \frac{mg}{A}$

Therefore, $A = \frac{mg}{P}$

$$= \frac{(454\ \text{kg})(9.80\ \text{m/s}^2)}{5.0\times10^4\ \text{Pa}}$$
$$= 8.9\times10^{-2}\ \text{m}^2$$

6. A tank of helium gas used to inflate toy balloons is at a pressure of 15.5×10^6 Pa and a temperature of 293 K. The tank's volume is 0.020 m³. How large a balloon would it fill at 1.00 atmosphere and 323 K?

$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$, **so** $V_2 = \frac{T_2P_1V_1}{P_2T_1}$

1.00 atm $= 1.013\times10^5$ **Pa**

$$V_2 = \frac{(323\ \text{K})(15.5\times10^6\ \text{Pa})(0.020\ \text{m}^3)}{(1.013\times10^5\ \text{Pa})(293\ \text{K})}$$

$$= 3.4\ \text{m}^3$$

7. What is the mass of the helium gas in the previous problem? The molar mass of helium gas is 4.00 g/mol.

$$PV = nRT$$

$$n = \frac{PV}{RT} = \frac{(15.5\times10^6\ \text{Pa})(0.020\ \text{m}^3)}{(8.31\ \text{Pa·m}^3/\text{mol·K})(293\ \text{K})}$$

$$= 127.3\ \text{mol}$$

$$m = (127.3\ \text{mol})(4.00\ \text{g/mol}) = 5.1\times10^2\ \text{g}$$

8. A tank containing 200.0 L of hydrogen gas at 0.0°C is kept at 156 kPa. The temperature is raised to 95°C, and the volume is decreased to 175 L. What is the new pressure of the gas?

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \text{ with } T_1 = 273\ \text{K and}$$

$$T_2 = 95°\text{C} + 273°\text{C} = 368\ \text{K}$$

$$P_2 = \frac{T_2P_1V_1}{V_2T_1}$$

$$= \frac{(368\ \text{K})(156\ \text{kPa})(200.0\ \text{L})}{(175\ \text{L})(273\ \text{K})}$$

$$= 2.4\times10^2\ \text{kPa}$$

9. The average molar mass of the components of air (mainly diatomic oxygen gas and diatomic nitrogen gas) is about 29 g/mol. What is the volume of 1.0 kg of air at atmospheric pressure and 20.0°C?

$$PV = nRT$$

$$V = \frac{nRT}{P}$$

$$\text{where } n = \frac{m}{M} = \frac{1.0\times10^3\ \text{g}}{29\ \text{g/mol}}$$

$$\text{and } T = 20.0°\text{C} + 273 = 293\ \text{K}$$

$$V = \frac{\left(\frac{1.0\times10^3\ \text{g}}{29\text{g/mol}}\right)(8.31\ \text{Pa·m}^3/\text{mol·K})(293\ \text{K})}{(1.013\times10^5\ \text{Pa})}$$

$$= 0.83\ \text{m}^3$$

Section Review

13.1 Properties of Fluids pages 341–348

page 348

10. Pressure and Force Suppose that you have two boxes. One is 20 cm × 20 cm × 20 cm. The other is 20 cm × 20 cm × 40 cm.

a. How does the pressure of the air on the outside of the two boxes compare?

The pressure of the air is the same on the two boxes.

b. How does the magnitude of the total force of the air on the two boxes compare?

Because $F = PA$ the total force of the air is greater on the box with the greater area. The second box has twice the surface area, so it has twice the total force of the first box.

11. Meteorology A weather balloon used by meteorologists is made of a flexible bag that allows the gas inside to freely expand. If a weather balloon containing 25.0 m^3 of helium gas is released from sea level, what is the volume of gas when the balloon reaches a height of 2100 m, where the pressure is 0.82×10^5 Pa? Assume that the temperature is unchanged.

$$P_1V_1 = P_2V_2$$

$$V_2 = \frac{P_1V_1}{P_2}$$

$$= \frac{(1.013\times10^5\ \text{Pa})(25.0\ \text{m}^3)}{0.82\times10^5\ \text{Pa}}$$

$$= 3.1\times10^1\ \text{m}^3$$

12. Gas Compression In a certain internal-combustion engine, 0.0021 m^3 of air at atmospheric pressure and 303 K is rapidly compressed to a pressure of 20.1×10^5 Pa and a volume of 0.0003 m^3. What is the final temperature of the compressed gas?

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$T_2 = \frac{T_1P_2V_2}{P_1V_1}$$

$$= \frac{(303\ K)(20.1\times10^5\ Pa)(0.0003\ m^3)}{(1.013\times10^5\ Pa)(0.0021\ m^3)}$$

$$= 9\times10^2\ K$$

13. **Density and Temperature** Starting at 0°C, how will the density of water change if it is heated to 4°C? To 8°C?

As the water is heated from 0°C, the density will increase until it reaches a maximum at 4°C. On further heating to 8°C, the density of the water will decrease.

14. **The Standard Molar Volume** What is the volume of 1.00 mol of a gas at atmospheric pressure and a temperature of 273 K?

$$V = \frac{nRT}{P}$$

$$= \frac{(1.00\ mol)(8.31\ Pa\cdot m^3/mol\cdot K)(273\ K)}{1.013\times10^5\ Pa}$$

$$= 0.0224\ m^3$$

15. **The Air in a Refrigerator** How many moles of air are in a refrigerator with a volume of 0.635 m^3 at a temperature of 2.00°C? If the average molar mass of air is 29 g/mol, what is the mass of the air in the refrigerator?

$$n = \frac{PV}{RT}$$

$$= \frac{(1.013\times10^5\ Pa)(0.635\ m^3)}{(8.31\ Pa\cdot m^3/mol\cdot K)(275\ K)}$$

$$= 28.1\ mol$$

$$m = nM$$

$$= (28.1\ mol)(29\ g/mol)$$

$$= 0.81\ kg$$

16. **Critical Thinking** Compared to the particles that make up carbon dioxide gas, the particles that make up helium gas are very small. What can you conclude about the number of particles in a 2.0-L sample of carbon dioxide gas compared to the number of particles in a 2.0-L sample of helium gas if both samples are at the same temperature and pressure?

There are an equal number of particles in the two samples. In an ideal gas, the size of the particles is not relevant to the volume of the gas or the pressure exerted by the gas.

Section Review

13.2 Forces Within Liquids pages 349–351

page 351

17. **Evaporation and Cooling** In the past, when a baby had a high fever, the doctor might have suggested gently sponging off the baby with rubbing alcohol. Why would this help?

Since alcohol evaporates easily, there is a very noticeable evaporative cooling effect.

18. **Surface Tension** A paper clip, which has a density greater than that of water, can be made to stay on the surface of water. What procedures must you follow for this to happen? Explain.

The paper clip should be placed carefully and flatly onto the surface of the water. This will reduce the weight per unit area of water surface on which it will rest. The surface tension of the water then is sufficient to support the reduced weight per unit area of the paper clip.

19. **Language and Physics** The English language includes the terms *adhesive tape* and *working as a cohesive group*. In these terms, are *adhesive* and *cohesive* being used in the same context as their meanings in physics?

Yes, adhesive tape is sticking to something different than tape. A cohesive group is a collection of people working together.

20. **Adhesion and Cohesion** In terms of adhesion and cohesion, explain why alcohol clings to the surface of a glass rod but mercury does not.

Adhesion is the force between unlike materials. Alcohol has a greater adhesive attraction to glass than mercury has. The cohesive forces of mercury are strong enough to overcome its adhesive force with glass.

21. Floating How can you tell that the paper clip in problem 18 was not floating?

If the paper clip broke through the surface of the water, it sank. An object that floats would simply bob back to the surface.

22. Critical Thinking On a hot, humid day, Beth sat on the patio with a glass of cold water. The outside of the glass was coated with water. Her younger sister, Jo, suggested that the water had leaked through the glass from the inside to the outside. Suggest an experiment that Beth could do to show Jo where the water came from.

Beth could weigh the glass before putting it in the refrigerator for a while to cool it down. Then she could remove it from the refrigerator and allow moisture to collect on the outside. Finally, she would weigh the glass a second time. If water simply leaks from the inside to the outside, the mass of the glass and water will be unchanged. However, if the moisture is condensation, there will be an increase in the mass at the second weighing.

Practice Problems

13.3 Fluids at Rest and in Motion pages 352–358

page 353

23. Dentists' chairs are examples of hydraulic-lift systems. If a chair weighs 1600 N and rests on a piston with a cross-sectional area of 1440 cm^2, what force must be applied to the smaller piston, with a cross-sectional area of 72 cm^2, to lift the chair?

$$F_2 = \frac{F_1A_2}{A_1} = \frac{(1600\text{ N})(72\text{ cm}^2)}{1440\text{ cm}^2}$$

$$= 8.0\times10^1\text{ N}$$

24. A mechanic exerts a force of 55 N on a 0.015 m^2 hydraulic piston to lift a small automobile. The piston that the automobile sits on has an area of 2.4 m^2. What is the weight of the automobile?

$$F_2 = \frac{F_1A_2}{A_1} = \frac{(55\text{ N})(2.4\text{ m}^2)}{(0.015\text{ m}^2)} = 8.8\times10^3\text{ N}$$

25. By multiplying a force, a hydraulic system serves the same purpose as a lever or seesaw. If a 400-N child standing on one piston is balanced by a 1100-N adult standing on another piston, what is the ratio of the areas of their pistons?

$$F_2 = \frac{F_1A_2}{A_1}$$

$$\frac{A_2}{A_1} = \frac{F_2}{F_1} = \frac{400\text{ N}}{1100\text{ N}} = 0.4$$

The adult stands on the larger piston.

26. In a machine shop, a hydraulic lift is used to raise heavy equipment for repairs. The system has a small piston with a cross-sectional area of 7.0×10^{-2} m^2 and a large piston with a cross-sectional area of 2.1×10^{-1} m^2. An engine weighing 2.7×10^3 N rests on the large piston.

a. What force must be applied to the small piston to lift the engine?

$$F_2 = \frac{F_1A_2}{A_1}$$

$$= \frac{(2.7\times10^3\text{ N})(7.0\times10^{-2}\text{ m}^2)}{2.1\times10^{-1}\text{ m}^2}$$

$$= 9.0\times10^2\text{ N}$$

b. If the engine rises 0.20 m, how far does the smaller piston move?

$$V_1 = V_2 \text{ and } A_1h_1 = A_2h_2$$

$$h_2 = \frac{A_1h_1}{A_2} = \frac{(2.1\times10^{-1}\text{ m}^2)(0.20\text{ m})}{7.0\times10^{-2}\text{ m}^2}$$

$$= 0.60\text{ m}$$

page 356

27. Common brick is about 1.8 times denser than water. What is the apparent weight of a 0.20 m^3 block of bricks under water?

$F_{apparent} = F_g - F_{buoyant}$

$= \rho_{brick}Vg - \rho_{water}Vg$

$= (\rho_{brick} - \rho_{water})Vg$

$= (1.8\times10^3\ kg/m^3 - 1.00\times10^3\ kg/m^3)(0.20\ m^3)(9.80\ m/s^2)$

$= 1.6\times10^3\ N$

28. A girl is floating in a freshwater lake with her head just above the water. If she weighs 610 N, what is the volume of the submerged part of her body?

She is floating so she displaces a volume of water that weighs as much as she does.

$F_g = F_{buoyant} = \rho_{water}Vg$

$V = \frac{F_g}{\rho_{water}g}$

$= \frac{610\ N}{(1.00\times10^3\ kg/m^3)(9.80\ m/s^2)}$

$= 6.2\times10^{-2}\ m^3$

29. What is the tension in a wire supporting a 1250-N camera submerged in water? The volume of the camera is $16.5\times10^{-3}\ m^3$.

To hold the camera in place the tension in the wire must equal the apparent weight of the camera.

$T = F_{apparent}$

$= F_g - F_{buoyant}$

$= F_g - \rho_{water}Vg$

$= 1250\ N - (1.00\times10^3\ kg/m^3)(16.5\times10^{-3}\ m^3)(9.80\ m/s^2)$

$= 1.09\times10^3\ N$

30. Plastic foam is about 0.10 times as dense as water. What weight of bricks could you stack on a 1.0 m × 1.0 m × 0.10 m slab of foam so that the slab of foam floats in water and is barely submerged, leaving the bricks dry?

The foam would displace $V = (1.0\ m)(1.0\ m)(0.10\ m) = 0.10\ m^3$ of water. The weight of the foam is

$F_{g,\ foam} = \rho_{foam}Vg$

$= (1.0\times10^2\ kg/m^3)(0.10\ m^3)(9.80\ m/s^2)$

$= 98\ N$

The buoyant force is

$F_{buoyant} = \rho_{water}Vg$

$= (1.00\times10^3\ kg/m^3)(0.10\ m^3)(9.80\ m/s^2)$

$= 980\ N$

The weight of brick that you could stack is

$F_{g,\ brick} = F_{buoyant} - F_{g\ foam}$

$= 980\ N - 98\ N$

$= 8.8\times10^2\ N$

31. Canoes often have plastic foam blocks mounted under the seats for flotation in case the canoe fills with water. What is the approximate minimum volume of foam needed for flotation for a 480-N canoe?

The buoyant force on the foam must equal 480 N. We are assuming the canoe is made of dense material.

$F_{buoyant} = \rho_{water}Vg$

$V = \frac{F_{buoyant}}{\rho_{water}g}$

$= \frac{480\ N}{(1.00\times10^3\ kg/m^3)(9.80\ m/s^2)}$

$= 4.9\times10^{-2}\ m^3$

Section Review

13.3 Fluids at Rest and in Motion pages 352–358

page 358

32. Floating and Sinking Does a full soda pop can float or sink in water? Try it. Does it matter whether or not the drink is diet? All soda pop cans contain the same volume of liquid, 354 mL, and displace the same volume of water. What is the difference between a can that sinks and one that floats?

The difference is a lot of sugar. About one-fourth cup of sugar is dissolved in the regular drink, making it denser than water. The diet drink has a small amount of an artificial sweetener. The diet drink is less dense than the sugar-laden regular soft drink.

33. Floating and Density A fishing bobber made of cork floats with one-tenth of its volume below the water's surface. What is the density of cork?

The weight of the water displaced equals the weight of the bobber.

$$F_g = \rho_{water}V_{water}g = \rho_{cork}V_{cork}\,g$$

Therefore, $\frac{\rho_{cork}}{\rho_{water}} = \frac{V_{water}}{V_{cork}}$

$$= \frac{1}{10}$$

The cork is about one-tenth as dense as water.

34. Floating in Air A helium balloon rises because of the buoyant force of the air lifting it. The density of helium is 0.18 kg/m^3, and the density of air is 1.3 kg/m^3. How large a volume would a helium balloon need to lift a 10-N lead brick?

$F_{apparent}$ **must equal −10 N to counteract the weight of the lead brick.**

$$F_{apparent} = F_g - F_{buoyant}$$

$$= \rho_{helium}V_{balloon}g - \rho_{air}V_{balloon}g$$

$$= (\rho_{helium} - \rho_{air})V_{balloon}g$$

Thus,

$$V_{balloon} = \frac{F_{apparent}}{(\rho_{helium} - \rho_{air})g}$$

$$= \frac{-10\text{ N}}{(0.18\text{ kg/m}^3 - 1.3\text{ kg/m}^3)(9.80\text{ m/s}^2)}$$

$$= 0.9\text{ m}^3$$

35. Transmission of Pressure A toy rocket launcher is designed so that a child stomps on a rubber cylinder, which increases the air pressure in a launching tube and pushes a foam rocket into the sky. If the child stomps with a force of 150 N on a 2.5×10^{-3} m^2 area piston, what is the additional force transmitted to the 4.0×10^{-4} m^2 launch tube?

$$F_2 = \frac{F_1A_2}{A_1}$$

$$= \frac{(150\text{ N})(4.0\times10^{-4}\text{ m}^2)}{2.5\times10^{-3}\text{ m}^2}$$

$$= 24\text{ N}$$

36. **Pressure and Force** An automobile weighing 2.3×10^4 N is lifted by a hydraulic cylinder with an area of 0.15 m^2.

a. What is the pressure in the hydraulic cylinder?

$$P = \frac{F}{A}$$
$$= \frac{2.3\times10^4\ \text{N}}{0.15\ \text{m}^2}$$
$$= 1.5\times10^5\ \text{Pa}$$

b. The pressure in the lifting cylinder is produced by pushing on a 0.0082 m^2 cylinder. What force must be exerted on this small cylinder to lift the automobile?

$$F_2 = \frac{F_1A_2}{A_1}$$
$$= \frac{(2.3\times10^4\ \text{N})(0.0082\ \text{m}^2)}{0.15\ \text{m}^2}$$
$$= 1.3\times10^3\ \text{N}$$

37. **Displacement** Which of the following displaces more water when it is placed in an aquarium?

a. A 1.0-kg block of aluminum or a 1.0-kg block of lead?

Both aluminum and iron will sink to the bottom of the aquarium. Because aluminum is less dense than iron, 1 kg of aluminum has a greater volume than 1 kg of iron. Therefore, the block of aluminum will displace more water.

b. A 10-cm^3 block of aluminum or a 10-cm^3 block of lead?

Both blocks will sink, and each will displace the same volume of water, 10 cm^3.

38. **Critical Thinking** As you discovered in Practice Problem 4, a tornado passing over a house sometimes makes the house explode from the inside out. How might Bernoulli's principle explain this phenomenon? What could be done to reduce the danger of a door or window exploding outward?

The fast-moving air of the tornado has a lower pressure than the still air inside the house. Therefore, the air inside the house is at a higher pressure and produces an enormous force on the windows, doors, and walls of the house. This pressure difference is reduced by opening doors and windows to let the air flow freely to the outside.

Practice Problems

13.4 Solids pages 359–363

page 362

39. A piece of aluminum house siding is 3.66 m long on a cold winter day of −28°C. How much longer is it on a very hot summer day at 39°C?

$L_2 = L_1 + \alpha L_1(T_2 - T_1)$, so

$$\Delta L = \alpha L_1(T_2 - T_1)$$
$$= (25\times10^{-6}{}^\circ\text{C}^{-1})(3.66\ \text{m})(39^\circ\text{C} - (-28^\circ\text{C}))$$
$$= 6.1\times10^{-3}\ \text{m} = 6.1\ \text{mm}$$

40. A piece of steel is 11.5 cm long at 22°C. It is heated to 1221°C, close to its melting temperature. How long is it?

$$L_2 = L_1 + \alpha L_1(T_2 - T_1)$$
$$= (0.115\ \text{m}) + (12\times10^{-6}{}^\circ\text{C}^{-1})(0.115\ \text{m})(1221^\circ\text{C} - 22^\circ\text{C})$$
$$= 1.2\times10^{-1}\ \text{m} = 12\ \text{cm}$$

41. A 400-mL glass beaker at room temperature is filled to the brim with cold water at 4.4°C. When the water warms up to 30.0°C, how much water will spill from the beaker?

At the beginning, 400 mL of 4.4°C water is in the beaker. Find the change in volume at 30.0°C.

$$\Delta V = \beta V \Delta T$$
$$= (210\times10^{-6}{}^\circ\text{C}^{-1})(400\times10^{-6}\ \text{m}^3)(30.0^\circ\text{C} - 4.4^\circ\text{C})$$
$$= 2\times10^{-6}\ \text{m}^3 = 2\ \text{mL}$$

42. A tank truck takes on a load of 45,725 L of gasoline in Houston, where the temperature is 28.0°C. The truck delivers its load in Minneapolis, where the temperature is −12.0°C.

a. How many liters of gasoline does the truck deliver?

$$\beta = \frac{\Delta V}{V_1 \Delta T} = \frac{V_2 - V_1}{V_1 \Delta T}$$

$$V_2 = \beta V_1 \Delta T + V_1$$

$$= (950\times10^{-6}\text{°C}^{-1})(45{,}725\ \text{L})(-12.0\text{°C} - 28.0\text{°C}) + 45{,}725\ \text{L}$$

$$= 4.4\times10^4\ \text{L}$$

b. What happened to the gasoline?

The gasoline volume decreased because the temperature decreased. The mass of the gasoline remained the same.

43. A hole with a diameter of 0.85 cm is drilled into a steel plate. At 30.0°C, the hole exactly accommodates an aluminum rod of the same diameter. What is the spacing between the plate and the rod when they are cooled to 0.0°C?

The aluminum shrinks more than the steel. Let *L* be the diameter of the rod.

$$\Delta L_{aluminum} = \alpha L \Delta T$$

$$= (25\times10^{-6}\text{°C}^{-1})(0.85\ \text{cm})(0.0\text{°C} - 30.0\text{°C})$$

$$= -6.38\times10^{-4}\ \text{cm}$$

For the steel, the diameter of the hole shrinks by

$$\Delta L_{steel} = \alpha L \Delta T$$

$$= (12\times10^{-6}\text{°C}^{-1})(0.85\ \text{cm})(0.0\text{°C} - 30.0\text{°C})$$

$$= -3.06\times10^{-4}\ \text{cm}$$

The spacing between the rod and the hole will be

$$\left(\frac{1}{2}\right)(6.4\times10^{-4}\ \text{cm} - 3.1\times10^{-4}\ \text{cm})$$

$$= 1.6\times10^{-4}\ \text{cm}$$

44. A steel ruler is marked in millimeters so that the ruler is absolutely correct at 30.0°C. By what percentage would the ruler be incorrect at −30.0°C?

Because the steel shrinks, the distances between the millimeter marks decrease when cooled.

$$\%\ \text{incorrect} = (100)\left(\frac{\Delta L}{L}\right)$$

$$= (100)\alpha(T_f - T_i)$$

$$= (100)(12\times10^{-6}\text{°C}^{-1})(-30.0\text{°C} - 30.0\text{°C})$$

$$= -0.072\%$$

Section Review

13.4 Solids pages 359–363

page 363

45. Relative Thermal Contraction On a hot day, you are installing an aluminum screen door in a concrete door frame. You want the door to fit well on a cold winter day. Should you make the door fit tightly in the frame or leave extra room?

Fit the door tightly. Aluminum shrinks when cooled much more than concrete does.

46. States of Matter Why could candle wax be considered a solid? Why might it also be considered a viscous liquid?

The wax could be considered a solid because it has a definite volume and shape. It could be considered a viscous liquid because the particles do not form a fixed crystalline pattern.

47. Thermal Expansion Can you heat a piece of copper enough to double its length?

The thermal expansion coefficient for copper is 16×10^{-6}/°C. To double its length $\Delta L = L = \alpha L \Delta T$, which means that

$$\alpha \Delta T = 1$$

$$\Delta T = \frac{1}{\alpha}$$

$$= \frac{1}{16\times10^{-6}\text{°C}^{-1}}$$

$$= 63{,}000\text{°C}$$

The copper would be vaporized at that temperature.

48. **States of Matter** Does Table 13-2 provide a way to distinguish between solids and liquids?

The coefficients of volume expansion are much greater for liquids than for solids.

49. **Solids and Liquids** A solid can be defined as a material that can be bent and will resist bending. Explain how these properties relate to the binding of atoms in a solid, but do not apply to a liquid.

Particles in a solid are closer and, therefore, more tightly bound. They vibrate about a fixed position. This allows the solid to be bent, but it also resists bending. Particles in a liquid are farther apart and less tightly bound. Because the particles are free to flow past one another, a liquid cannot be bent.

50. **Critical Thinking** The iron ring in **Figure 13-23** was made by cutting a small piece from a solid ring. If the ring in the figure is heated, will the gap become wider or narrower? Explain your answer.

■ **Figure 13-23**

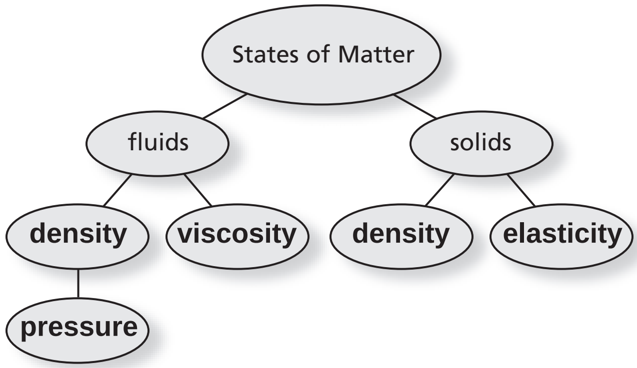
The gap will become wider. All of the measurements of the ring increase when heated.

Chapter Assessment

Concept Mapping

page 368

51. Complete the concept map below using the following terms: *density, viscosity, elasticity, pressure.* A term may be used more than once.



Mastering Concepts

page 368

52. How are force and pressure different? (13.1)

Force depends only on the push or pull on an object. Pressure depends on the force as well as the area over which the force is applied.

53. A gas is placed in a sealed container, and some liquid is placed in a container of the same size. The gas and liquid both have definite volume. How do they differ? (13.1)

The liquid's volume will remain unchanged. The gas will expand to fill the volume of the container.

54. In what way are gases and plasmas similar? In what way are they different? (13.1)

Both gases and plasmas have no definite volume and no definite shape. A gas is made of atoms. A plasma is made of positively charged ions and negatively charged electrons. The particles of a plasma are more energetic than the particles of a gas. Plasmas can conduct electricity. Gases cannot.

55. The Sun is made of plasma. How is this plasma different from the plasmas on Earth? (13.1)

The Sun's plasma is extremely hot, but more importantly, it is very dense—denser than most solids on Earth.

56. **Lakes** A frozen lake melts in the spring. What effect does this have on the temperature of the air above the lake? (13.2)

To melt, the ice must absorb energy in the amount of its heat of fusion from the air and water. It will cool the air above it.

57. **Hiking** Canteens used by hikers often are covered with canvas bags. If you wet the canvas bag covering a canteen, the water in the canteen will be cooled. Explain. (13.2)

The water evaporates into the air, absorbing energy from the canteen and the water inside.

58. What do the equilibrium tubes in **Figure 13-24** tell you about the pressure exerted by a liquid? (13.3)

■ **Figure 13-24**

The equilibrium tubes illustrate that pressure is independent of the shape of the container.

59. According to Pascal's principle, what happens to the pressure at the top of a container if the pressure at the bottom is increased? (13.3)

Changes in pressure are distributed equally to all parts of the container. The pressure at the top increases.

60. How does the water pressure 1 m below the surface of a small pond compare with the water pressure the same distance below the surface of a lake? (13.3)

Size or shape of the body of water does not matter, only the depth. The pressure is the same in each case.

61. Does Archimedes' principle apply to an object inside a flask that is inside a spaceship in orbit? (13.3)

No, it does not. The apparent weight of the displaced fluid is zero because the fluid is in free-fall. Thus, there is no buoyant force.

62. A stream of water goes through a garden hose into a nozzle. As the water speeds up, what happens to the water pressure? (13.3)

The water pressure decreases because of Bernoulli's principle.

63. How does the arrangement of atoms in a crystalline substance differ from that in an amorphous substance? (13.4)

The atoms in a crystalline substance are arranged in an ordered pattern. In the amorphous substance, the atoms are randomly arranged.

64. Does the coefficient of linear expansion depend on the unit of length used? Explain. (13.4)

No. The coefficient is a measure of the expansion of an object relative to its total length. Units and total length do not change the coefficient of linear expansion.

Applying Concepts

page 368–369

65. A rectangular box with its largest surface resting on a table is rotated so that its smallest surface is now on the table. Has the pressure on the table increased, decreased, or remained the same?

The pressure increased. The weight stayed the same, but the weight per area increased.

66. Show that a pascal is equivalent to a kg/m·s^2.

$$Pa = N/m^2 = (kg \cdot m/s^2)/m^2$$
$$= kg/m \cdot s^2$$

67. Shipping Cargo Compared to an identical empty ship, would a ship filled with table-tennis balls sink deeper into the water or rise in the water? Explain.

It would sink deeper into the water because it would have a greater weight.

68. Drops of mercury, water, ethanol, and acetone are placed on a smooth, flat surface, as shown in **Figure 13-25.** From this figure, what can you conclude about the cohesive forces in these liquids?

■ **Figure 13-25**

The cohesive forces are strongest in mercury and weakest in acetone. The stronger the cohesive force, the more spherical the drop will be.

69. How deep would a water container have to be to have the same pressure at the bottom as that found at the bottom of a 10.0-cm deep beaker of mercury, which is 13.55 times as dense as water?

$$P_{water} = P_{mercury}$$

$$\rho_{water} h_{water} g = \rho_{mercury} h_{mercury} g$$

$$h_{water} = \left(\frac{\rho_{mercury}}{\rho_{water}}\right) h_{mercury}$$

$$= (13.55)(10.0\ \text{cm})$$

$$= 136\ \text{cm}$$

70. Alcohol evaporates more quickly than water does at the same temperature. What does this observation allow you to conclude about the properties of the particles in the two liquids?

The cohesive forces of water are greater than those of alcohol.

71. Suppose you use a hole punch to make a circular hole in aluminum foil. If you heat the foil, will the size of the hole decrease or increase? Explain.

As you heat the foil, the hole becomes larger. Heating transfers more energy to particles of the aluminum, causing the volume of the aluminum to increase.

72. Equal volumes of water are heated in two narrow tubes that are identical, except that tube A is made of soft glass and tube B is made of ovenproof glass. As the temperature increases, the water level rises higher in tube B than in tube A. Give a possible explanation.

The ovenproof glass expands less than the soft glass when heated. The water does not rise as high in A because the soft glass tube is expanding in volume.

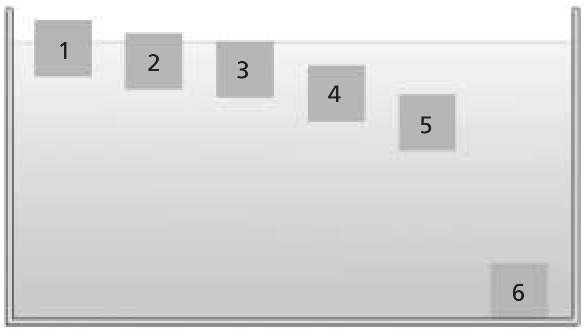
73. A platinum wire easily can be sealed in a glass tube, but a copper wire does not form a tight seal with the glass. Explain.

Platinum's coefficient of thermal expansion is similar to that of glass, so it expands and contracts as the glass does. Copper has a much larger coefficient than glass.

74. Five objects with the following densities are put into a tank of water.

a. 0.85 g/cm^3 **d.** 1.15 g/cm^3
b. 0.95 g/cm^3 **e.** 1.25 g/cm^3
c. 1.05 g/cm^3

The density of water is 1.00 g/cm^3. The diagram in **Figure 13-26** shows six possible positions of these objects. Select a position, from 1 to 6, for each of the five objects. Not all positions need to be selected.



■ **Figure 13-26**

The positions of the objects should be a–1, b–2, c–6, d–6, e–6

Mastering Problems

13.1 Properties of Fluids

pages 369–370

Level 1

75. Textbooks A 0.85-kg physics book with dimensions of 24.0 cm × 20.0 cm is at rest on a table.

a. What force does the book apply to the table?

The force on the table is the weight of the book.

$W = mg = (0.85\ \text{kg})(9.80\ \text{m/s}^2)$

$= 8.3\ \text{N}$

b. What pressure does the book apply?

The pressure applied by the book is

$$P = \frac{F}{A} = \frac{mg}{lw} = \frac{(0.85\ \text{kg})(9.80\ \text{m/s}^2)}{(2.40\times10^{-1}\ \text{m})(2.00\times10^{-1}\ \text{m})} = 1.7\times10^2\ \text{Pa}$$

76. A 75-kg solid cylinder that is 2.5 m long and has an end radius of 7.0 cm stands on one end. How much pressure does it exert?

$$P = \frac{F}{A} = \frac{mg}{\pi r^2} = \frac{(75\ \text{kg})(9.80\ \text{m/s}^2)}{\pi(0.070\ \text{m})^2} = 4.8\times10^4\ \text{Pa}$$

77. What is the total downward force of the atmosphere on the top of your head right now? Assume that the top of your head has an area of about 0.025 m^2.

$F = PA = (1.01\times10^5\ \text{Pa})(0.025\ \text{m}^2)$

$= 2.5\times10^3\ \text{N}$

78. Soft Drinks Sodas are made fizzy by the carbon dioxide (CO_2) dissolved in the liquid. An amount of carbon dioxide equal to about 8.0 L of carbon dioxide gas at atmospheric pressure and 300.0 K can be dissolved in a 2-L bottle of soda. The molar mass of CO_2 is 44 g/mol.

a. How many moles of carbon dioxide are in the 2-L bottle? (1 L = 0.001 m^3)

From the ideal gas law

$$n = \frac{PV}{RT} = \frac{(1.01\times10^5\ \text{Pa})(0.0080\ \text{m}^3)}{(8.31\ \text{Pa·m}^3/\text{mol·K})(300.0\ \text{K})} = 0.32\ \text{moles}$$

b. What is the mass of the carbon dioxide in the 2-L bottle of soda?

The molecular weight of carbon dioxide is

$M = 12 + 2(16)$

$= 44\ \text{g/mol}$

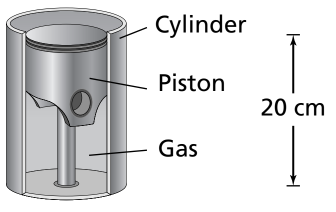
Therefore, the mass is

$m = nM$

$= (0.32\ \text{mol})(44\ \text{g/mol})$

$= 14\ \text{g}$

79. As shown in **Figure 13-27,** a constant-pressure thermometer is made with a cylinder containing a piston that can move freely inside the cylinder. The pressure and the amount of gas enclosed in the cylinder are kept constant. As the temperature increases or decreases, the piston moves up or down in the cylinder. At 0°C, the height of the piston is 20 cm. What is the height of the piston at 100°C?



■ **Figure 13-27**

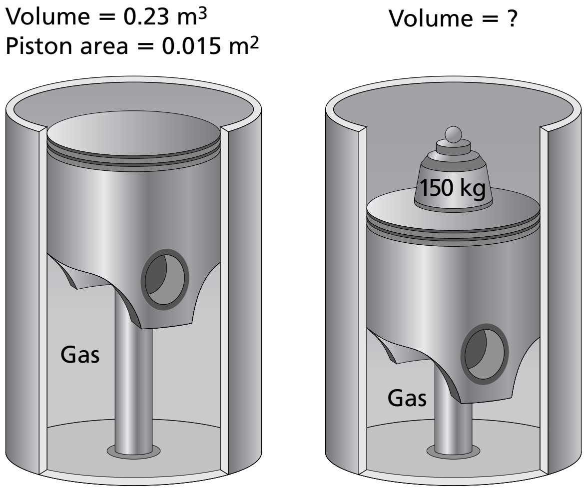
Because the pressure is kept constant, $V_1/T_1 = V_2/T_2$. The height of the piston is directly proportional to the volume of the cylinder. Therefore,

$$\frac{h_1}{T_1} = \frac{h_2}{T_2}$$

$$h_2 = \frac{h_1T_2}{T_1}$$
$$= \frac{(20\text{ cm})(373\text{ K})}{273\text{ K}}$$
$$= 3\times10^1\text{ cm}$$

Level 2

80. A piston with an area of 0.015 m^2 encloses a constant amount of gas in a cylinder with a volume of 0.23 m^3. The initial pressure of the gas is 1.5×10^5 Pa. A 150-kg mass is then placed on the piston, and the piston moves downward to a new position, as shown in **Figure 13-28.** If the temperature is constant, what is the new volume of the gas in the cylinder?



■ **Figure 13-28**

$$P_1V_1 = P_2V_2$$
$$V_2 = \frac{P_1V_1}{P_2}$$
$$= \frac{P_1V_1}{\left(P_1 + \frac{mg}{A}\right)}$$
$$= \frac{(1.5\times10^5\text{ Pa})(0.23\text{ m}^3)}{1.5\times10^5\text{ Pa} + \frac{(150\text{ kg})(9.80\text{ m/s}^2)}{0.015\text{ m}^2}}$$
$$= 0.14\text{ m}^3$$

Level 3

81. Automobiles A certain automobile tire is specified to be used at a gauge pressure of 30.0 psi, or 30.0 pounds per square inch. (One pound per square inch equals 6.90×10^3 Pa.) The term *gauge pressure* means the pressure above atmospheric pressure. Thus, the actual pressure in the tire is 1.01×10^5 Pa + (30.0 psi)(6.90×10^3 Pa/psi) = 3.08×10^5 Pa. As the car is driven, the tire's temperature increases, and the volume and pressure increase. Suppose you filled a car's tire to a volume of 0.55 m^3 at a temperature of 280 K. The initial pressure was 30.0 psi, but during the drive, the tire's temperature increased to 310 K and the tire's volume increased to 0.58 m^3.

a. What is the new pressure in the tire?

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$
$$P_2 = \frac{P_1V_1T_2}{T_1V_2}$$
$$= \frac{(3.08\times10^5\text{ Pa})(0.55\text{ m}^3)(310\text{ K})}{(280\text{ K})(0.58\text{ m}^3)}$$
$$= 3.2\times10^5\text{ Pa}$$

b. What is the new gauge pressure?

$$P_{gauge} = \frac{(30.0\text{ psi})(0.55\text{ m}^3)(310\text{ K})}{(280\text{ K})(0.58\text{ m}^3)}$$
$$= 31\text{ psi}$$

13.3 Fluids at Rest and in Motion
page 370

Level 1

82. Reservoirs A reservoir behind a dam is 17-m deep. What is the pressure of the water at the following locations?

a. the base of the dam

$$P = \rho hg$$
$$= (1.00\times10^3\text{ kg/m}^3)(17\text{ m})(9.80\text{ m/s}^2)$$
$$= 1.7\times10^5\text{ Pa}$$

b. 4.0 m from the top of the dam

$$P = \rho hg$$
$$= (1.00\times10^3\text{ kg/m}^3)(4.0\text{ m})(9.80\text{ m/s}^2)$$
$$= 3.9\times10^4\text{ Pa}$$

83. A test tube standing vertically in a test-tube rack contains 2.5 cm of oil ($\rho = 0.81\ g/cm^3$) and 6.5 cm of water. What is the pressure exerted by the two liquids on the bottom of the test tube?

$$P = P_{oil} + P_{water}$$
$$= \rho_{oil}h_{oil}g + \rho_{water}h_{water}g$$
$$= (810\ kg/m^3)(0.025\ m)(9.80\ m/s^2) + (1.00\times10^3\ kg/m^3)(0.065\ m)(9.80\ m/s^2)$$
$$= 8.4\times10^2\ Pa$$

84. Antiques An antique yellow metal statuette of a bird is suspended from a spring scale. The scale reads 11.81 N when the statuette is suspended in air, and it reads 11.19 N when the statuette is completely submerged in water.

a. Find the volume of the statuette.

$$F_{buoyant} = \rho_{water}Vg = F_g - F_{apparent}$$

Thus,

$$V = \frac{F_g - F_{apparent}}{\rho_{water}g}$$
$$= \frac{11.81\ N - 11.19\ N}{(1.00\times10^3\ kg/m^3)(9.80\ m/s^2)}$$
$$= 6.33\times10^{-5}\ m^3$$

b. Is the bird made of gold ($\rho = 19.3\times10^3\ kg/m^3$) or gold-plated aluminum ($\rho = 2.7\times10^3\ kg/m^3$)?

$$\rho = \frac{m}{V}$$
$$= \frac{F_g}{V_g}$$
$$= \frac{11.81\ N}{(6.33\times10^{-5}\ m^3)(9.80\ m/s^2)}$$
$$= 19.0\times10^3\ kg/m^3$$

The statuette is made of gold.

85. During an ecology experiment, an aquarium half-filled with water is placed on a scale. The scale shows a weight of 195 N.

a. A rock weighing 8 N is added to the aquarium. If the rock sinks to the bottom of the aquarium, what will the scale read?

$$F_g = 195\ N + 8\ N = 203\ N$$

b. The rock is removed from the aquarium, and the amount of water is adjusted until the scale again reads 195 N. A fish weighing 2 N is added to the aquarium. What is the scale reading with the fish in the aquarium?

$$F_g = 195\ N + 2\ N = 197\ N$$

In each case the buoyant force is equal to the weight of the water displaced.

86. What is the size of the buoyant force on a 26.0-N ball that is floating in fresh water?

If the ball is floating

$$F_{buoyant} = F_g = 26.0\ N$$

87. What is the apparent weight of a rock submerged in water if the rock weighs 45 N in air and has a volume of $2.1\times10^{-3}\ m^3$?

$$F_{apparent} = F_g - F_{buoyant}$$
$$= F_g - \rho_{water}Vg$$
$$= 45\ N - (1.00\times10^3\ kg/m^3)(2.1\times10^{-3}\ m^3)(9.80\ m/s^2)$$
$$= 24\ N$$

88. What is the maximum weight that a balloon filled with 1.00 m^3 of helium can lift in air? Assume that the density of air is 1.20 kg/m^3 and that of helium is 0.177 kg/m^3. Neglect the mass of the balloon.

$$F_{apparent} = F_g - F_{buoyant}$$
$$= \rho_{helium}Vg - \rho_{air}Vg$$
$$= (\rho_{helium} - \rho_{air})Vg$$
$$= (0.177\ kg/m^3 - 1.20\ kg/m^3)(1.00\ m^3)(9.80\ m/s^2)$$
$$= -10.0\ N$$

Level 2

89. If a rock weighs 54 N in air and has an apparent weight of 46 N when submerged in a liquid with a density twice that of water, what will be its apparent weight when it is submerged in water?

$$F_{\text{apparent, water}} = F_g - \rho_{\text{water}}Vg$$

and $F_{\text{apparent, liquid}} = F_g - 2\rho_{\text{water}}Vg$

or $V = \dfrac{F_g - F_{\text{apparent, liquid}}}{2\rho_{\text{water}}g}$

Substitute this into the first equation.

$$F_{\text{apparent, water}} = F_g - \rho_{\text{water}}g\left(\frac{F_g - F_{\text{apparent, liquid}}}{2\rho_{\text{water}}g}\right)$$

$$= F_g - \left(\frac{1}{2}\right)(F_g - F_{\text{apparent, liquid}})$$

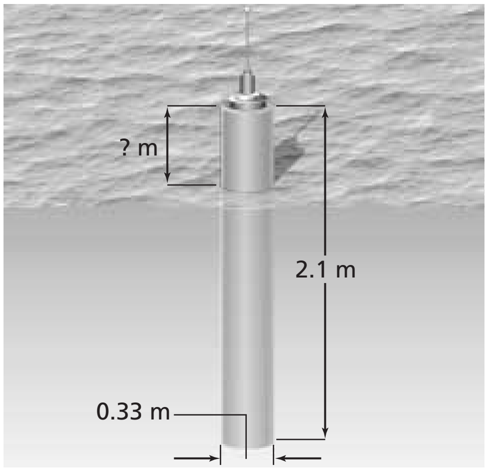
$$= \left(\frac{1}{2}\right)(F_g - F_{\text{apparent, liquid}})$$

$$= \left(\frac{1}{2}\right)(54 \text{ N} + 46 \text{ N})$$

$$= 5.0\times10^{1} \text{ N}$$

Level 3

90. Oceanography As shown in **Figure 13-29,** a large buoy used to support an oceanographic research instrument is made of a cylindrical, hollow iron tank. The tank is 2.1 m in height and 0.33 m in diameter. The total mass of the buoy and the research instrument is about 120 kg. The buoy must float so that one end is above the water to support a radio transmitter. Assuming that the mass of the buoy is evenly distributed, how much of the buoy will be above the waterline when it is floating?



■ **Figure 13-29**

The height of the buoy above water is

$$l_{\text{above}} = \left(1 - \frac{V_{\text{water}}}{V_{\text{buoy}}}\right)l_{\text{total}}$$

$$= \left(1 - \frac{\left(\frac{m}{\rho_{\text{water}}}\right)}{\pi r^2 h}\right)l_{\text{total}}$$

$$= \left(1 - \frac{m}{\pi r^2 h \rho_{\text{water}}}\right)l_{\text{total}}$$

$$= \left(1 - \frac{120 \text{ kg}}{\pi\left(\left(\frac{1}{2}\right)(0.33 \text{ m})\right)^2(2.1 \text{ m})(1.00\times10^3 \text{ kg/m}^3)}\right)(2.1 \text{ m})$$

$$= 0.70 \text{ m}$$

13.4 Solids

pages 370–371

Level 1

91. A bar of an unknown metal has a length of 0.975 m at 45°C and a length of 0.972 m at 23°C. What is its coefficient of linear expansion?

$$\alpha = \frac{L_2 - L_1}{L_1(T_2 - T_1)}$$

$$= \frac{0.972\text{ m} - 0.975\text{ m}}{(0.975\text{ m})(23°\text{C} - 45°\text{C})}$$

$$= 1.4\times10^{-4}°\text{C}^{-1}$$

92. An inventor constructs a thermometer from an aluminum bar that is 0.500 m in length at 273 K. He measures the temperature by measuring the length of the aluminum bar. If the inventor wants to measure a 1.0-K change in temperature, how precisely must he measure the length of the bar?

$$\Delta T = 1.0\text{ K} = 1.0°\text{C}$$

$$\Delta L = \alpha L_1 \Delta T$$

$$= (25\times10^{-6}°\text{C}^{-1})(0.500\text{ m})(1.0°\text{C})$$

$$= 1.3\times10^{-5}\text{ m}$$

93. Bridges How much longer will a 300-m steel bridge be on a 30°C day in August than on a −10°C night in January?

$$\Delta L = \alpha L_1 \Delta T = \alpha L_1(T_2 - T_1)$$

$$= (12\times10^{-6}°\text{C}^{-1})(300\text{ m})(30°\text{C} - (-10°\text{C}))$$

$$= 0.1\text{ m}$$

94. What is the change in length of a 2.00-m copper pipe if its temperature is raised from 23°C to 978°C?

$$\Delta L = \alpha L_1 \Delta T = \alpha L_1(T_2 - T_1)$$

$$= (16\times10^{-6}°\text{C}^{-1})(2.00\text{ m})(978°\text{C} - 23°\text{C})$$

$$= 3.1\times10^{-2}\text{ m}$$

95. What is the change in volume of a 1.0-m^3 concrete block if its temperature is raised 45°C?

$$\Delta V = \beta V_1 \Delta T$$

$$= (36\times10^{-6}°\text{C}^{-1})(1.0\text{ m}^3)(45°\text{C})$$

$$= 1.6\times10^{-3}\text{ m}^3$$

96. Bridges Bridge builders often use rivets that are larger than the rivet hole to make the joint tighter. The rivet is cooled before it is put into the hole. Suppose that a builder drills a hole 1.2230 cm in diameter for a steel rivet 1.2250 cm in diameter. To what temperature must the rivet be cooled if it is to fit into the rivet hole, which is at 20.0°C?

$$L_2 = L_1 + \alpha L_1(T_2 - T_1)$$

$$T_2 = T_1 + \frac{(L_2 - L_1)}{\alpha L_1}$$

$$= 20.0°\text{C} + \frac{1.2230\text{ cm} - 1.2250\text{ cm}}{(12\times10^{-6}°\text{C}^{-1})(1.2250\text{ cm})}$$

$$= -1.2\times10^{2}°\text{C}$$

Level 2

97. A steel tank filled with methanol is 2.000 m in diameter and 5.000 m in height. It is completely filled at 10.0°C. If the temperature rises to 40.0°C, how much methanol (in liters) will flow out of the tank, given that both the tank and the methanol will expand?

$$\Delta V = \beta V_1 \Delta T$$

$$= (\beta_{\text{methanol}} - \beta_{\text{steel}})(\pi r^2 h)(T_2 - T_1)$$

$$= (1200\times10^{-6}°\text{C}^{-1} - 35\times10^{-6}°\text{C}^{-1})(\pi)(1.000\text{ m})^2(5.000\text{ m})(40.0°\text{C} - 10.0°\text{C})$$

$$= 0.55\text{ m}^3$$

98. An aluminum sphere is heated from 11°C to 580°C. If the volume of the sphere is 1.78 cm^3 at 11°C, what is the increase in volume of the sphere at 580°C?

$$\Delta V = \beta V_1 \Delta T$$

$$= (75\times10^{-6}°\text{C}^{-1})(1.78\text{ cm}^3)(580°\text{C} - 11°\text{C})$$

$$= 7.6\times10^{-2}\text{ cm}^3$$

99. The volume of a copper sphere is 2.56 cm^3 after being heated from 12°C to 984°C. What was the volume of the copper sphere at 12°C?

$$V_2 = V_1 + V_1\beta\Delta T = V_1(1 + \beta\Delta T)$$

$$V_1 = \frac{V_2}{1 + \beta\Delta T}$$

$$= \frac{2.56\text{ cm}^3}{(1 + (48\times10^{-6}°\text{C}^{-1})(984°\text{C} - 12°\text{C}))}$$

$$= 2.4\text{ cm}^3$$

Level 3

100. A square of iron plate that is 0.3300 m on each side is heated from 0°C to 95°C.

a. What is the change in the length of the sides of the square?

$$\Delta L = \alpha L_1\Delta T = \alpha L_1\Delta(T_2 - T_1)$$

$$= (12\times10^{-6}°\text{C}^{-1})(0.3300\text{ m})(95°\text{C} - 0°\text{C})$$

$$= 3.8\times10^{-4}\text{ m}$$

b. What is the relative change in area of the square?

$$\text{relative change} = \frac{\Delta A}{A_1}$$

$$= \frac{A_2 - A_1}{A_1}$$

$$= \frac{{L_2}^2 - {L_1}^2}{{L_1}^2}$$

$$= \frac{(L_1 + \Delta L)^2 - {L_1}^2}{{L_1}^2}$$

$$= \frac{(0.3300\text{ m} + 3.8\times10^{-4}\text{ m})^2 - (0.3300\text{ m})^2}{(0.3300\text{ m})^2}$$

$$= 2.3\times10^{-3}$$

101. An aluminum cube with a volume of 0.350 m^3 at 350.0 K is cooled to 270.0 K.

a. What is its volume at 270.0 K?

$$V_2 = V_1 + V_1\beta\Delta T$$

$$= V_1(1 + \beta\Delta T)$$

$$= V_1(1 + \beta(T_2 - T_1))$$

$$= (0.350\text{ m}^3)(1 + (75\times10^{-6}°\text{C}^{-1})(270.0\text{ K} - 350.0\text{ K}))$$

$$= 0.348\text{ m}^3$$

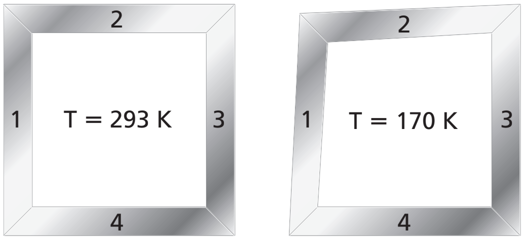
b. What is the length of a side of the cube at 270.0 K?

$$L = (V_2)^{\frac{1}{3}}$$

$$= (0.348\text{ m}^3)^{\frac{1}{3}}$$

$$= 0.703\text{ m}$$

102. **Industry** A machinist builds a rectangular mechanical part for a special refrigerator system from two rectangular pieces of steel and two rectangular pieces of aluminum. At 293 K, the part is a perfect square, but at 170 K, the part becomes warped, as shown in **Figure 13-30.** Which parts were made of steel and which were made of aluminum?



■ **Figure 13-30**

Parts 1 and 2 experienced a greater reduction in length than parts 3 and 4; therefore, parts 1 and 2 must have been made of aluminum, which has a larger coefficient of expansion than steel.

Mixed Review

page 371

Level 1

103. What is the pressure on the hull of a submarine at a depth of 65 m?

$$P = P_{atmosphere} + \rho_{water}gh$$

$$= (1.01\times10^5\ \text{Pa}) + (1.00\times10^{-3}\ \text{kg/m}^3)(9.80\ \text{m/s}^2)(65\ \text{m})$$

$$= 7.4\times10^5\ \text{Pa}$$

104. **Scuba Diving** A scuba diver swimming at a depth of 5.0 m under water exhales a 4.2×10^{-6} m^3 bubble of air. What is the volume of that bubble just before it reaches the surface of the water?

$$P_1V_1 = P_2V_2$$

$$V_2 = \frac{P_1V_1}{P_2}$$

$$= \frac{(P_{atmosphere} + \rho_{water}gh)V_1}{P_{atmosphere}}$$

$$= \frac{(1.01\times10^5\ \text{Pa} + (1.00\times10^3\ \text{kg/m}^3)(9.80\ \text{m/s}^2)(5.0\ \text{m}))(4.2\times10^{-6}\ \text{m}^3)}{1.01\times10^5\ \text{Pa}}$$

$$= 6.2\times10^{-6}\ \text{m}^3$$

105. An 18-N bowling ball floats with about half of the ball submerged.

a. What is the diameter of the bowling ball?

$$F_g = \rho V_{water}g = \rho\left(\frac{V_{ball}}{2}\right)g,$$

where $V_{ball} = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi\left(\frac{d}{2}\right)^3 = \frac{\pi d^3}{6}$

Then $F_g = \frac{1}{2}\rho\left(\frac{\pi d^3}{6}\right)g,$

so that $d = \sqrt[3]{\frac{12F_g}{\pi\rho g}}$

$= \sqrt[3]{\frac{(12)(18\text{ N})}{\pi(1.00\times10^3\text{ kg/m}^3)(9.80\text{ m/s}^2)}}$

$= 0.19\text{ m}$

b. What would be the approximate apparent weight of a 36-N bowling ball?

Half the ball sank when the weight was 18 N. The apparent weight of the 36-N ball should be near zero.

Level 2

106. An aluminum bar is floating in a bowl of mercury. When the temperature is increased, does the aluminum float higher or sink deeper into the mercury?

The volume coefficient of expansion of mercury is greater than the volume coefficient of expansion of aluminum. Therefore, as they are heated, the aluminum becomes denser relative to the mercury and would sink deeper into the mercury.

107. There is 100.0 mL of water in an 800.0-mL soft-glass beaker at 15.0°C. How much will the water level have dropped or risen when the bottle and water are heated to 50.0°C?

The water expands:

$\Delta V = \beta V \Delta T$

$= (210\times10^{-6}°\text{C}^{-1})(100.0\text{ mL})(35.0°\text{C})$

$= 0.735\text{ mL}$

The bottle expands:

$\Delta V = \beta V \Delta T$

$= (27\times10^{-6}°\text{C}^{-1})(800.0\text{ mL})(35.0°\text{C})$

$= 0.756\text{ mL}$

The water level will go down slightly, but not enough to notice.

108. **Auto Maintenance** A hydraulic jack used to lift cars for repairs is called a three-ton jack. The large piston is 22 mm in diameter, and the small one is 6.3 mm in diameter. Assume that a force of 3 tons is 3.0×10^4 N.

a. What force must be exerted on the small piston to lift a 3-ton weight?

$F_2 = \frac{F_1 A_2}{A_1}$

$= \frac{F_1 \pi r_2^2}{\pi r_1^2}$

$= F_1\left(\frac{d_2^2}{d_1^2}\right)$

$= (3.0\times10^4\text{ N})\left(\frac{6.3\text{ mm}}{22\text{ mm}}\right)^2$

$= 2.5\times10^3\text{ N}$

b. Most jacks use a lever to reduce the force needed on the small piston. If the resistance arm is 3.0 cm, how long must the effort arm of an ideal lever be to reduce the force to 100.0 N?

$$F_rL_r = F_eL_e$$

$$L_e = \frac{F_rL_r}{F_e}$$

$$= \frac{(2.5\times10^3\ \text{N})(3.0\ \text{cm})}{100.0\ \text{N}}$$

$$= 75\ \text{cm}$$

109. Ballooning A hot-air balloon contains a fixed volume of gas. When the gas is heated, it expands and pushes some gas out at the lower, open end. As a result, the mass of the gas in the balloon is reduced. Why would the air in a balloon have to be hotter to lift the same number of people above Vail, Colorado, which has an altitude of 2400 m, than above the tidewater flats of Virginia, which have an altitude of 6 m?

Atmospheric pressure is lower at higher altitudes. Therefore, the mass of the volume of fluid displaced by a balloon of the same volume is less at higher altitudes. To obtain the same buoyant force at higher altitudes, a balloon must expel more gas, requiring higher temperatures.

110. The Living World Some plants and animals are able to live in conditions of extreme pressure.

a. What is the pressure exerted by the water on the skin of a fish or worm that lives near the bottom of the Puerto Rico Trench, 8600 m below the surface of the Atlantic Ocean? Use 1030 kg/m^3 for the density of seawater.

The pressure is

$$P = \rho gh$$

$$= (1030\ \text{kg/m}^3)(9.80\ \text{m/s}^2)(8600\ \text{m})$$

$$= 8.7\times10^7\ \text{Pa}$$

b. What would be the density of air at that pressure, relative to its density above the surface of the ocean?

The pressure in the water is $(8.7\times10^7\ \text{Pa})/(1.01\times10^5\ \text{Pa}) =$ 860 times greater than standard air pressure. Therefore, the density of air would be 860 times greater than the density of the air on the surface of the ocean.

Thinking Critically

page 372

111. Apply Concepts You are washing dishes in the sink. A serving bowl has been floating in the sink. You fill the bowl with water from the sink, and it sinks to the bottom. Did the water level in the sink go up or down when the bowl was submerged?

When it was floating, the bowl displaced a volume of water that weighed as much as it did. When it sank, it displaced a volume of water that weighed less than the bowl, because the buoyancy force is the weight of the water displaced. In the second case, the bowl displaces less water and the level in the sink goes down.

112. Apply Concepts Persons confined to bed are less likely to develop bedsores if they use a waterbed rather than an ordinary mattress. Explain.

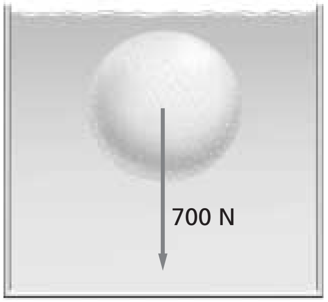
The surface of the waterbed conforms more than the surface of a mattress to the contours of your body. One "sinks" more easily into a waterbed. Because $\rho_{H_2O} < \rho_{mattress}$, the buoyant force from a waterbed is less.

113. Analyze and Conclude One method of measuring the percentage of body fat is based on the fact that fatty tissue is less dense than muscle tissue. How can a person's average density be assessed with a scale and a swimming pool? What measurements does a physician need to record to find a person's average percentage of body fat?

The physician weighs the person normally and then weighs the person totally submerged. Weight has to be

added to the weighing device because the density of a human is normally less than the density of water. The volume of water displaced by the person also should be measured. The average density of the person can be calculated from the balance of forces that hold the person in equilibrium underwater.

114. Analyze and Conclude A downward force of 700 N is required to fully submerge a plastic foam sphere, as shown in **Figure 13-31.** The density of the foam is 95 kg/m^3.



■ **Figure 13-31**

a. What percentage of the sphere would be submerged if the sphere were released to float freely?

The density of the foam relative to the water is $\frac{95\ \text{kg/m}^3}{1.00\times10^3\ \text{kg/m}^3} = 0.095$**, so 9.5 percent of the floating sphere would be submerged.**

b. What is the weight of the sphere in air?

The weight of water displaced by 9.5 percent of the sphere's volume balances the entire weight of the sphere, F_g. An additional 700 N is needed to submerge the remaining 90.5 percent of the sphere's volume. Thus,

$$\frac{F_g}{0.095} = \frac{700\ \text{N}}{0.905}$$

$$F_g = 7\times10^1\ \text{N}$$

c. What is the volume of the sphere?

$$F_{buoyant} = F_g + F_{down}$$

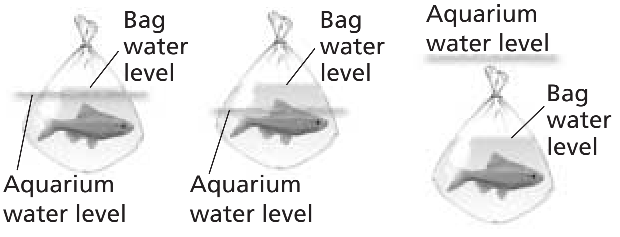
$$\rho_{water}Vg = \rho_{foam}Vg + F_{down}$$

$$V = \frac{F_{down}}{(\rho_{water} - \rho_{down})g}$$

$$= \frac{700\ \text{N}}{(1.00\times10^3\ \text{kg/m}^3 - 95\ \text{kg/m}^3)(9.80\ \text{m/s}^2)}$$

$$= 8\times10^{-2}\ \text{m}^3$$

115. Apply Concepts Tropical fish for aquariums are often transported home from pet shops in transparent plastic bags filled mostly with water. If you placed a fish in its unopened transport bag in a home aquarium, which of the cases in **Figure 13-32** best represents what would happen? Explain your reasoning.



■ **Figure 13-32**

The density of the water in the bag, the fish, and the plastic are all near the density of the water in the aquarium. Therefore, the bag should float with the water level in the bag at the same height as the water level in the aquarium.

Writing in Physics

page 372

116. Some solid materials expand when they are cooled. Water between 4° and 0°C is the most common example, but rubber bands also expand in length when cooled. Research what causes this expansion.

Rubber bands are made of long rubber molecules called polymers that act like chains with many long links. The properties of rubber come from the ability of the chain links to twist and turn. When the rubber is colder, the polymer links are stretched out in a straight line, like the links in a steel chain that you hold at one end and let hang freely. Because the links are ordered that way, the polymers have relatively little disorder, or entropy. Adding heat to the polymers increases their thermal motion. The links begin to shake about and their disorder increases. If you shake a chain like this, you will see that its average length becomes less than if the chain were hanging motionless.

117. Research Joseph Louis Gay-Lussac and his contributions to the gas laws. How did Gay-Lussac's work contribute to the discovery of the formula for water?

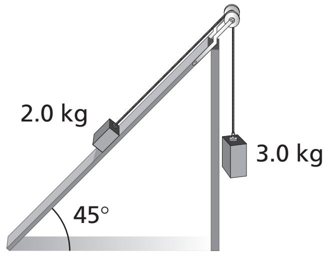
Gay-Lussac was a French scientist who also was interested in high-altitude balloon ascents. He discovered that when gases are at the same temperature and pressure, their volumes react in ratios of small, whole numbers. Gay-Lussac's work contributed to the discovery of water's formula by showing that two volumes of hydrogen gas react with one volume of oxygen gas. Avogadro built on Gay-Lussac's work to develop the relationship between moles of a gas and volume.

Cumulative Review

page 372

118. Two blocks are connected by a string over a frictionless, massless pulley such that one is resting on an inclined plane and the other is hanging over the top edge of the plane, as shown in **Figure 13-33.** The hanging block has a mass of 3.0 kg and the block on the plane has a mass of 2.0 kg. The coefficient of kinetic friction between the block and the inclined plane is 0.19. Answer the following questions assuming the blocks are released from rest. (Chapter 5)

a. What is the acceleration of the blocks?



■ **Figure 13-33**

For the 2-kg block,

$T - \mu_k F_N - mg \sin \theta = ma$

where $F_N = mg \cos \theta$ is the normal force.

Thus,

$T - \mu_k mg \cos \theta - mg \sin \theta = ma$

$T - (mg)(\mu_k \cos \theta + \sin \theta) = ma$

For the 3-kg block,

$Mg - T = Ma$

or, $T = Mg - Ma$

Substitute this for T in the 2-kg block equation.

$Mg - Ma - (mg)(\mu_k \cos \theta + \sin \theta) = ma$

Solve for acceleration.

$$a = \frac{Mg - (mg)(\mu_k \cos\theta + \sin\theta)}{m + M}$$

$$= \frac{(3.0\ \text{kg})(9.80\ \text{m/s}^2) - (2.0\ \text{kg})(9.80\ \text{m/s}^2)((0.19)(\cos 45°) + \sin 45°)}{2.0\ \text{kg} + 3.0\ \text{kg}}$$

$$= 2.6\ \text{m/s}^2$$

b. What is the tension in the string connecting the blocks?

To find T, use the equation for the 3-kg block.

$$T = Mg - Ma$$

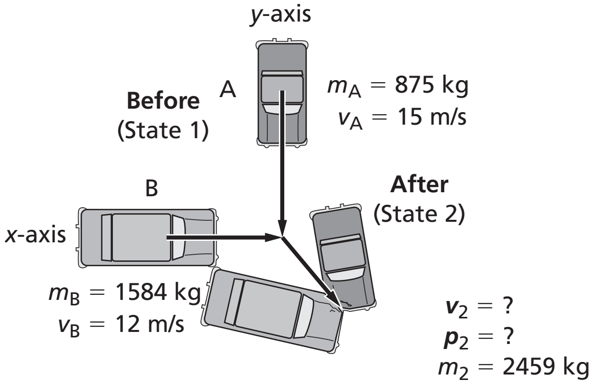
$$= M(g - a)$$

$$= (3.0\ \text{kg})(9.80\ \text{m/s}^2 - 2.6\ \text{m/s}^2)$$

$$= 22\ \text{N}$$

119. A compact car with a mass of 875 kg, moving south at 15 m/s, is struck by a full-sized car with a mass of 1584 kg, moving east at 12 m/s. The two cars stick together, and momentum is conserved. (Chapter 9)

a. Sketch the situation, assigning coordinate axes and identifying "before" and "after."



b. Find the direction and speed of the wreck immediately after the collision, remembering that momentum is a vector quantity.

$$p_{A1} = m_A v_A = (875\ \text{kg})(15\ \text{m/s})$$

$$= 1.31\times10^4\ \text{kg·m/s south}$$

$$p_{B1} = m_B v_B = (1584\ \text{kg})(12\ \text{m/s})$$

$$= 1.90\times10^4\ \text{kg·m/s east}$$

$$p_2 = \sqrt{{p_{A1}}^2 + {p_{B1}}^2}$$

$$= \sqrt{(1.31\times10^4\ \text{kg·m/s})^2 + (1.90\times10^4\ \text{kg·m/s})^2}$$

$$= 2.3\times10^4\ \text{kg·m/s}$$

$$\tan\theta = \frac{p_{B1}}{p_{A1}}$$

$$\theta = \tan^{-1}\left(\frac{p_{B1}}{p_{A1}}\right)$$
$$= \tan^{-1}\left(\frac{1.90\times10^4\ \text{kg·m/s}}{1.31\times10^4\ \text{kg·m/s}}\right)$$
$$= 55°\ \text{east of south}$$

$$v_2 = \frac{p_2}{m_2} = \frac{2.3\times10^4\ \text{kg·m/s}}{2459\ \text{kg}}$$
$$= 9.4\ \text{m/s}$$

c. The wreck skids along the ground and comes to a stop. The coefficient of kinetic friction while the wreck is skidding is 0.55. Assume that the acceleration is constant. How far does the wreck skid after impact?

To find the distance, use the equation of motion:

$$v^2 = v_i^2 + 2a(d - d_i)$$

where the final velocity is zero and $d_i = 0$. Solve for d:

$$d = \frac{-v_i^2}{2a}$$

To find acceleration, notice that the force that slows the cars equals the frictional force.

$$(m_a + m_b)a = -\mu_k(m_a + m_b)g$$
$$a = -\mu_k g$$

The distance is then

$$d = \frac{v_0^2}{2\mu_k g}$$
$$= \frac{(9.4\ \text{m/s})^2}{(2)(0.55)(9.80\ \text{m/s}^2)}$$
$$= 8.2\ \text{m}$$

120. A 188-W motor will lift a load at the rate (speed) of 6.50 cm/s. How great a load can the motor lift at this rate? (Chapter 10)

$$v = 6.50\ \text{cm/s} = 0.0650\ \text{m/s}$$
$$P = \frac{W}{t} = \frac{Fd}{t} = F\left(\frac{d}{t}\right) = Fv$$
$$P = F_g v$$
$$F_g = \frac{P}{v} = \frac{188\ \text{W}}{0.0650\ \text{m/s}} = 2.89\times10^3\ \text{N}$$

Challenge Problem

page 363

You need to make a 1.00-m-long bar that expands with temperature in the same way as a 1.00-m-long bar of copper would. As shown in the figure at the right, your bar must be made from a bar of iron and a bar of aluminum attached end to end. How long should each of them be?

$$L_{copper} = L_{aluminum} + L_{iron}$$

and

$$\alpha_{copper}L_{copper}\Delta T = (\alpha_{aluminum}L_{aluminum} + \alpha_{iron}L_{iron})\Delta T$$

Substituting $L_{aluminum} = L_{copper} - L_{iron}$, this gives

$$L_{iron} = \frac{(\alpha_{copper} - \alpha_{aluminum})L_{copper}}{\alpha_{iron} - \alpha_{aluminum}}$$
$$= \frac{(16\times10^{-6}°\text{C}^{-1} - 25\times10^{-6}°\text{C}^{-1})(1.00\ \text{m})}{12\times10^{-6}°\text{C}^{-1} - 25\times10^{-6}°\text{C}^{-1}}$$
$$= 0.69\ \text{m}$$

$$L_{aluminum} = L_{copper} - L_{iron}$$
$$= 1.00\ \text{m} - 0.69\ \text{m}$$
$$= 0.31\ \text{m}$$

CHAPTER

14 Vibrations and Waves

Practice Problems

14.1 Periodic Motion pages 375–380

page 378

1. How much force is necessary to stretch a spring 0.25 m when the spring constant is 95 N/m?

   $F = kx$

   $= (95\ \text{N/m})(0.25\ \text{m})$

   $= 24\ \text{N}$

2. A spring has a spring constant of 56 N/m. How far will it stretch when a block weighing 18 N is hung from its end?

   $F = kx$

   $x = \frac{F}{k} = \frac{18\ \text{N}}{56\ \text{N/m}} = 0.32\ \text{m}$

3. What is the spring constant of a spring that stretches 12 cm when an object weighing 24 N is hung from it?

   $F = kx$

   $k = \frac{F}{x}$

   $= \frac{24\ \text{N}}{0.12\ \text{m}}$

   $= 2.0\times10^{2}\ \text{N/m}$

4. A spring with a spring constant of 144 N/m is compressed by a distance of 16.5 cm. How much elastic potential energy is stored in the spring?

   $PE_{sp} = \frac{1}{2}kx^2$

   $= \frac{1}{2}(144\ \text{N/m})(0.165\ \text{m})^2 = 1.96\ \text{J}$

5. A spring has a spring constant of 256 N/m. How far must it be stretched to give it an elastic potential energy of 48 J?

   $PE_{sp} = \frac{1}{2}kx^2$

   $x = \sqrt{\frac{2PE_{sp}}{k}} = \sqrt{\frac{(2)(48\ \text{J})}{256\ \text{N/m}}} = 0.61\ \text{m}$

page 379

6. What is the period on Earth of a pendulum with a length of 1.0 m?

   $T = 2\pi\sqrt{\frac{l}{g}} = 2\pi\sqrt{\frac{1.0\ \text{m}}{9.80\ \text{m/s}^2}} = 2.0\ \text{s}$

7. How long must a pendulum be on the Moon, where $g = 1.6\ \text{m/s}^2$, to have a period of 2.0 s?

   $T = 2\pi\sqrt{\frac{l}{g}}$

   $l = g\left(\frac{T}{2\pi}\right)^2 = (1.6\ \text{m/s}^2)\left(\frac{2.0\ \text{s}}{2\pi}\right)^2 = 0.16\ \text{m}$

8. On a planet with an unknown value of *g*, the period of a 0.75-m-long pendulum is 1.8 s. What is *g* for this planet?

   $T = 2\pi\sqrt{\frac{l}{g}}$

   $g = l\left(\frac{2\pi}{T}\right)^2 = (0.75\ \text{m})\left(\frac{2\pi}{1.8\ \text{s}}\right)^2 = 9.1\ \text{m/s}^2$

Section Review

14.1 Periodic Motion pages 375–380

page 380

9. **Hooke's Law** Two springs look alike but have different spring constants. How could you determine which one has the greater spring constant?

   Hang the same object from both springs. The one that stretches less has the greater spring constant.

10. **Hooke's Law** Objects of various weights are hung from a rubber band that is suspended from a hook. The weights of the objects are plotted on a graph against the

stretch of the rubber band. How can you tell from the graph whether or not the rubber band obeys Hooke's law?

If the graph is a straight line, the rubber band obeys Hooke's law. If the graph is curved, it does not.

11. Pendulum How must the length of a pendulum be changed to double its period? How must the length be changed to halve the period?

$$PE_{sp} = \frac{1}{2}kx^2\text{, so}$$

$$\frac{PE_1}{PE_2} = \frac{x_1^2}{x_2^2}$$

$$= \frac{(0.40\text{ m})^2}{(0.20\text{ m})^2}$$

$$= 4.0$$

The energy of the first spring is 4.0 times greater than the energy of the second spring.

12. Energy of a Spring What is the difference between the energy stored in a spring that is stretched 0.40 m and the energy stored in the same spring when it is stretched 0.20 m?

$$T = 2\pi\sqrt{\frac{l}{g}}\text{, so } \frac{T_2}{T_1} = \sqrt{\frac{l_2}{l_1}}$$

To double the period:

$$\frac{T_2}{T_1} = \sqrt{\frac{l_2}{l_1}} = 2\text{, so } \frac{l_2}{l_1} = 4$$

The length must be quadrupled.

To halve the period:

$$\frac{T_2}{T_1} = \sqrt{\frac{l_2}{l_1}} = \frac{1}{2}\text{, so } \frac{l_2}{l_1} = \frac{1}{4}$$

The length is reduced to one-fourth its original length.

13. Resonance If a car's wheel is out of balance, the car will shake strongly at a specific speed, but not when it is moving faster or slower than that speed. Explain.

At that speed, the tire's rotation frequency matches the resonant frequency of the car.

14. Critical Thinking How is uniform circular motion similar to simple harmonic motion? How are they different?

Both are periodic motions. In uniform circular motion, the accelerating force is not proportional to the displacement. Also, simple harmonic motion is one-dimensional and uniform circular motion is two-dimensional.

Practice Problems

14.2 Wave Properties pages 381–386

page 386

15. A sound wave produced by a clock chime is heard 515 m away 1.50 s later.

a. What is the speed of sound of the clock's chime in air?

$$v = \frac{d}{t}$$

$$= \frac{515\text{ m}}{1.50\text{ s}}$$

$$= 343\text{ m/s}$$

b. The sound wave has a frequency of 436 Hz. What is the period of the wave?

$$T = \frac{1}{f}$$

$$= \frac{1}{436\text{ Hz}}$$

$$= 2.29\times10^{-3}\text{ s}$$

c. What is the wave's wavelength?

$$\lambda = \frac{v}{f}$$

$$= \frac{343\text{ m/s}}{436\text{ Hz}}$$

$$= 0.787\text{ m}$$

16. A hiker shouts toward a vertical cliff 465 m away. The echo is heard 2.75 s later.

a. What is the speed of sound of the hiker's voice in air?

$$v = \frac{d}{t} = \frac{(2)(465\text{ m})}{2.75\text{ s}} = 338\text{ m/s}$$

b. The wavelength of the sound is 0.750 m. What is its frequency?

$v = \lambda f$, so $f = \frac{v}{\lambda} = \frac{338 \text{ m/s}}{0.750 \text{ m}} = 451 \text{ Hz}$

c. What is the period of the wave?

$T = \frac{1}{f} = \frac{1}{451 \text{ Hz}} = 2.22\times10^{-3} \text{ s}$

17. If you want to increase the wavelength of waves in a rope, should you shake it at a higher or lower frequency?

at a lower frequency, because wavelength varies inversely with frequency

18. What is the speed of a periodic wave disturbance that has a frequency of 3.50 Hz and a wavelength of 0.700 m?

$v = \lambda f = (0.700 \text{ m})(3.50 \text{ Hz}) = 2.45 \text{ m/s}$

19. The speed of a transverse wave in a string is 15.0 m/s. If a source produces a disturbance that has a frequency of 6.00 Hz, what is its wavelength?

$v = \lambda f$, so $\lambda = \frac{v}{f} = \frac{15.0 \text{ m/s}}{6.00 \text{ Hz}} = 2.50 \text{ m}$

20. Five pulses are generated every 0.100 s in a tank of water. What is the speed of propagation of the wave if the wavelength of the surface wave is 1.20 cm?

$\frac{0.100 \text{ s}}{5 \text{ pulses}} = 0.0200 \text{ s/pulse}$, so

$T = 0.0200 \text{ s}$

$\lambda = vT$, so

$v = \frac{\lambda}{T}$

$= \frac{1.20 \text{ cm}}{0.0200 \text{ s}}$

$= 60.0 \text{ cm/s} = 0.600 \text{ m/s}$

21. A periodic longitudinal wave that has a frequency of 20.0 Hz travels along a coil spring. If the distance between successive compressions is 0.600 m, what is the speed of the wave?

$v = \lambda f = (0.600 \text{ m})(20.0 \text{ Hz}) = 12.0 \text{ m/s}$

Section Review

14.2 Wave Properties pages 381–386

page 386

22. Speed in Different Media If you pull on one end of a coiled-spring toy, does the pulse reach the other end instantaneously? What happens if you pull on a rope? What happens if you hit the end of a metal rod? Compare and contrast the pulses traveling through these three materials.

It takes time for the pulse to reach the other end in each case. It travels faster on the rope than on the spring, and fastest in the metal rod.

23. Wave Characteristics You are creating transverse waves in a rope by shaking your hand from side to side. Without changing the distance that your hand moves, you begin to shake it faster and faster. What happens to the amplitude, wavelength, frequency, period, and velocity of the wave?

The amplitude and velocity remain unchanged, but the frequency increases while the period and the wavelength decrease.

24. Waves Moving Energy Suppose that you and your lab partner are asked to demonstrate that a transverse wave transports energy without transferring matter. How could you do it?

Tie a piece of yarn somewhere near the middle of a rope. With your partner holding one end of the rope, shake the other end up and down to create a transverse wave. Note that while the wave moves down the rope, the yarn moves up and down but stays in the same place on the rope.

25. Longitudinal Waves Describe longitudinal waves. What types of media transmit longitudinal waves?

In longitudinal waves, the particles of the medium vibrate in a direction parallel to the motion of the wave.

Nearly all media—solids, liquids, and gases—transmit longitudinal waves.

26. **Critical Thinking** If a raindrop falls into a pool, it creates waves with small amplitudes. If a swimmer jumps into a pool, waves with large amplitudes are produced. Why doesn't the heavy rain in a thunderstorm produce large waves?

The energy of the swimmer is transferred to the wave in a small space over a short time, whereas the energy of the raindrops is spread out in area and time.

Section Review

14.3 Wave Behavior pages 387–391

page 391

27. **Waves at Boundaries** Which of the following wave characteristics remain unchanged when a wave crosses a boundary into a different medium: frequency, amplitude, wavelength, velocity, and/or direction?

Frequency remains unchanged. In general, amplitude, wavelength, and velocity will change when a wave enters a new medium. Direction may or may not change, depending on the original direction of the wave.

28. **Refraction of Waves** Notice in **Figure 14-17a** how the wave changes direction as it passes from one medium to another. Can two-dimensional waves cross a boundary between two media without changing direction? Explain.

Yes, if they strike the boundary while traveling normal to its surface, or if they have the same speed in both media.

29. **Standing Waves** In a standing wave on a string fixed at both ends, how is the number of nodes related to the number of antinodes?

The number of nodes is always one greater than the number of antinodes.

30. **Critical Thinking** As another way to understand wave reflection, cover the right-hand side of each drawing in **Figure 14-13a** with a piece of paper. The edge of the paper should be at point N, the node. Now, concentrate on the resultant wave, shown in darker blue. Note that it acts like a wave reflected from a boundary. Is the boundary a rigid wall, or is it open-ended? Repeat this exercise for **Figure 14-13b.**

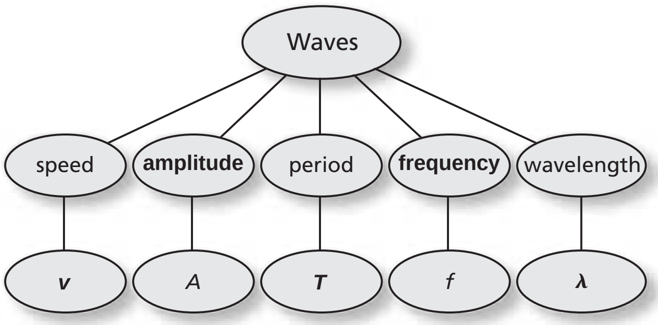
Figure 14-14a behaves like a rigid wall because the reflected wave is inverted; 14-14b behaves like an open end because the boundary is an antinode and the reflected wave is not inverted.

Chapter Assessment

Concept Mapping

page 396

31. Complete the concept map using the following terms and symbols: *amplitude, frequency, v, λ, T*.



Mastering Concepts

page 396

32. What is periodic motion? Give three examples of periodic motion. (14.1)

Periodic motion is motion that repeats in a regular cycle. Examples include oscillation of a spring, swing of a simple pendulum, and uniform circular motion.

33. What is the difference between frequency and period? How are they related? (14.1)

Frequency is the number of cycles or repetitions per second, and period is the time required for one cycle. Frequency is the inverse of the period.

34. What is simple harmonic motion? Give an example of simple harmonic motion. (14.1)

Simple harmonic motion is periodic motion that results when the restoring force on an object is directly proportional to its displacement. A block bouncing on the end of a spring is one example.

35. If a spring obeys Hooke's law, how does it behave? (14.1)

The spring stretches a distance that is directly proportional to the force applied to it.

36. How can the spring constant of a spring be determined from a graph of force versus displacement? (14.1)

The spring constant is the slope of the graph of F versus x.

37. How can the potential energy in a spring be determined from the graph of force versus displacement? (14.1)

The potential energy is the area under the curve of the graph of F versus x.

38. Does the period of a pendulum depend on the mass of the bob? The length of the string? Upon what else does the period depend? (14.1)

no; yes; the acceleration of gravity, g

39. What conditions are necessary for resonance to occur? (14.1)

Resonance will occur when a force is applied to an oscillating system at the same frequency as the natural frequency of the system.

40. How many general methods of energy transfer are there? Give two examples of each. (14.2)

Two. Energy is transferred by particle transfer and by waves. There are many examples that can be given of each: a baseball and a bullet for particle transfer; sound waves and light waves.

41. What is the primary difference between a mechanical wave and an electromagnetic wave? (14.2)

The primary difference is that mechanical waves require a medium to travel through and electromagnetic waves do not need a medium.

42. What are the differences among transverse, longitudinal, and surface waves? (14.2)

A transverse wave causes the particles of the medium to vibrate in a direction that is perpendicular to the direction in which the wave is moving. A longitudinal wave causes the particles of the medium to vibrate in a direction parallel with the direction of the wave. Surface waves have characteristics of both.

43. Waves are sent along a spring of fixed length. (14.2)

a. Can the speed of the waves in the spring be changed? Explain.

Speed of the waves depends only on the medium and cannot be changed.

b. Can the frequency of a wave in the spring be changed? Explain.

Frequency can be changed by changing the frequency at which the waves are generated.

44. What is the wavelength of a wave? (14.2)

Wavelength is the distance between two adjacent points on a wave that are in phase.

45. Suppose you send a pulse along a rope. How does the position of a point on the rope before the pulse arrives compare to the point's position after the pulse has passed? (14.2)

Once the pulse has passed, the point is exactly as it was prior to the advent of the pulse.

46. What is the difference between a wave pulse and a periodic wave? (14.2)

A pulse is a single disturbance in a medium, whereas a periodic wave consists of several adjacent disturbances.

47. Describe the difference between wave frequency and wave velocity. (14.2)

Frequency is the number of vibrations per second of a part of the medium. Velocity describes the motion of the wave through the medium.

48. Suppose you produce a transverse wave by shaking one end of a spring from side to side. How does the frequency of your hand compare with the frequency of the wave? (14.2)

They are the same.

49. When are points on a wave in phase with each other? When are they out of phase? Give an example of each. (14.2)

Points are in phase when they have the same displacement and the same velocity. Otherwise, the points are out of phase. Two crests are in phase with each other. A crest and a trough are out of phase with each other.

50. What is the amplitude of a wave and what does it represent? (14.2)

Amplitude is the maximum displacement of a wave from the rest or equilibrium position. The amplitude of the wave represents the amount of energy transferred.

51. Describe the relationship between the amplitude of a wave and the energy it carries. (14.2)

The energy carried by a wave is proportional to the square of its amplitude.

52. When a wave reaches the boundary of a new medium, what happens to it? (14.3)

Part of the wave can be reflected and part of the wave can be transmitted into the new medium.

53. When a wave crosses a boundary between a thin and a thick rope, as shown in **Figure 14-18,** its wavelength and speed change, but its frequency does not. Explain why the frequency is constant. (14.3)

■ **Figure 14-18**

The frequency depends only on the rate at which the thin rope is shaken and the thin rope causes the vibrations in the thick rope.

54. How does a spring pulse reflected from a rigid wall differ from the incident pulse? (14.3)

The reflected pulse will be inverted.

55. Describe interference. Is interference a property of only some types of waves or all types of waves? (14.3)

The superposition of two or more waves is interference. The superposition of two waves with equal but opposite amplitudes results in destructive interference. The superposition of two waves with amplitudes in the same direction results in constructive interference; all waves; it is a prime test for wave nature.

56. What happens to a spring at the nodes of a standing wave? (14.3)

Nothing, the spring does not move.

57. **Violins** A metal plate is held fixed in the center and sprinkled with sugar. With a violin bow, the plate is stroked along one edge and made to vibrate. The sugar begins to collect in certain areas and move away from others. Describe these regions in terms of standing waves. (14.3)

Bare areas are antinodal regions where there is maximum vibration. Sugar-covered areas are nodal regions where there is no vibration.

58. If a string is vibrating in four parts, there are points where it can be touched without disturbing its motion. Explain. How many of these points exist? (14.3)

A standing wave exists and the string can be touched at any of its five nodal points.

59. Wave fronts pass at an angle from one medium into a second medium, where they travel with a different speed. Describe two changes in the wave fronts. What does not change? (14.3)

The wavelength and direction of the wave fronts change. The frequency does not change.

Applying Concepts

page 397

60. A ball bounces up and down on the end of a spring. Describe the energy changes that take place during one complete cycle. Does the total mechanical energy change?

At the bottom of the motion, the elastic potential energy is at a maximum, while gravitational potential energy is at a minimum and the kinetic energy is zero. At the equilibrium position, the *KE* is at a maximum and the elastic potential energy is zero. At the top of the bounce, the *KE* is zero, the gravitational potential energy is at a maximum, and the elastic potential energy is at a maximum. The total mechanical energy is conserved.

61. Can a pendulum clock be used in the orbiting *International Space Station?* Explain.

No, the space station is in free-fall, and therefore, the apparent value of *g* is zero. The pendulum will not swing.

62. Suppose you hold a 1-m metal bar in your hand and hit its end with a hammer, first, in a direction parallel to its length, and second, in a direction at right angles to its length. Describe the waves produced in the two cases.

In the first case, longitudinal waves; in the second case, transverse waves.

63. Suppose you repeatedly dip your finger into a sink full of water to make circular waves. What happens to the wavelength as you move your finger faster?

The frequency of the waves will increase; the speed will remain the same; the wavelength will decrease.

64. What happens to the period of a wave as the frequency increases?

As the frequency increases, the period decreases.

65. What happens to the wavelength of a wave as the frequency increases?

As the frequency increases, the wavelength decreases.

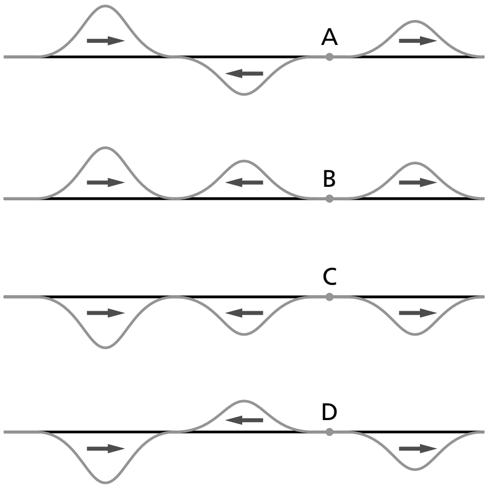
66. Suppose you make a single pulse on a stretched spring. How much energy is required to make a pulse with twice the amplitude?

approximately two squared, or four times the energy

67. You can make water slosh back and forth in a shallow pan only if you shake the pan with the correct frequency. Explain.

The period of the vibration must equal the time for the wave to go back and forth across the pan to create constructive interference.

68. In each of the four waves in **Figure 14-19,** the pulse on the left is the original pulse moving toward the right. The center pulse is a reflected pulse; the pulse on the right is a transmitted pulse. Describe the rigidity of the boundaries at A, B, C, and D.



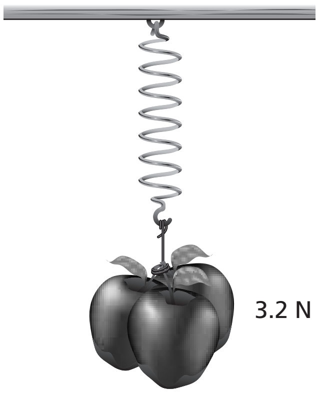
■ **Figure 14-19**

Boundary A is more rigid; boundary B is less rigid; boundary C is less rigid; boundary D is more rigid.

Mastering Problems

14.1 Periodic Motion
pages 397–398
Level 1

69. A spring stretches by 0.12 m when some apples weighing 3.2 N are suspended from it, as shown in **Figure 14-20.** What is the spring constant of the spring?



■ **Figure 14-20**

$F = kx$,

so $k = \frac{F}{x} = \frac{3.2\text{ N}}{0.12\text{ m}} = 27\text{ N/m}$

70. Car Shocks Each of the coil springs of a car has a spring constant of 25,000 N/m. How much is each spring compressed if it supports one-fourth of the car's 12,000-N weight?

$F = kx$,

so $x = \frac{F}{k}$

$= \frac{\left(\frac{1}{4}\right)(12{,}000\text{ N})}{25{,}000\text{ N/m}}$

$= 0.12\text{ m}$

71. How much potential energy is stored in a spring with a spring constant of 27 N/m if it is stretched by 16 cm?

$PE_{sp} = \frac{1}{2}kx^2$

$= \left(\frac{1}{2}\right)(27\text{ N/m})(0.16\text{ m})^2 = 0.35\text{ J}$

Level 2

72. Rocket Launcher A toy rocket-launcher contains a spring with a spring constant of 35 N/m. How far must the spring be compressed to store 1.5 J of energy?

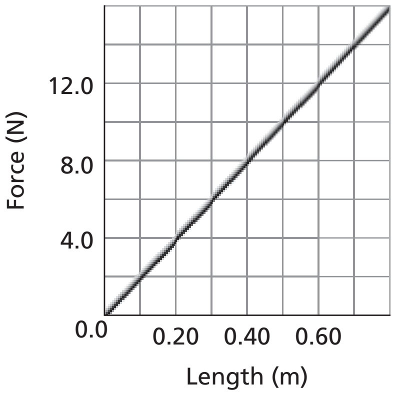
$PE_{sp} = \frac{1}{2}kx^2$,

so $x = \sqrt{\frac{2PE_{sp}}{k}} = \sqrt{\frac{(2)(1.5\text{ J})}{35\text{ N/m}}}$

$= 0.29\text{ m}$

Level 3

73. Force-versus-length data for a spring are plotted on the graph in **Figure 14-21.**



■ **Figure 14-21**

a. What is the spring constant of the spring?

$k = \text{slope}$

$= \frac{\Delta F}{\Delta x} = \frac{12.0\ \text{N} - 4.0\ \text{N}}{0.6\ \text{m} - 0.2\ \text{m}}$

$= 20\ \text{N/m}$

b. What is the energy stored in the spring when it is stretched to a length of 50.0 cm?

$PE_{sp} = \text{area} = \frac{1}{2}bh$

$= \left(\frac{1}{2}\right)(0.500\ \text{m})(10.0\ \text{N}) = 2.50\ \text{J}$

74. How long must a pendulum be to have a period of 2.3 s on the Moon, where $g = 1.6\ \text{m/s}^2$?

$T = 2\pi\sqrt{\frac{l}{g}}$, so $l = \frac{T^2 g}{4\pi^2}$

$= \frac{(2.3\ \text{s})^2(1.6\ \text{m/s}^2)}{4\pi^2} = 0.21\ \text{m}$

14.2 Wave Properties

page 398

Level 1

75. Building Motion The Sears Tower in Chicago, shown in **Figure 14-22,** sways back and forth in the wind with a frequency of about 0.12 Hz. What is its period of vibration?

■ **Figure 14-22**

$f = \frac{1}{T}$

$T = \frac{1}{f} = \frac{1}{0.12\ \text{Hz}} = 8.3\ \text{s}$

76. Ocean Waves An ocean wave has a length of 12.0 m. A wave passes a fixed location every 3.0 s. What is the speed of the wave?

$v = \lambda f = \lambda\left(\frac{1}{T}\right) = (12.0\ \text{m})\left(\frac{1}{3.0\ \text{s}}\right)$

$= 4.0\ \text{m/s}$

77. Water waves in a shallow dish are 6.0-cm long. At one point, the water moves up and down at a rate of 4.8 oscillations/s.

a. What is the speed of the water waves?

$v = \lambda f$

$= (0.060\ \text{m})(4.8\ \text{Hz}) = 0.29\ \text{m/s}$

b. What is the period of the water waves?

$T = \frac{1}{f} = \frac{1}{4.8\ \text{Hz}} = 0.21\ \text{s}$

78. Water waves in a lake travel 3.4 m in 1.8 s. The period of oscillation is 1.1 s.

a. What is the speed of the water waves?

$v = \frac{d}{t} = \frac{3.4\ \text{m}}{1.8\ \text{s}} = 1.9\ \text{m/s}$

b. What is their wavelength?

$\lambda = \frac{v}{f} = vT$

$= (1.9\ \text{m/s})(1.1\ \text{s})$

$= 2.1\ \text{m}$

Level 2

79. Sonar A sonar signal of frequency 1.00×10^6 Hz has a wavelength of 1.50 mm in water.

a. What is the speed of the signal in water?

$v = \lambda f$

$= (1.50\times10^{-3}\ \text{m})(1.00\times10^{6}\ \text{Hz})$

$= 1.50\times10^{3}\ \text{m/s}$

b. What is its period in water?

$T = \frac{1}{f} = \frac{1}{1.00\times10^{6}\ \text{Hz}}$

$= 1.00\times10^{-6}\ \text{s}$

c. What is its period in air?

1.00×10^{-6} s

The period and frequency remain unchanged.

80. A sound wave of wavelength 0.60 m and a velocity of 330 m/s is produced for 0.50 s.

a. What is the frequency of the wave?

$v = \lambda f$

$f = \frac{v}{\lambda} = \frac{330\text{ m/s}}{0.60\text{ m}}$

$= 550\text{ Hz}$

b. How many complete waves are emitted in this time interval?

$ft = (550\text{ Hz})(0.50\text{ s})$

$= 280$ **complete waves**

c. After 0.50 s, how far is the front of the wave from the source of the sound?

$d = vt$

$= (330\text{ m/s})(0.50\text{ s})$

$= 1.6\times10^{2}\text{ m}$

81. The speed of sound in water is 1498 m/s. A sonar signal is sent straight down from a ship at a point just below the water surface, and 1.80 s later, the reflected signal is detected. How deep is the water?

The time for the wave to travel down and back up is 1.80 s. The time one way is half 1.80 s or 0.900 s.

$d = vt$

$= (1498\text{ m/s})(0.900\text{ s})$

$= 1350\text{ m}$

Level 3

82. Pepe and Alfredo are resting on an offshore raft after a swim. They estimate that 3.0 m separates a trough and an adjacent crest of each surface wave on the lake. They count 12 crests that pass by the raft in 20.0 s. Calculate how fast the waves are moving.

$\lambda = (2)(3.0\text{ m}) = 6.0\text{ m}$

$f = \frac{12\text{ waves}}{20.0\text{ s}} = 0.60\text{ Hz}$

$v = \lambda f$

$= (6.0\text{ m})(0.60\text{ Hz})$

$= 3.6\text{ m/s}$

83. Earthquakes The velocity of the transverse waves produced by an earthquake is 8.9 km/s, and that of the longitudinal waves is 5.1 km/s. A seismograph records the arrival of the transverse waves 68 s before the arrival of the longitudinal waves. How far away is the earthquake?

$d = vt$. We do not know t, only the difference in time, Δt. The transverse distance, $d_T = v_T t$, is the same as the longitudinal distance, $d_L = v_L(t + \Delta t)$. Use $v_T t = v_L(t + \Delta t)$, and solve for t:

$t = \frac{v_L \Delta t}{v_T - v_L}$

$t = \frac{(5.1\text{ km/s})(68\text{ s})}{8.9\text{ km/s} - 5.1\text{ km/s}} = 91\text{ s}$

Then putting t back into

$d_T = v_T t = (8.9\text{ km/s})(91\text{ s})$

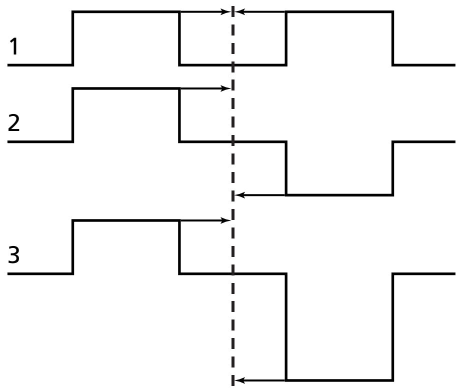
$= 8.1\times10^{2}\text{ km}$

14.3 Wave Behavior

pages 398–399

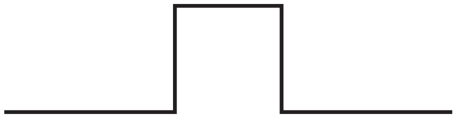
Level 1

84. Sketch the result for each of the three cases shown in **Figure 14-23,** when the centers of the two approaching wave pulses lie on the dashed line so that the pulses exactly overlap.



■ **Figure 14-23**

1. **The amplitude is doubled.**



2. **The amplitudes cancel each other.**

3. **If the amplitude of the first pulse is one-half of the second, the resultant pulse is one-half the amplitude of the second.**

85. If you slosh the water in a bathtub at the correct frequency, the water rises first at one end and then at the other. Suppose you can make a standing wave in a 150-cm-long tub with a frequency of 0.30 Hz. What is the velocity of the water wave?

$\lambda = 2(1.5 \text{ m}) = 3.0 \text{ m}$

$v = \lambda f$

$= (3.0 \text{ m})(0.30 \text{ Hz})$

$= 0.90 \text{ m/s}$

Level 2

86. Guitars The wave speed in a guitar string is 265 m/s. The length of the string is 63 cm. You pluck the center of the string by pulling it up and letting go. Pulses move in both directions and are reflected off the ends of the string.

a. How long does it take for the pulse to move to the string end and return to the center?

$$d = \frac{(2)(63 \text{ cm})}{2} = 63 \text{ cm}$$

$$\text{so } t = \frac{d}{v} = \frac{0.63 \text{ m}}{265 \text{ m/s}} = 2.4\times10^{-3} \text{ s}$$

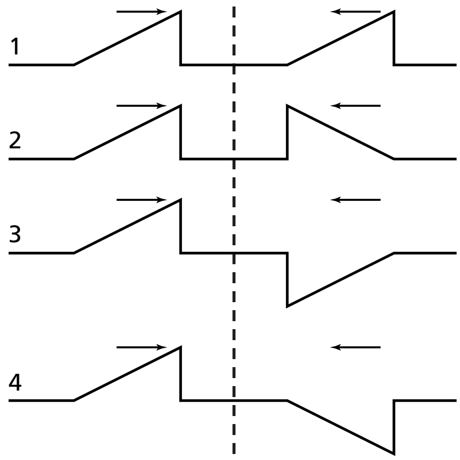
b. When the pulses return, is the string above or below its resting location?

Pulses are inverted when reflected from a more dense medium, so returning pulse is down (below).

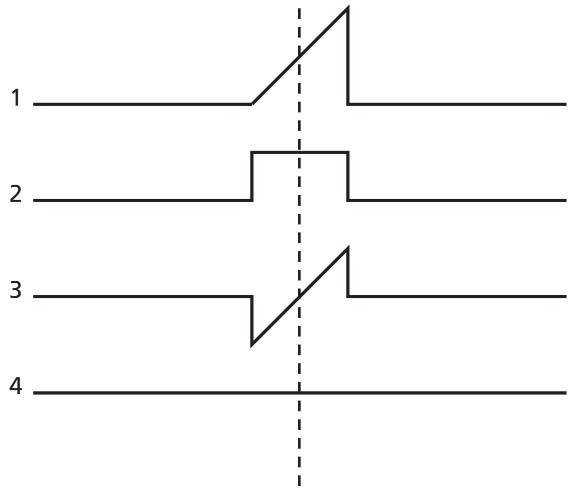
c. If you plucked the string 15 cm from one end of the string, where would the two pulses meet?

15 cm from the other end, where the distances traveled are the same.

87. Sketch the result for each of the four cases shown in **Figure 14-24,** when the centers of each of the two wave pulses lie on the dashed line so that the pulses exactly overlap.



■ **Figure 14-24**



Mixed Review

page 399–400

Level 1

88. What is the period of a pendulum with a length of 1.4 m?

$$T = 2\pi\sqrt{\frac{l}{g}}$$

$$= 2\pi\sqrt{\frac{1.4 \text{ m}}{9.80 \text{ m/s}^2}} = 2.4 \text{ s}$$

89. The frequency of yellow light is 5.1×10^{14} Hz. Find the wavelength of yellow light. The speed of light is 3.00×10^{8} m/s.

$$\lambda = \frac{c}{f}$$

$$= \frac{3.00\times10^{8}\ \text{m/s}}{5.1\times10^{14}\ \text{Hz}}$$

$$= 5.9\times10^{-7}\ \text{m}$$

90. Radio Wave AM-radio signals are broadcast at frequencies between 550 kHz (kilohertz) and 1600 kHz and travel 3.0×10^8 m/s.

a. What is the range of wavelengths for these signals?

$$v = \lambda f$$

$$\lambda_1 = \frac{v}{f_1} = \frac{3.0\times10^{8}\ \text{m/s}}{5.5\times10^{5}\ \text{Hz}}$$

$$= 550\ \text{m}$$

$$\lambda_2 = \frac{v}{f_2} = \frac{3.0\times10^{8}\ \text{m/s}}{1.6\times10^{6}\ \text{Hz}}$$

$$= 190\ \text{m}$$

Range is 190 m to 550 m.

b. FM frequencies range between 88 MHz (megahertz) and 108 MHz and travel at the same speed. What is the range of FM wavelengths?

$$\lambda = \frac{v}{f} = \frac{3.0\times10^{8}\ \text{m/s}}{8.8\times10^{7}\ \text{Hz}}$$

$$= 3.4\ \text{m}$$

$$\lambda = \frac{v}{f} = \frac{3.0\times10^{8}\ \text{m/s}}{1.08\times10^{8}\ \text{Hz}}$$

$$= 2.8\ \text{m}$$

Range is 2.8 m to 3.4 m.

91. You are floating just offshore at the beach. Even though the waves are steadily moving in toward the beach, you don't move any closer to the beach.

a. What type of wave are you experiencing as you float in the water?

transverse waves

b. Explain why the energy in the wave does not move you closer to shore.

The displacement is perpendicular to the direction of the wave—in this case, up and down.

c. In the course of 15 s you count ten waves that pass you. What is the period of the waves?

$$T = \frac{15\ \text{s}}{10\ \text{waves}} = 1.5\ \text{s}$$

d. What is the frequency of the waves?

$$f = \frac{1}{T} = \frac{1}{1.5\ \text{s}} = 0.67\ \text{Hz}$$

e. You estimate that the wave crests are 3 m apart. What is the velocity of the waves?

$$v = \lambda f = (3\ \text{m})(0.67\ \text{Hz}) = 2\ \text{m/s}$$

f. After returning to the beach, you learn that the waves are moving at 1.8 m/s. What is the actual wavelength of the waves?

$$\lambda = \frac{v}{f} = \frac{1.8\ \text{m/s}}{0.67\ \text{Hz}} = 2.7\ \text{m}$$

Level 2

92. Bungee Jumper A high-altitude bungee jumper jumps from a hot-air balloon using a 540-m-bungee cord. When the jump is complete and the jumper is just suspended from the cord, it is stretched 1710 m. What is the spring constant of the bungee cord if the jumper has a mass of 68 kg?

$$k = \frac{F}{x} = \frac{mg}{x} = \frac{(68\ \text{kg})(9.80\ \text{m/s}^2)}{1710\ \text{m} - 540\ \text{m}}$$

$$= 0.57\ \text{N/m}$$

93. The time needed for a water wave to change from the equilibrium level to the crest is 0.18 s.

a. What fraction of a wavelength is this?

$\frac{1}{4}$ **wavelength**

b. What is the period of the wave?

$$T = (4)(0.18\ \text{s}) = 0.72\ \text{s}$$

c. What is the frequency of the wave?

$$f = \frac{1}{T} = \frac{1}{0.72\ \text{s}} = 1.4\ \text{Hz}$$

94. When a 225-g mass is hung from a spring, the spring stretches 9.4 cm. The spring and mass then are pulled 8.0 cm from this new equilibrium position and released. Find the spring constant of the spring and the maximum speed of the mass.

$k = \frac{F}{x} = \frac{mg}{x}$

$= \frac{(0.225\text{ kg})(9.80\text{ m/s}^2)}{0.094\text{ m}} = 23\text{ N/m}$

Maximum velocity occurs when the mass passes through the equilibrium point, where all the energy is kinetic energy. Using the conservation of energy:

$PE_{sp} = KE_{mass}$

$\frac{1}{2}kx^2 = \frac{1}{2}mv^2$

$v^2 = \frac{kx^2}{m}$

$v = \sqrt{\frac{kx^2}{m}} = \sqrt{\frac{(23\text{ N/m})(0.080\text{ m})^2}{0.225\text{ kg}}}$

$= 0.81\text{ m/s}$

95. **Amusement Ride** You notice that your favorite amusement-park ride seems bigger. The ride consists of a carriage that is attached to a structure so it swings like a pendulum. You remember that the carriage used to swing from one position to another and back again eight times in exactly 1 min. Now it only swings six times in 1 min. Give your answers to the following questions to two significant digits.

a. What was the original period of the ride?

$T = \frac{1}{f} = \frac{1}{\left(\frac{8\text{ swings}}{60.0\text{ s}}\right)} = 7.5\text{ s}$

b. What is the new period of the ride?

$T = \frac{1}{f} = \frac{1}{\left(\frac{6\text{ swings}}{60.0\text{ s}}\right)} = 1.0\times10^1\text{ s}$

c. What is the new frequency?

$f = \frac{1}{T} = \frac{1}{1.0\times10^{-1}\text{ s}} = 0.10\text{ Hz}$

d. How much longer is the arm supporting the carriage on the larger ride?

Original:

$l = g\frac{T^2}{4\pi^2}$

$= (9.80\text{ m/s}^2)\frac{(7.5\text{ s})^2}{4\pi^2}$

$= 14\text{ m}$

New:

$l = g\frac{T^2}{4\pi^2}$

$= (9.80\text{ m/s}^2)\frac{(1.0\times10^1\text{ s})^2}{4\pi^2}$

$= 25\text{ m}$

The arm on the new structure is 11 m longer.

e. If the park owners wanted to double the period of the ride, what percentage increase would need to be made to the length of the pendulum?

Because of the square relationship, there would need to be a 4 times increase in the length of the pendulum, or a 300% increase.

96. **Clocks** The speed at which a grandfather clock runs is controlled by a swinging pendulum.

a. If you find that the clock loses time each day, what adjustment would you need to make to the pendulum so it will keep better time?

The clock must be made to run faster. The period of the pendulum can be shortened, thus increasing the speed of the clock, by shortening the length of the pendulum.

b. If the pendulum currently is 15.0 cm, by how much would you need to change the length to make the period lessen by 0.0400 s?

$\Delta T = 2\pi\sqrt{\frac{l_2}{g}} - 2\pi\sqrt{\frac{l_1}{g}}$

$\frac{\Delta T}{2\pi} = \sqrt{\frac{l_2}{g}} - \sqrt{\frac{l_1}{g}}$

$\frac{\Delta T}{2\pi} = \sqrt{\frac{1}{g}}\sqrt{l_2} - \sqrt{\frac{1}{g}}\sqrt{l_1}$

$\frac{\Delta T}{2\pi} = \frac{1}{\sqrt{g}}\sqrt{l_2} - \frac{1}{\sqrt{g}}\sqrt{l_1}$

$\frac{\Delta T\sqrt{g}}{2\pi} = \sqrt{l_2} - \sqrt{l_1}$

$$\sqrt{l_2} = \frac{\Delta T\sqrt{g}}{2\pi} + \sqrt{l_1}$$

$$l_2 = \left(\frac{\Delta T\sqrt{g}}{2\pi} + \sqrt{l_1}\right)^2$$

$$= \left(\frac{(-0.0400 \text{ s})\sqrt{9.80 \text{ m/s}^2}}{2\pi} + \sqrt{0.150 \text{ m}}\right)^2$$

$$= 0.135 \text{ m}$$

The length would need to shorten by

$$l_1 - l_2 = 0.150 \text{ m} - 0.135 \text{ m} = 0.015 \text{ m}$$

97. Bridge Swinging In the summer over the New River in West Virginia, several teens swing from bridges with ropes, then drop into the river after a few swings back and forth.

a. If Pam is using a 10.0-m length of rope, how long will it take her to reach the peak of her swing at the other end of the bridge?

swing to peak $= \frac{1}{2}T$

$$= \pi\sqrt{\frac{l}{g}} = \pi\sqrt{\frac{10.0 \text{ m}}{9.80 \text{ m/s}^2}} = 3.17 \text{ s}$$

b. If Mike has a mass that is 20 kg more than Pam, how would you expect the period of his swing to differ from Pam's?

There should be no difference. *T* is not affected by mass.

c. At what point in the swing is *KE* at a maximum?

At the bottom of the swing, *KE* is at a maximum.

d. At what point in the swing is *PE* at a maximum?

At the top of the swing, *PE* is at a maximum.

e. At what point in the swing is *KE* at a minimum?

At the top of the swing, *KE* is at a minimum.

f. At what point in the swing is *PE* at a minimum?

At the bottom of the swing, *PE* is at a minimum.

98. You have a mechanical fish scale that is made with a spring that compresses when weight is added to a hook attached below the scale. Unfortunately, the calibrations have completely worn off of the scale. However, you have one known mass of 500.0 g that displaces the spring 2.0 cm.

a. What is the spring constant for the spring?

$$F = mg = kx$$

$$k = \frac{mg}{x}$$

$$= \frac{(0.5000 \text{ kg})(9.80 \text{ m/s}^2)}{0.020 \text{ m}}$$

$$= 2.4\times10^2 \text{ N/m}$$

b. If a fish displaces the spring 4.5 cm, what is the mass of the fish?

$$F = mg = kx$$

$$m = \frac{kx}{g}$$

$$= \frac{(2.4\times10^{2}\ \text{N/m})(4.5\times10^{-2}\ \text{m})}{9.80\ \text{m/s}^2}$$

$$= 1.1\ \text{kg}$$

99. **Car Springs** When you add a 45-kg load to the trunk of a new small car, the two rear springs compress an additional 1.0 cm.

a. What is the spring constant for each of the springs?

$F = mg = (45\ \text{kg})(9.80\ \text{m/s}^2) = 440\ \text{N}$

force per spring = 220 N

$F = kx$, so $k = \frac{F}{x}$

$k = \frac{220\ \text{N}}{0.010\ \text{m}} = 22{,}000\ \text{N/m}$

b. How much additional potential energy is stored in each of the car springs after loading the trunk?

$$PE = \frac{1}{2}kx^2$$

$$= \left(\frac{1}{2}\right)(22{,}000\ \text{N/m})(0.010\ \text{m})^2$$

$$= 1.1\ \text{J}$$

Level 3

100. The velocity of a wave on a string depends on how tightly the string is stretched, and on the mass per unit length of the string. If F_T is the tension in the string, and μ is the mass/unit length, then the velocity, v, can be determined by the following equation.

$$v = \sqrt{\frac{F_T}{\mu}}$$

A piece of string 5.30-m long has a mass of 15.0 g. What must the tension in the string be to make the wavelength of a 125-Hz wave 120.0 cm?

$v = \lambda f = (1.200\ \text{m})(125\ \text{Hz})$

$= 1.50\times10^{2}\ \text{m/s}$

and $\mu = \frac{m}{L}$

$$= \frac{1.50\times10^{-2}\ \text{kg}}{5.30\ \text{m}}$$

$$= 2.83\times10^{-3}\ \text{kg/m}$$

Now $v = \sqrt{\frac{F_T}{\mu}}$, so

$$F_T = v^2\mu$$

$$= (1.50\times10^{2}\ \text{m/s})^2(2.83\times10^{-3}\ \text{kg/m})$$

$$= 63.7\ \text{N}$$

Thinking Critically

page 400

101. **Analyze and Conclude** A 20-N force is required to stretch a spring by 0.5 m.

a. What is the spring constant?

$F = kx$, so $k = \frac{F}{x} = \frac{20\ \text{N}}{0.5\ \text{m}} = 40\ \text{N/m}$

b. How much energy is stored in the spring?

$$PE_{sp} = \frac{1}{2}kx^2$$

$$= \left(\frac{1}{2}\right)(40\ \text{N/m})(0.5\ \text{m})^2 = 5\ \text{J}$$

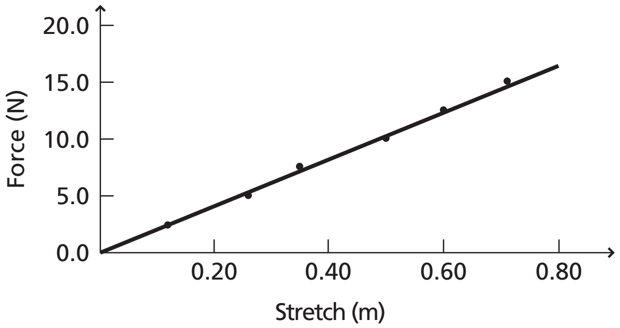
c. Why isn't the work done to stretch the spring equal to the force times the distance, or 10 J?

The force is not constant as the spring is stretched. The average force, 10 N, times the distance does give the correct work.

102. **Make and Use Graphs** Several weights were suspended from a spring, and the resulting extensions of the spring were measured. **Table 14-1** shows the collected data.

Table 14-1	
Weights on a Spring	
Force, F (N)	Extension, x (m)
2.5	0.12
5.0	0.26
7.5	0.35
10.0	0.50
12.5	0.60
15.0	0.71

a. Make a graph of the force applied to the spring versus the spring length. Plot the force on the *y*-axis.



b. Determine the spring constant from the graph.

The spring constant is the slope.

$$k = \text{slope} = \frac{\Delta F}{\Delta x} = \frac{15.0\text{ N} - 2.5\text{ N}}{0.71\text{ m} - 0.12\text{ m}} = 21\text{ N/m}$$

c. Using the graph, find the elastic potential energy stored in the spring when it is stretched to 0.50 m.

The potential energy is the area under the graph.

$$PE_{sp} = \text{area} = \frac{1}{2}bh$$

$$= \left(\frac{1}{2}\right)(0.50\text{ m})(10.0\text{ N})$$

$$= 2.5\text{ J}$$

103. Apply Concepts Gravel roads often develop regularly spaced ridges that are perpendicular to the road, as shown in **Figure 14-25.** This effect, called washboarding, occurs because most cars travel at about the same speed and the springs that connect the wheels to the cars oscillate at about the same frequency. If the ridges on a road are 1.5 m apart and cars travel on it at about 5 m/s, what is the frequency of the springs' oscillation?

■ **Figure 14-25**

$$v = \lambda f$$

$$f = \frac{v}{\lambda} = \frac{5\text{ m/s}}{1.5\text{ m}} = 3\text{ Hz}$$

Writing in Physics

page 400

104. **Research** Christiaan Huygens' work on waves and the controversy between him and Newton over the nature of light. Compare and contrast their explanations of such phenomena as reflection and refraction. Whose model would you choose as the best explanation? Explain why.

Huygens proposed the wave theory of light and Newton proposed the particle theory of light. The law of reflection can be explained using both theories. Huygen's principle and Newton's particle theory are opposed, however, in their explanation of the law of refraction.

Cumulative Review

page 400

105. A 1400-kg drag racer automobile can complete a one-quarter mile (402 m) course in 9.8 s. The final speed of the automobile is 250 mi/h (112 m/s). (Chapter 11)

a. What is the kinetic energy of the automobile?

$$KE = \frac{1}{2}mv^2$$

$$= \left(\frac{1}{2}\right)(1400\text{ kg})(112\text{ m/s})^2$$

$$= 8.8\times10^6\text{ J}$$

b. What is the minimum amount of work that was done by its engine? Why can't you calculate the total amount of work done?

The minimum amount of work must equal *KE*, or 8.8×10^6 J. The engine had to do more work than was dissipated in work done against friction.

c. What was the average acceleration of the automobile?

$$\bar{a} = \frac{\Delta v}{\Delta t}$$

$$= \frac{112\text{ m/s}}{9.8\text{ s}}$$

$$= 11\text{ m/s}^2$$

106. How much water would a steam engine have to evaporate in 1 s to produce 1 kW of power? Assume that the engine is 20 percent efficient. (Chapter 12)

$$\frac{W}{t} = 1000\text{ J/s}$$

If the engine is only 20 percent efficient it must use five times more heat to produce the 1000 J/s.

$$\frac{Q}{t} = 5000\text{ J/s} = \frac{mH_v}{t}$$

Therefore, $\frac{m}{t} = \frac{5000\text{ J/s}}{H_v}$

$$= \frac{5000\text{ J/s}}{2.26\times10^6\text{ J/kg}}$$

$$= 2\times10^{-3}\text{ kg/s}$$

Challenge Problem

page 380

A car of mass *m* rests at the top of a hill of height *h* before rolling without friction into a crash barrier located at the bottom of the hill. The crash barrier contains a spring with a spring constant, *k*, which is designed to bring the car to rest with minimum damage.

1. Determine, in terms of *m*, *h*, *k*, and *g*, the maximum distance, *x*, that the spring will be compressed when the car hits it.

Conservation of energy implies that the gravitational potential energy of the car at the top of the hill will be equal to the elastic potential energy in the spring when it has brought the car to rest. The equations for these energies can be set equal and solved for *x*.

$PE_g = PE_{sp}$, **so** $mgh = \frac{1}{2}kx^2$

$$x = \sqrt{\frac{2mgh}{k}}$$

2. If the car rolls down a hill that is twice as high, how much farther will the spring be compressed?

   The height is doubled and *x* is proportional to the square root of the height, so *x* will increase by $\sqrt{2}$.

3. What will happen after the car has been brought to rest?

   In the case of an ideal spring, the spring will propel the car back to the top of the hill.

CHAPTER 15 Sound

Practice Problems

15.1 Properties and Detection of Sound pages 403–410

page 405

1. Find the wavelength in air at 20°C of an 18-Hz sound wave, which is one of the lowest frequencies that is detectable by the human ear.

$$\lambda = \frac{v}{f} = \frac{343\text{ m/s}}{18\text{ Hz}} = 19\text{ m}$$

2. What is the wavelength of an 18-Hz sound wave in seawater at 25°C?

$$\lambda = \frac{v}{f} = \frac{1533\text{ m/s}}{18\text{ Hz}} = 85\text{ m}$$

3. Find the frequency of a sound wave moving through iron at 25°C with a wavelength of 1.25 m.

$$f = \frac{v}{\lambda} = \frac{5130\text{ m/s}}{1.25\text{ m}} = 4.10\times10^3\text{ Hz}$$

4. If you shout across a canyon and hear the echo 0.80 s later, how wide is the canyon?

$$v = \frac{d}{t}$$

so $d = vt = (343\text{ m/s})(0.40\text{ s}) = 140\text{ m}$

5. A 2280-Hz sound wave has a wavelength of 0.655 m in an unknown medium. Identify the medium.

$$\lambda = \frac{v}{f}$$

so $v = \lambda f = (0.655\text{ m})(2280\text{ Hz})$

$= 1490\text{ m/s}$

This speed corresponds to water at 25°C.

page 409

6. Repeat Example Problem 1, but with the car moving away from you. What frequency would you hear?

$v_s = -24.6\text{ m/s}$

$$f_d = 524\text{ Hz}\left(\frac{1}{1 - \frac{(-24.6\text{ m/s})}{343\text{ m/s}}}\right)$$

$= 489\text{ Hz}$

7. You are in an auto traveling at 25.0 m/s toward a pole-mounted warning siren. If the siren's frequency is 365 Hz, what frequency do you hear? Use 343 m/s as the speed of sound.

$v = 343\text{ m/s}, f_s = 365\text{ Hz}, v_s = 0,$

$v_d = -25.0\text{ m/s}$

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right)$$

$$= (365\text{ Hz})\left(\frac{343\text{ m/s} + 25.0\text{ m/s}}{343\text{ m/s}}\right)$$

$= 392\text{ Hz}$

8. You are in an auto traveling at 55 mph (24.6 m/s). A second auto is moving toward you at the same speed. Its horn is sounding at 475 Hz. What frequency do you hear? Use 343 m/s as the speed of sound.

$v = 343\text{ m/s}, f_s = 475\text{ Hz}, v_s = +24.6\text{ m/s},$

$v_d = -24.6\text{ m/s}$

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right)$$

$$= (475\text{ Hz})\left(\frac{343\text{ m/s} + 24.6\text{ m/s}}{343\text{ m/s} - 24.6\text{ m/s}}\right)$$

$= 548\text{ Hz}$

9. A submarine is moving toward another submarine at 9.20 m/s. It emits a 3.50-MHz ultrasound. What frequency would the second sub, at rest, detect? The speed of sound in water is 1482 m/s.

$v = 1482\text{ m/s}, f_s = 3.50\text{ MHz},$

$v_s = 9.20\text{ m/s}, v_d = 0\text{ m/s}$

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right)$$

$$= (3.50\ \text{MHz})\left(\frac{1482\ \text{m/s}}{1482\ \text{m/s} - 9.20\ \text{m/s}}\right)$$

$$= 3.52\ \text{MHz}$$

10. A sound source plays middle C (262 Hz). How fast would the source have to go to raise the pitch to C sharp (271 Hz)? Use 343 m/s as the speed of sound.

v = 343 m/s, f_s = 262 Hz, f_d = 271 Hz,

v_d = 0 m/s, v_s is unknown

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right)$$

Solve this equation for v_s.

$$v_s = v - \frac{f_s}{f_d}(v - v_d)$$

$$= 343\ \text{m/s} - \left(\frac{262\ \text{Hz}}{271\ \text{Hz}}\right)(343\ \text{m/s} - 0\ \text{m/s})$$

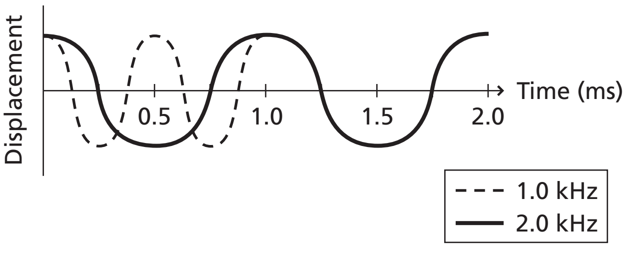
$$= 11.4\ \text{m/s}$$

Section Review

15.1 Properties and Detection of Sound pages 403–410

page 410

11. Graph The eardrum moves back and forth in response to the pressure variations of a sound wave. Sketch a graph of the displacement of the eardrum versus time for two cycles of a 1.0-kHz tone and for two cycles of a 2.0-kHz tone.



12. Effect of Medium List two sound characteristics that are affected by the medium through which the sound passes and two characteristics that are not affected.

affected: speed and wavelength; unaffected: period and frequency

13. Sound Properties What physical characteristic of a sound wave should be changed to change the pitch of the sound? To change the loudness?

frequency; amplitude

14. Decibel Scale How much greater is the sound pressure level of a typical rock band's music (110 dB) than a normal conversation (50 dB)?

The sound pressure level increases by a factor of 10 for every 20-dB increase in sound level. Therefore, 60 dB corresponds to a 1000-fold increase in SPL.

15. Early Detection In the nineteenth century, people put their ears to a railroad track to get an early warning of an approaching train. Why did this work?

The velocity of sound is greater in solids than in gases. Therefore, sound travels faster in steel rails than in air, and the rails help focus the sound so it does not die out as quickly as in air.

16. Bats A bat emits short pulses of high-frequency sound and detects the echoes.

a. In what way would the echoes from large and small insects compare if they were the same distance from the bat?

They would differ in intensity. Larger insects would reflect more of the sound energy back to the bat.

b. In what way would the echo from an insect flying toward the bat differ from that of an insect flying away from the bat?

An insect flying toward the bat would return an echo of higher frequency (Doppler shift). An insect flying away from the bat would return an echo of lower frequency.

17. Critical Thinking Can a trooper using a radar detector at the side of the road determine the speed of a car at the instant the car passes the trooper? Explain.

No. The car must be approaching or

receding from the detector for the Doppler effect to be observed. Transverse motion produces no Doppler effect.

Practice Problems

15.2 The Physics of Music pages 411–419

page 416

18. A 440-Hz tuning fork is held above a closed pipe. Find the spacing between the resonances when the air temperature is 20°C.

Resonance spacing = $\frac{\lambda}{2}$ **so using** $\lambda = \frac{v}{f}$ **the resonance spacing is**

$$\frac{\lambda}{2} = \frac{v}{2f} = \frac{343\text{ m/s}}{(2)(440\text{ Hz})} = 0.39\text{ m}$$

19. A 440-Hz tuning fork is used with a resonating column to determine the velocity of sound in helium gas. If the spacings between resonances are 110 cm, what is the velocity of sound in helium gas?

Resonance spacing = $\frac{\lambda}{2}$ **= 1.1 m**

so λ **= 2.2 m**

$v = \lambda f = (2.2\text{ m})(440\text{ Hz}) = 970\text{ m/s}$

20. The frequency of a tuning fork is unknown. A student uses an air column at 27°C and finds resonances spaced by 20.2 cm. What is the frequency of the tuning fork? Use the speed calculated in Example Problem 2 for the speed of sound in air at 27°C.

$v = 347\text{ m/s}$ **at 27°C**

Resonance spacing gives $\frac{\lambda}{2}$ **= 0.202 m, or** λ **= 0.404 m**

$$f = \frac{v}{\lambda} = \frac{347\text{ m/s}}{0.404\text{ m}} = 859\text{ Hz}$$

21. A bugle can be thought of as an open pipe. If a bugle were straightened out, it would be 2.65-m long.

a. If the speed of sound is 343 m/s, find the lowest frequency that is resonant for a bugle (ignoring end corrections).

$\lambda_1 = 2L = (2)(2.65\text{ m}) = 5.30\text{ m}$

The lowest frequency is

$$f_1 = \frac{v}{\lambda_1} = \frac{343\text{ m/s}}{5.30\text{ m}} = 64.7\text{ Hz}$$

b. Find the next two resonant frequencies for the bugle.

$$f_2 = \frac{v}{\lambda_2} = \frac{v}{L} = \frac{343\text{ m/s}}{2.65\text{ m}} = 129\text{ Hz}$$

$$f_3 = \frac{v}{\lambda_3} = \frac{3v}{2L} = \frac{(3)(343\text{ m/s})}{(2)(2.65\text{ m})} = 194\text{ Hz}$$

Section Review

15.2 The Physics of Music pages 411–419

page 419

22. Origins of Sound What is the vibrating object that produces sounds in each of the following?

a. a human voice

vocal cords

b. a clarinet

a reed

c. a tuba

the player's lips

d. a violin

a string

23. Resonance in Air Columns Why is the tube from which a tuba is made much longer than that of a cornet?

The longer the tube, the lower the resonant frequency it will produce.

24. Resonance in Open Tubes How must the length of an open tube compare to the wavelength of the sound to produce the strongest resonance?

The length of the tube should be one-half the wavelength.

25. Resonance on Strings A violin sounds a note of F sharp, with a pitch of 370 Hz. What are the frequencies of the next three harmonics produced with this note?

A string's harmonics are whole number multiples of the fundamental, so the frequencies are:

$f_2 = 2f_1 = (2)(370\text{ Hz}) = 740\text{ Hz}$

$f_3 = 3f_1 = (3)(370\text{ Hz}) = 1110\text{ Hz}$
$= 1100\text{ Hz}$

$f_4 = 4f_1 = (4)(370\text{ Hz}) = 1480\text{ Hz}$
$= 1500\text{ Hz}$

26. **Resonance in Closed Pipes** One closed organ pipe has a length of 2.40 m.

a. What is the frequency of the note played by this pipe?

$\lambda = 4L = (4)(2.40\text{ m}) = 9.60\text{ m}$

$\lambda = \frac{v}{f}$

$f = \frac{v}{\lambda} = \frac{343\text{ m/s}}{9.60\text{ m}} = 35.7\text{ Hz}$

b. When a second pipe is played at the same time, a 1.40-Hz beat note is heard. By how much is the second pipe too long?

$f = 35.7\text{ Hz} - 1.40\text{ Hz} = 34.3\text{ Hz}$

$\lambda = \frac{v}{f} = \frac{343\text{ m/s}}{34.3\text{ Hz}} = 10.0\text{ m}$

$\lambda = 4L$

$L = \frac{\lambda}{4} = \frac{10.0\text{ m}}{4} = 2.50\text{ m}$

The difference in lengths is
2.50 m − 2.40 m = 0.10 m

27. **Timbre** Why do various instruments sound different even when they play the same note?

Each instrument produces its own set of fundamental and harmonic frequencies, so they have different timbres.

28. **Beats** A tuning fork produces three beats per second with a second, 392-Hz tuning fork. What is the frequency of the first tuning fork?

It is either 389 Hz or 395 Hz. You can't tell which without more information.

29. **Critical Thinking** Strike a tuning fork with a rubber hammer and hold it at arm's length. Then press its handle against a desk, a door, a filing cabinet, and other objects. What do you hear? Why?

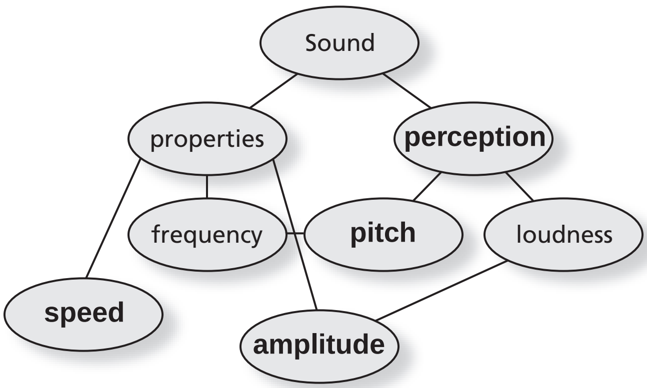
The tuning fork's sound is amplified greatly when it is pressed against other objects because they resonate like a sounding board. They sound different because they resonate with different harmonics; therefore, they have different timbres.

Chapter Assessment

Concept Mapping

page 424

30. Complete the concept map below using the following terms: *amplitude, perception, pitch, speed.*



Mastering Concepts

page 424

31. What are the physical characteristics of sound waves? (15.1)

Sound waves can be described by frequency, wavelength, amplitude, and speed.

32. When timing the 100-m run, officials at the finish line are instructed to start their stopwatches at the sight of smoke from the starter's pistol and not at the sound of its firing. Explain. What would happen to the times for the runners if the timing started when sound was heard? (15.1)

Light travels at 3.00×10^8 m/s, while sound travels at 343 m/s. Officials would see the smoke before they would hear the pistol fire. The times would be less than actual if sound were used.

33. Name two types of perception of sound and the physical characteristics of sound waves that correspond to them. (15.1)

pitch—frequency, loudness—amplitude

34. Does the Doppler shift occur for only some types of waves or for all types of waves? (15.1)

all types of waves

35. Sound waves with frequencies higher than can be heard by humans, called ultrasound, can be transmitted through the human body. How could ultrasound be used to measure the speed of blood flowing in veins or arteries? Explain how the waves change to make this measurement possible. (15.1)

Doctors can measure the Doppler shift from sound reflected by the moving blood cells. Because the blood is moving, sound gets Doppler shifted, the compressions either get piled up or spaced apart. This alters the frequency of the wave.

36. What is necessary for the production and transmission of sound? (15.2)

a vibrating object and a material medium

37. **Singing** How can a certain note sung by an opera singer cause a crystal glass to shatter? (15.2)

The frequency of the note is the same as the natural resonance of the crystal, causing its molecules to increase their amplitude of vibration as energy from the sound is accepted.

38. **Marching** In the military, as marching soldiers approach a bridge, the command "route step" is given. The soldiers then walk out-of-step with each other as they cross the bridge. Explain. (15.2)

While marching in step, a certain frequency is established that could resonate the bridge into destructive oscillation. No single frequency is maintained under "route step."

39. **Musical Instruments** Why don't most musical instruments sound like tuning forks? (15.2)

Tuning forks produce simple, single-frequency waves. Musical instruments produce complex waves containing many different frequencies. This gives them their timbres.

40. **Musical Instruments** What property distinguishes notes played on both a trumpet and a clarinet if they have the same pitch and loudness? (15.2)

the sound quality or timbre

41. **Trombones** Explain how the slide of a trombone, shown in **Figure 15-21,** changes the pitch of the sound in terms of a trombone being a resonance tube. (15.2)

■ **Figure 15-21**

The slide of a trombone varies pitch by changing the length of the resonating column of vibrating air.

Applying Concepts

pages 424–425

42. **Estimation** To estimate the distance in kilometers between you and a lightning flash, count the seconds between the flash and the thunder and divide by 3. Explain how this rule works. Devise a similar rule for miles.

The speed of sound = 343 m/s = 0.343 km/s = (1/2.92) km/s; or, sound travels approximately 1 km in 3 s. Therefore, divide the number of seconds by three. For miles, sound travels approximately 1 mile in 5 s. Therefore, divide the number of seconds by five.

43. The speed of sound increases by about 0.6 m/s for each degree Celsius when the air temperature rises. For a given sound, as the temperature increases, what happens to the following?

a. the frequency

There is no change in frequency.

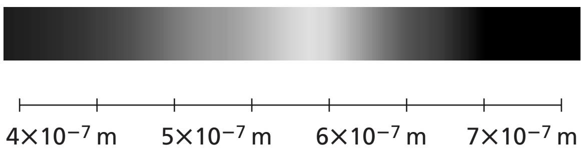
b. the wavelength

The wavelength increases.

44. **Movies** In a science-fiction movie, a satellite blows up. The crew of a nearby ship immediately hears and sees the explosion. If you had been hired as an advisor, what two physics errors would you have noticed and corrected?

First, if you had heard a sound, you would have heard it after you saw the explosion. Sound waves travel much more slowly than electromagnetic waves. Second, in space the density of matter is so small that the sound waves do not propagate. Consequently, no sound should have been heard.

45. **The Redshift** Astronomers have observed that the light coming from distant galaxies appears redder than light coming from nearer galaxies. With the help of **Figure 15-22,** which shows the visible spectrum, explain why astronomers conclude that distant galaxies are moving away from Earth.



■ **Figure 15-23**

Red light has a longer wavelength and therefore, a lower frequency than other colors. The Doppler shift of their light to lower frequencies indicates that distant galaxies are moving away from us.

46. Does a sound of 40 dB have a factor of 100 (10^2) times greater pressure variation than the threshold of hearing, or a factor of 40 times greater?

A 40-dB sound has sound pressures 100 times greater.

47. If the pitch of sound is increased, what are the changes in the following?

a. the frequency

Frequency will increase.

b. the wavelength

Wavelength will decrease.

c. the wave velocity

Wave velocity will remain the same.

d. the amplitude of the wave

Amplitude will remain the same.

48. The speed of sound increases with temperature. Would the pitch of a closed pipe increase or decrease when the temperature of the air rises? Assume that the length of the pipe does not change.

$\lambda = 4l$ **and** $v = f\lambda$ **so** $v = 4fl$**. If** v **increases and** l **remains unchanged,** f **increases and pitch increases.**

49. **Marching Bands** Two flutists are tuning up. If the conductor hears the beat frequency increasing, are the two flute frequencies getting closer together or farther apart?

The frequencies are getting farther apart.

50. **Musical Instruments** A covered organ pipe plays a certain note. If the cover is removed to make it an open pipe, is the pitch increased or decreased?

The pitch is increased; the frequency is twice as high for an open pipe as for a closed pipe.

51. **Stringed Instruments** On a harp, **Figure 15-23a,** long strings produce low notes and short strings produce high notes. On a guitar, **Figure 15-23b,** the strings are all the same length. How can they produce notes of different pitches?

■ Figure 15-23

The strings have different tensions and masses per unit length. Thinner, tighter strings produce higher notes than do thicker, looser strings.

Mastering Problems

15.1 Properties and Detection of Sound
pages 425–426

Level 1

52. You hear the sound of the firing of a distant cannon 5.0 s after seeing the flash. How far are you from the cannon?

$d = vt = (343\text{ m/s})(5.0\text{ s}) = 1.7\text{ km}$

53. If you shout across a canyon and hear an echo 3.0 s later, how wide is the canyon?

$d = vt = (343\text{ m/s})(3.0\text{ s})$ is the total distance traveled. The distance to the wall is $\frac{1}{2}(343\text{ m/s})(3.0\text{ s}) = 5.1\times10^2\text{ m}$

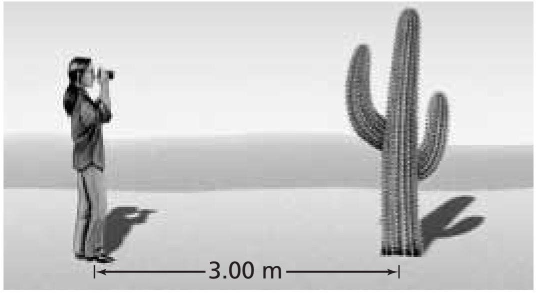
54. A sound wave has a frequency of 4700 Hz and travels along a steel rod. If the distance between compressions, or regions of high pressure, is 1.1 m, what is the speed of the wave?

$v = \lambda f = (1.1\text{ m})(4700\text{ Hz}) = 5200\text{ m/s}$

55. **Bats** The sound emitted by bats has a wavelength of 3.5 mm. What is the sound's frequency in air?

$f = \frac{v}{\lambda} = \frac{343\text{ m/s}}{0.0035\text{ m}} = 9.8\times10^4\text{ Hz}$

56. **Photography** As shown in **Figure 15-24,** some cameras determine the distance to the subject by sending out a sound wave and measuring the time needed for the echo to return to the camera. How long would it take the sound wave to return to such a camera if the subject were 3.00 m away?



■ Figure 15-24

The total distance the sound must travel is 6.00 m.

$v = \frac{d}{t}$

so $t = \frac{d}{v} = \frac{6.00\text{ m}}{343\text{ m/s}} = 0.0175\text{ s}$

57. Sound with a frequency of 261.6 Hz travels through water at 25°C. Find the sound's wavelength in water. Do not confuse sound waves moving through water with surface waves moving through water.

$\lambda = \frac{v}{f} = \frac{1493\text{ m/s}}{261.6\text{ Hz}} = 5.707\text{ m}$

58. If the wavelength of a 4.40×10^2-Hz sound in freshwater is 3.30 m, what is the speed of sound in freshwater?

$v = \lambda f = (3.30\text{ m})(4.40\times10^2\text{ Hz})$
$= 1.45\times10^3\text{ m/s}$

59. Sound with a frequency of 442 Hz travels through an iron beam. Find the wavelength of the sound in iron.

$\lambda = \frac{v}{f} = \frac{5130\text{ m/s}}{442\text{ Hz}} = 11.6\text{ m}$

60. **Aircraft** Adam, an airport employee, is working near a jet plane taking off. He experiences a sound level of 150 dB.

a. If Adam wears ear protectors that reduce the sound level to that of a typical rock concert, what decrease in dB is provided?

A typical rock concert is 110 dB, so 40 dB reduction is needed.

b. If Adam then hears something that sounds like a barely audible whisper, what will a person not wearing the ear protectors hear?

A barely audible whisper is 10 dB, so the actual level would be 50 dB, or that of an average classroom.

61. **Rock Music** A rock band plays at an 80-dB sound level. How many times greater is the sound pressure from another rock band playing at each of the following sound levels?

a. 100 dB

Each 20 dB increases pressure by a factor of 10, so 10 times greater pressure.

b. 120 dB

(10)(10) = 100 times greater pressure

62. A coiled-spring toy is shaken at a frequency of 4.0 Hz such that standing waves are observed with a wavelength of 0.50 m. What is the speed of propagation of the wave?

$v = \lambda f = (0.50 \text{ m})(4.0 \text{ s}^{-1}) = 2.0 \text{ m/s}$

63. A baseball fan on a warm summer day (30°C) sits in the bleachers 152 m away from home plate.

a. What is the speed of sound in air at 30°C?

The speed increases 0.6 m/s per °C, so the increase from 20°C to 30°C is 6 m/s. Thus, the speed is 343 + 6 = 349 m/s.

b. How long after seeing the ball hit the bat does the fan hear the crack of the bat?

$t = \frac{d}{v} = \frac{152 \text{ m}}{349 \text{ m}} = 0.436 \text{ s}$

64. On a day when the temperature is 15°C, a person stands some distance, *d*, as shown in **Figure 15-25,** from a cliff and claps his hands. The echo returns in 2.0 s. How far away is the cliff?

■ **Figure 15-25**

At 15°C, the speed of sound is 3 m/s slower than at 20°C. Thus, the speed of sound is 340 m/s.

$v = 340 \text{ m/s}$ **and** $2t = 2.0 \text{ s}$

$d = vt = (340 \text{ m/s})(1.0 \text{ s}) = 3.4\times10^{2} \text{ m}$

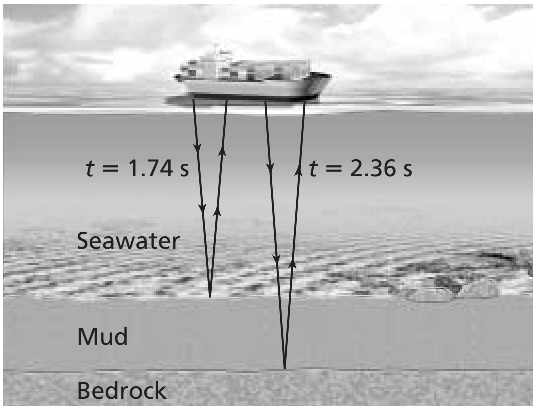
Level 2

65. Medical Imaging Ultrasound with a frequency of 4.25 MHz can be used to produce images of the human body. If the speed of sound in the body is the same as in salt water, 1.50 km/s, what is the length of a 4.25-MHz pressure wave in the body?

$\lambda = \frac{v}{f} = \frac{1.50\times10^{3} \text{ m/s}}{4.25\times10^{6} \text{ Hz}} = 3.53\times10^{-4} \text{ m}$

$= 0.353 \text{ mm}$

66. Sonar A ship surveying the ocean bottom sends sonar waves straight down into the seawater from the surface. As illustrated in **Figure 15-26,** the first reflection, off of the mud at the sea floor, is received 1.74 s after it was sent. The second reflection, from the bedrock beneath the mud, returns after 2.36 s. The seawater is at a temperature of 25°C, and the speed of sound in mud is 1875 m/s.



■ **Figure 15-26**

a. How deep is the water?

The speed of sound in the seawater is 1533 m/s and the time for a one-way trip is 0.87 s, so

$d_w = vt_w = (1533 \text{ m/s})(0.87 \text{ s})$

$= 1300 \text{ m}$

b. How thick is the mud?

The round-trip time in the mud is

2.36 s − 1.74 s = 0.62 s

The one-way time in the mud is 0.31 s,

so $d_m = vt_m = (1875 \text{ m/s})(0.31 \text{ s})$

$= 580 \text{ m}$

67. Determine the variation in sound pressure of a conversation being held at a sound level of 60 dB.

The pressure variation at 0 dB is 2×10^{-5} Pa. For every 20-dB increase, the pressure variation increases by a factor of 10. Therefore, 60 dB has a pressure variation amplitude of 2×10^{-2} Pa.

68. A fire truck is moving at 35 m/s, and a car in front of the truck is moving in the same direction at 15 m/s. If a 327-Hz siren blares from the truck, what frequency is heard by the driver of the car?

$v_s = 35$ m/s, $v = 343$ m/s, $v_d = 15$ m/s, $f_s = 327$ Hz

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right)$$

$$= (327\text{ Hz})\left(\frac{343 - 15}{343 - 35}\right) = 350\text{ Hz}$$

Level 3

69. A train moving toward a sound detector at 31.0 m/s blows a 305-Hz whistle. What frequency is detected on each of the following?

a. a stationary train

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right)$$

$$= \frac{(305\text{ Hz})(343\text{ m/s} - 0)}{343\text{ m/s} - 31.0\text{ m/s}}$$

$$= 335\text{ Hz}$$

b. a train moving toward the first train at 21.0 m/s

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right)$$

$$= \frac{(305\text{ Hz})(343\text{ m/s} - (-21.0\text{ m/s}))}{343\text{ m/s} - 31.0\text{ m/s}}$$

$$= 356\text{ Hz}$$

70. The train in the previous problem is moving away from the detector. What frequency is now detected on each of the following?

a. a stationary train

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right)$$

$$= \frac{(305\text{ Hz})(343\text{ m/s} - 0)}{343\text{ m/s} - (-31.0\text{ m/s})}$$

$$= 2.80\times10^2\text{ Hz}$$

b. a train moving away from the first train at a speed of 21.0 m/s

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right)$$

$$= \frac{(305\text{ Hz})(343\text{ m/s} - 21.0\text{ m/s})}{343\text{ m/s} - (-31.0\text{ m/s})}$$

$$= 2.63\times10^2\text{ Hz}$$

15.2 The Physics of Music

pages 426–427

Level 1

71. A vertical tube with a tap at the base is filled with water, and a tuning fork vibrates over its mouth. As the water level is lowered in the tube, resonance is heard when the water level has dropped 17 cm, and again after 49 cm of distance exists from the water to the top of the tube. What is the frequency of the tuning fork?

49 cm − 17 cm = 32 cm or 0.32 m

$\frac{1}{2}\lambda$ **exists between points of resonance**

$$\frac{1}{2}\lambda = 0.32\text{ m}$$

$$\lambda = 0.64\text{ m}$$

$$f = \frac{v}{\lambda} = \frac{343\text{ m/s}}{0.64\text{ m}} = 540\text{ Hz}$$

72. **Human Hearing** The auditory canal leading to the eardrum is a closed pipe that is 3.0 cm long. Find the approximate value (ignoring end correction) of the lowest resonance frequency.

$$L = \frac{\lambda}{4}$$

$$\lambda = \frac{v}{f}$$

$$f = \frac{v}{4L} = \frac{343\text{ m/s}}{(4)(0.030\text{ m})} = 2.9\text{ kHz}$$

73. If you hold a 1.2-m aluminum rod in the center and hit one end with a hammer, it will oscillate like an open pipe. Antinodes of pressure correspond to nodes of molecular motion, so there is a pressure antinode in the center of the bar. The speed of sound in aluminum is 5150 m/s. What would be the bar's lowest frequency of oscillation?

The rod length is $\frac{1}{2}\lambda$, so $\lambda = 2.4$ m

$$f = \frac{v}{\lambda} = \frac{5150\text{ m/s}}{2.4\text{ m}} = 2.1\text{ kHz}$$

74. One tuning fork has a 445-Hz pitch. When a second fork is struck, beat notes occur with a frequency of 3 Hz. What are the two possible frequencies of the second fork?

445 Hz − 3 Hz = 442 Hz

and 445 Hz + 3 Hz = 448 Hz

75. **Flutes** A flute acts as an open pipe. If a flute sounds a note with a 370-Hz pitch, what are the frequencies of the second, third, and fourth harmonics of this pitch?

$f_2 = 2f_1 = (2)(370\text{ Hz}) = 740\text{ Hz}$

$f_3 = 3f_1 = (3)(370\text{ Hz}) = 1110\text{ Hz}$

$= 1100\text{ Hz}$

$f_4 = 4f_1 = (4)(370\text{ Hz}) = 1480\text{ Hz}$

$= 1500\text{ Hz}$

76. **Clarinets** A clarinet sounds the same note, with a pitch of 370 Hz, as in the previous problem. The clarinet, however, acts as a closed pipe. What are the frequencies of the lowest three harmonics produced by this instrument?

$3f_1 = (3)(370\text{ Hz}) = 1110\text{ Hz} = 1100\text{ Hz}$

$5f_1 = (5)(370\text{ Hz}) = 1850\text{ Hz} = 1800\text{ Hz}$

$7f_1 = (7)(370\text{ Hz}) = 2590\text{ Hz} = 2600\text{ Hz}$

77. **String Instruments** A guitar string is 65.0 cm long and is tuned to produce a lowest frequency of 196 Hz.

a. What is the speed of the wave on the string?

$\lambda_1 = 2L = (2)(0.650\text{ m}) = 1.30\text{ m}$

$v = \lambda f = (1.30\text{ m})(196\text{ Hz}) = 255\text{ m/s}$

b. What are the next two higher resonant frequencies for this string?

$f_2 = 2f_1 = (2)(196\text{ Hz}) = 392\text{ Hz}$

$f_3 = 3f_1 = (3)(196\text{ Hz}) = 588\text{ Hz}$

78. **Musical Instruments** The lowest note on an organ is 16.4 Hz.

a. What is the shortest open organ pipe that will resonate at this frequency?

$\lambda = \frac{v}{f} = \frac{343\text{ m/s}}{16.4\text{ Hz}} = 20.9\text{ m}$ **and**

$L = \frac{\lambda}{2}$, **so**

$L = \frac{v}{2f} = \frac{343\text{ m/s}}{(2)(16.4\text{Hz})} = 10.5\text{ m}$

b. What is the pitch if the same organ pipe is closed?

Since a closed pipe produces a fundamental with a wavelength twice as long as that of an open pipe of the same length, the frequency would be $\frac{1}{2}(16.4\text{ Hz}) = 8.20\text{ Hz}$.

79. **Musical Instruments** Two instruments are playing musical A (440.0 Hz). A beat note with a frequency of 2.5 Hz is heard. Assuming that one instrument is playing the correct pitch, what is the frequency of the pitch played by the second instrument?

It could be either 440.0 + 2.5 = 442.5 Hz or 440.0 − 2.5 = 437.5 Hz.

80. A flexible, corrugated, plastic tube, shown in **Figure 15-27,** is 0.85 m long. When it is swung around, it creates a tone that is the lowest pitch for an open pipe of this length. What is the frequency?

■ **Figure 15-27**

$L = 0.85\text{ m} = \frac{\lambda}{2}$, **so** $\lambda = 1.7\text{ m}$

$f = \frac{v}{\lambda} = \frac{343\text{ m/s}}{1.7\text{ m}} = 2.0\times10^2\text{ Hz}$

81. The tube from the previous problem is swung faster, producing a higher pitch. What is the new frequency?

$f_2 = 2f_1 = (2)(2.0\times10^2\text{ Hz}) = 4.0\times10^2\text{ Hz}$

Level 2

82. During normal conversation, the amplitude of a pressure wave is 0.020 Pa.

a. If the area of an eardrum is 0.52 cm^2, what is the force on the eardrum?

$$F = PA$$
$$= (0.020\ \text{N/m}^2)(0.52\times10^{-4}\ \text{m}^2)$$
$$= 1.0\times10^{-6}\ \text{N}$$

b. The mechanical advantage of the three bones in the middle ear is 1.5. If the force in part **a** is transmitted undiminished to the bones, what force do the bones exert on the oval window, the membrane to which the third bone is attached?

$$MA = \frac{F_r}{F_e} \text{ so } F_r = (MA)(F_e)$$
$$F_r = (1.5)(1.0\times10^{-6}\ \text{N}) = 1.5\times10^{-6}\ \text{N}$$

c. The area of the oval window is 0.026 cm^2. What is the pressure increase transmitted to the liquid in the cochlea?

$$P = \frac{F}{A} = \frac{1.5\times10^{-6}\ \text{N}}{0.026\times10^{-4}\ \text{m}^2} = 0.58\ \text{Pa}$$

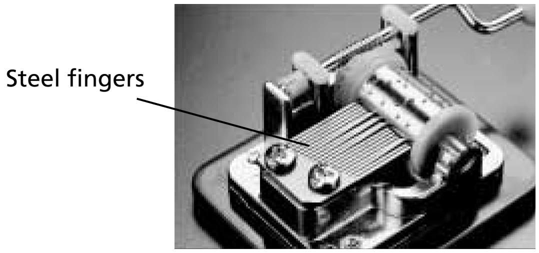
83. Musical Instruments One open organ pipe has a length of 836 mm. A second open pipe should have a pitch that is one major third higher. How long should the second pipe be?

$$L = \frac{\lambda}{2}, \text{ so } \lambda = 2L \text{ and } \lambda = \frac{v}{f}$$
$$f = \frac{v}{2L} = \frac{343\ \text{m/s}}{(2)(0.836\ \text{m})} = 205\ \text{Hz}$$

The ratio of a frequency one major third higher is 5:4, so (205 Hz)$\left(\frac{5}{4}\right)$ = 256 Hz. The length of the second pipe is

$$L = \frac{v}{2f} = \frac{343\ \text{m/s}}{(2)(256\ \text{Hz})} = 6.70\times10^2\ \text{mm}$$

84. As shown in **Figure 15-28,** a music box contains a set of steel fingers clamped at one end and plucked on the other end by pins on a rotating drum. What is the speed of a wave on a finger that is 2.4 cm long and plays a note of 1760 Hz?



■ **Figure 15-28**

The length of the steel finger clamped at one end and free to vibrate at the other is $\frac{1}{4}$ wavelength. Therefore,

$$\lambda = 4L = 4(0.024\ \text{m}) = 0.096\ \text{m, and}$$
$$v = f\lambda = (1760\ \text{Hz})(0.096\ \text{m})$$
$$= 1.7\times10^2\ \text{m/s}$$

Mixed Review

pages 427–428

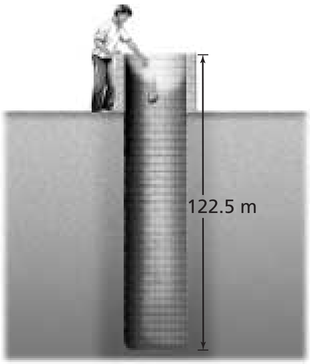
Level 1

85. An open organ pipe is 1.65 m long. What fundamental frequency note will it produce if it is played in helium at 0°C?

An open pipe has a length equal to one-half its fundamental wavelength. Therefore, λ = 3.30 m. The speed of sound in helium is 972 m/s. Therefore,

$$f = \frac{v}{\lambda} = \frac{972\ \text{m/s}}{3.30\ \text{m}} = 295\ \text{Hz}$$

86. If you drop a stone into a well that is 122.5 m deep, as illustrated in **Figure 15-29,** how soon after you drop the stone will you hear it hit the bottom of the well?



■ **Figure 15-29**

First find the time it takes the stone to fall down the shaft by $d = \frac{1}{2}gt^2$, so

$$t = \sqrt{\frac{d}{\frac{1}{2}g}} = \sqrt{\frac{122.5\ \text{m}}{\left(\frac{1}{2}\right)(9.80\ \text{m/s}^2)}} = 5.00\ \text{s}$$

The time it takes the sound to comes back up is found with $d = v_s t$, so

$$t = \frac{d}{v_s} = \frac{122.5\ \text{m}}{343\ \text{m/s}} = 0.357\ \text{s}$$

The total time is 5.00 s + 0.357 s = 5.36 s.

87. A bird on a newly discovered planet flies toward a surprised astronaut at a speed of 19.5 m/s while singing at a pitch of 945 Hz. The astronaut hears a tone of 985 Hz. What is the speed of sound in the atmosphere of this planet?

$f_d = 985$ Hz, $f_s = 945$ Hz, $v_s = 19.5$ m/s, $v = ?$

$$\frac{f_d}{f_s} = \frac{v}{v - v_s} = \frac{1}{1 - \frac{v_s}{v}}$$

So $\frac{v_s}{v} = 1 - \frac{f_s}{f_d}$,

$$\text{or } v = \frac{v_s}{1 - \frac{f_s}{f_d}} = \frac{19.5 \text{ m/s}}{1 - \left(\frac{945 \text{ Hz}}{985 \text{ Hz}}\right)}$$

$$= 4.80\times10^2 \text{ m/s}$$

88. In North America, one of the hottest outdoor temperatures ever recorded is 57°C and one of the coldest is −62°C. What are the speeds of sound at those two temperatures?

$v(T) = v(0°\text{C}) + (0.6 \text{ m/s})T$, where $v(0°\text{C}) = 331$ m/s. So, $v(57°\text{C})$

$$= (331 \text{ m/s}) + \left(\frac{0.6 \text{ m/s}}{°\text{C}}\right)(57°\text{C})$$

$$= 365 \text{ m/s}$$

$$v(-62°\text{C}) = (331 \text{ m/s}) + \left(\frac{0.6 \text{ m/s}}{°\text{C}}\right)(-62°\text{C})$$

$$= 294 \text{ m/s}$$

Level 2

89. A ship's sonar uses a frequency of 22.5 kHz. The speed of sound in seawater is 1533 m/s. What is the frequency received on the ship that was reflected from a whale traveling at 4.15 m/s away from the ship? Assume that the ship is at rest.

Part 1. From ship to whale:

$v_d = +4.15$ m/s, $v = 1533$ m/s,

$f_s = 22.5$ kHz, $v_s = 0$

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right) = (22.5 \text{ kHz})\left(\frac{1533 - 4.15}{1533}\right)$$

$$= 22.4 \text{ kHz}$$

Part 2. From whale to ship:

$v_s = -4.15$ m/s, $v = 1533$ m/s,

$f_s = 22.4$ kHz, $v_d = 0$

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right) = (22.4 \text{ kHz})\left(\frac{1533}{1533 + 4.15}\right)$$

$$= 22.3 \text{ kHz}$$

90. When a wet finger is rubbed around the rim of a glass, a loud tone of frequency 2100 Hz is produced. If the glass has a diameter of 6.2 cm and the vibration contains one wavelength around its rim, what is the speed of the wave in the glass?

The wavelength is equal to the circumference of the glass rim, $\lambda = \pi d$

Therefore, the speed is

$$v = \lambda f = \pi d f$$

$$= \pi(0.062 \text{ m})(2100 \text{ Hz}) = 4.1\times10^2 \text{ m/s}$$

91. **History of Science** In 1845, Dutch scientist Christoph Buys-Ballot developed a test of the Doppler effect. He had a trumpet player sound an A note at 440 Hz while riding on a flatcar pulled by a locomotive. At the same time, a stationary trumpeter played the same note. Buys-Ballot heard 3.0 beats per second. How fast was the train moving toward him?

$f_d = 440 \text{ Hz} + 3.0 \text{ Hz} = 443$ Hz

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right)$$

so $(v - v_s)f_d = (v - v_d)f_s$ and

$$v_s = v - \frac{(v - v_d)f_s}{f_d}$$

$$= 343 \text{ m/s} - \frac{(343 \text{ m/s} - 0)(440 \text{ Hz})}{443 \text{ Hz}}$$

$$= 2.3 \text{ m/s}$$

92. You try to repeat Buys-Ballot's experiment from the previous problem. You plan to have a trumpet played in a rapidly moving car. Rather than listening for beat notes, however, you want to have the car move fast enough so that the moving trumpet sounds one major third above a stationary trumpet.

a. How fast would the car have to move?

major third ratio $= \frac{5}{4}$

$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right)$

so $(v - v_s)f_d = (v - v_d)f_s$

and $v_s = v - \frac{(v - v_d)f_s}{f_d}$

$= 343 \text{ m/s} - (343 \text{ m/s} - 0)\left(\frac{4}{5}\right)$

$= 68.6 \text{ m/s}$

b. Should you try the experiment? Explain.

$v = (68.6 \text{ m/s})\left(\frac{3600 \text{ s}}{1 \text{ h}}\right)\left(\frac{1 \text{ mi}}{1609 \text{ m}}\right)$

$= 153$ mph,

so the car would be moving dangerously fast. Do not try the experiment.

Level 3

93. Guitar Strings The equation for the speed of a wave on a string is $v = \sqrt{\frac{F_T}{\mu}}$, where F_T is the tension in the string and μ is the mass per unit length of the string. A guitar string has a mass of 3.2 g and is 65 cm long. What must be the tension in the string to produce a note whose fundamental frequency is 147 Hz?

$\mu = \frac{0.0032 \text{ kg}}{0.65 \text{ m}} = 4.9\times10^{-3} \text{ kg/m}$

$\lambda = 2L = 2(0.65 \text{ m}) = 1.30 \text{ m}$

$v = f\lambda = (147 \text{ Hz})(1.30 \text{ m}) = 191 \text{ m/s}$

$F_T = v^2\mu = (191 \text{ m/s})^2(4.9\times10^{-3} \text{ kg/m})$

$= 180 \text{ N}$

94. A train speeding toward a tunnel at 37.5 m/s sounds its horn at 327 Hz. The sound bounces off the tunnel mouth. What is the frequency of the reflected sound heard on the train? *Hint: Solve the problem in two parts. First, assume that the tunnel is a stationary observer and find the frequency. Then, assume that the tunnel is a stationary source and find the frequency measured on the train.*

Part 1. $v_s = +37.5 \text{ m/s}$, $v = 343 \text{ m/s}$,

$f_s = 327 \text{ Hz}$

$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right) = (327 \text{ Hz})\left(\frac{343}{343 - 37.5}\right)$

$= 367 \text{ Hz}$

Part 2. $v_d = -37.5 \text{ m/s}$, $v = 343 \text{ m/s}$,

$f_s = 367 \text{ Hz}$

$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right) = (367 \text{ Hz})\left(\frac{343 - (-37.5)}{343}\right)$

$= 407 \text{ Hz}$

Thinking Critically

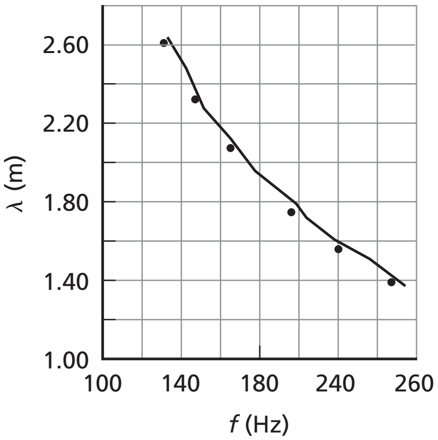
page 428

95. Make and Use Graphs The wavelengths of the sound waves produced by a set of tuning forks with given frequencies are shown in **Table 15-2** below.

Table 15-2	
Tuning Forks	
Frequency (Hz)	Wavelength (m)
131	2.62
147	2.33
165	2.08
196	1.75
220	1.56
247	1.39

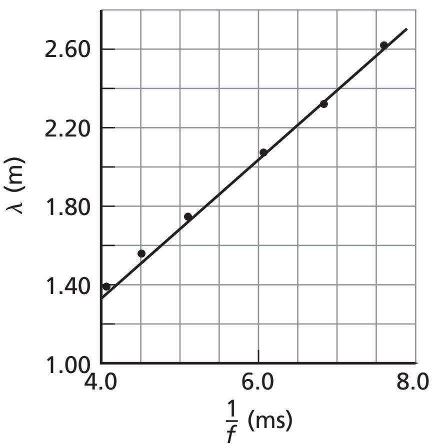
a. Plot a graph of the wavelength versus the frequency (controlled variable). What type of relationship does the graph show?

The graph shows an inverse relationship between frequency and wavelength.



b. Plot a graph of the wavelength versus the inverse of the frequency (1/*f*). What kind of graph is this? Determine the speed of sound from this graph.

The graph shows a direct relationship between period (1/*f*) and wavelength. The speed of sound is represented by the slope, ~343 m/s.



96. Make Graphs Suppose that the frequency of a car horn is 300 Hz when it is stationary. What would the graph of the frequency versus time look like as the car approached and then moved past you? Complete a rough sketch.

The graph should show a fairly steady frequency above 300 Hz as it approaches and a fairly steady frequency below 300 Hz as it moves away.

97. Analyze and Conclude Describe how you could use a stopwatch to estimate the speed of sound if you were near the green on a 200-m golf hole as another group of golfers hit their tee shots. Would your estimate of the speed of sound be too large or too small?

You could start the watch when you saw the hit and stop the watch when the sound reached you. The speed would be calculated by dividing the distance, 200 m, by the measured time. The measured time would be too large because you could anticipate the impact by sight, but you could not anticipate the sound. The calculated speed would be too small.

98. Apply Concepts A light wave coming from a point on the left edge of the Sun is found by astronomers to have a slightly higher frequency than light from the right side. What do these measurements tell you about the Sun's motion?

The Sun must be rotating on its axis in the same manner as Earth. The Doppler shift indicates that the left side of the Sun is coming toward us, while the right side is moving away.

99. Design an Experiment Design an experiment that could test the formula for the speed of a wave on a string. Explain what measurements you would make, how you would make them, and how you would use them to test the formula.

Measure the mass and length of the string to determine μ. Then clamp the string to a table, hang one end over the table edge, and stretch the string by hanging weights on its end to obtain F_T. Calculate the speed of the wave using the formula. Next, pluck the string in its middle and determine the frequency by matching it to a frequency generator, using beats to tune the generator. Multiply the frequency by twice the string length, which is equal to the wavelength, to obtain the speed from the wave equation. Compare the results. Repeat for different tensions and other strings with different masses per unit length. Consider possible causes of error.

Writing in Physics

page 428

100. Research the construction of a musical instrument, such as a violin or French horn. What factors must be considered besides the length of the strings or tube? What is the difference between a quality instrument and a cheaper one? How are they tested for tone quality?

Answers will vary. A report on violin construction might include information about the bridge as a link between the strings and body and information about the role of the body in causing air molecules around the violin to vibrate. Students also might discuss

the ways in which the woods and finishes used in making violins affect the quality of the sound produced by the instruments.

101. Research the use of the Doppler effect in the study of astronomy. What is its role in the big bang theory? How is it used to detect planets around other stars? To study the motions of galaxies?

Students should discuss the work of Edwin Hubble, the redshift and the expanding universe, spectroscopy, and the detection of wobbles in the motion of planet-star systems.

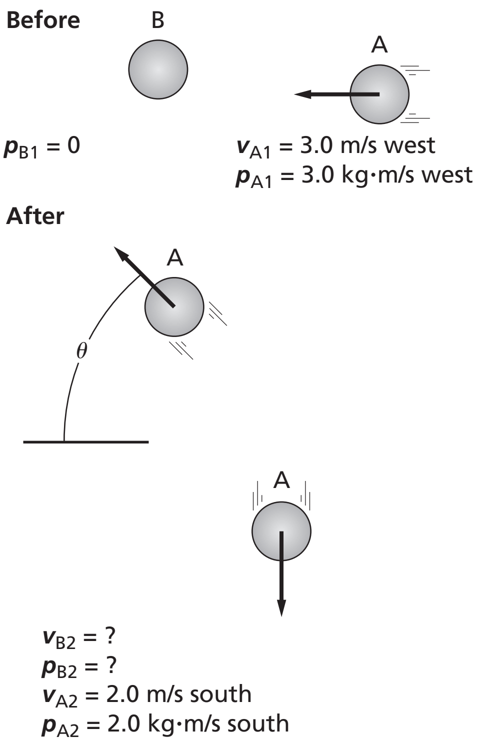
Cumulative Review

page 428

102. Ball A, rolling west at 3.0 m/s, has a mass of 1.0 kg. Ball B has a mass of 2.0 kg and is stationary. After colliding with ball B, ball A moves south at 2.0 m/s. (Chapter 9)

a. Sketch the system, showing the velocities and momenta before and after the collision.

Westward and southward are positive.



b. Calculate the momentum and velocity of ball B after the collision.

Horizontal: $m_A v_{A1} = m_B v_{B2}$

So $m_B v_{B2} = (1.0\text{ kg})(3.0\text{ m/s})$

$= 3.0\text{ kg·m/s}$

Vertical: $0 = m_A v_{A2} + m_B v_{B2}$

So $m_B v_{B2} = -(1.0\text{ kg})(2.0\text{ m/s})$

$= -2.0\text{ kg·m/s}$

The vector sum is

m_v

$= \sqrt{(3.0\text{ kg·m/s})^2 + (-2.0\text{ kg·m/s})^2}$

$= 3.6\text{ kg·m/s}$ **and** $\tan\theta = \frac{2.0\text{ kg·m/s}}{3.0\text{ kg·m/s}}$

so $\theta = 34°$

Therefore, $m_B v_{B2} = 3.6\text{ kg·m/s}$ **at 34° north of west**

$v_{B2} = \frac{3.6\text{ kg·m/s}}{2.0\text{ kg}}$

$= 1.8\text{ m/s}$ **at 34° north of west**

103. Chris carries a 10-N carton of milk along a level hall to the kitchen, a distance of 3.5 m. How much work does Chris do? (Chapter 10)

No work, because the force and the displacement are perpendicular.

104. A movie stunt person jumps from a five-story building (22 m high) onto a large pillow at ground level. The pillow cushions her fall so that she feels a deceleration of no more than 3.0 m/s^2. If she weighs 480 N, how much energy does the pillow have to absorb? How much force does the pillow exert on her? (Chapter 11)

The energy to be absorbed equals the mechanical energy that she had, which equals her initial potential energy.
U = mgh = (480 N)(22 m) = 11 kJ.

The force on her is

$F = ma = \frac{F_g}{g}(a) = \left(\frac{480\text{ N}}{9.80\text{ m/s}^2}\right)(3.0\text{ m/s}^2)$

$= 150\text{ N}$

Challenge Problem

page 417

1. Determine the tension, F_T, in a violin string of mass *m* and length *L* that will play the fundamental note at the same frequency as a closed pipe also of length *L*. Express your answer in terms of *m*, *L*, and the speed of sound in air, *v*. The equation for the speed of a wave on a string is $u = \sqrt{\frac{F_T}{\mu}}$. where F_T is the tension string and μ is the mass per unit length of the string.

   The wavelength of the fundamental in a closed pipe is equal to 4*L*, so the frequency is $f = \frac{v}{4L}$. The wavelength of the fundamental on a string is equal to 2*L*, so the frequency of the string is $f = \frac{u}{2L}$, where *u* is the speed of the wave on the string, $u = \sqrt{\frac{F_T}{\mu}}$. The mass per unit length of the string $\mu = m/L$. Squaring the frequencies and setting them equal gives

   $$\frac{v^2}{16L^2} = \frac{u^2}{4L^2} = \frac{F_T}{4L^2\mu} = \frac{F_TL}{4L^2m} = \frac{F_T}{4Lm}$$

   Finally, rearranging for the tension gives $F_T = \frac{mv^2}{4L}$

2. What is the tension in a string of mass 1.0 g and 40.0 cm long that plays the same note as a closed pipe of the same length?

   For a string of mass 1.0 g and length 0.400 m, the tension is

   $$F_T = \frac{mv^2}{4L} = \frac{(0.0010\ \text{kg})(343\ \text{m/s})^2}{4(0.400\ \text{m})} = 74\ \text{N}$$

CHAPTER 16 Fundamentals of Light

Practice Problems

16.1 Illumination pages 431–438

page 436

1. A lamp is moved from 30 cm to 90 cm above the pages of a book. Compare the illumination on the book before and after the lamp is moved.

$$\frac{E_{after}}{E_{before}} = \frac{\left(\frac{P}{4\pi d_{after}^2}\right)}{\left(\frac{P}{4\pi d_{before}^2}\right)} = \frac{d_{before}^2}{d_{after}^2}$$

$$= \frac{(30\text{ cm})^2}{(90\text{ cm})^2} = \frac{1}{9}$$ **; therefore, after the lamp is moved the illumination is one-ninth of the original illumination.**

2. What is the illumination on a surface that is 3.0 m below a 150-W incandescent lamp that emits a luminous flux of 2275 lm?

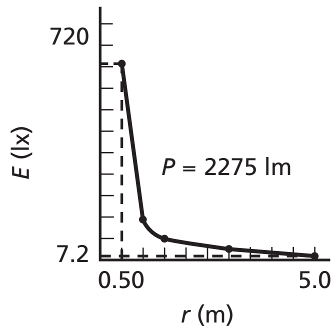
$$E = \frac{P}{4\pi d^2} = \frac{2275\text{ lm}}{4\pi(3.0\text{ m})^2} = 2.0\times10^1\text{ lx}$$

3. Draw a graph of the illuminance produced by a 150-W incandescent lamp between 0.50 m and 5.0 m.

Illuminance of a 150-W bulb

$P = 2275$, $d = 0.50, 0.75, \ldots, 5.0$

$$E(d) = \frac{P}{4\pi d^2}$$



4. A 64-cd point source of light is 3.0 m above the surface of a desk. What is the illumination on the desk's surface in lux?

$P = 4\pi(64\text{ cd}) = 256\pi\text{ lm}$

so $E = \frac{P}{4\pi d^2} = \frac{256\pi\text{ lm}}{4\pi(3.0\text{ m})^2} = 7.1\text{ lx}$

5. A public school law requires a minimum illuminance of 160 lx at the surface of each student's desk. An architect's specifications call for classroom lights to be located 2.0 m above the desks. What is the minimum luminous flux that the lights must produce?

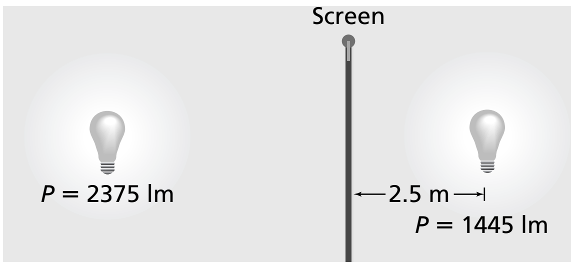
$E = \frac{P}{4\pi d^2}$

$P = 4\pi E d^2$

$= 4\pi(160\text{ lm/m}^2)(2.0\text{ m})^2$

$= 8.0\times10^3\text{ lm}$

6. A screen is placed between two lamps so that they illuminate the screen equally, as shown in **Figure 16-7.** The first lamp emits a luminous flux of 1445 lm and is 2.5 m from the screen. What is the distance of the second lamp from the screen if the luminous flux is 2375 lm?



■ **Figure 16-7** (Not to scale)

$E_1 = E_2$

So $\frac{P_1}{d_1^2} = \frac{P_2}{d_2^2}$

or $d_2 = d_1\sqrt{\frac{P_2}{P_1}}$

$= (2.5\text{ m})\sqrt{\frac{2375}{1445}}$

$= 3.2\text{ m}$

Section Review

16.1 Illumination pages 431–438

page 438

7. **Use of Material Light Properties** Why might you choose a window shade that is translucent? Opaque?

   You would use a translucent window shade to keep people from looking in or out, while still allowing daylight in. You would use an opaque window shade to keep the daylight out.

8. **Illuminance** Does one lightbulb provide more illuminance than two identical lightbulbs at twice the distance? Explain.

   One lightbulb provides an illuminance that is four times larger than two of the same lightbulb at twice the distance, because $E \propto \frac{P}{d^2}$.

9. **Luminous Intensity** Two lamps illuminate a screen equally—lamp A at 5.0 m, lamp B at 3.0 m. If lamp A is rated 75 cd, what is lamp B rated?

   $E = \frac{I}{d^2}$

   Since the illumination is equal,

   $E_1 = E_2$

   So $\frac{I_1}{d_1^2} = \frac{I_2}{d_2^2}$

   or $I_2 = \frac{I_1 d_2^2}{d_1^2}$

   $= \frac{(75\text{ cd})(3.0\text{ m})^2}{(5.0\text{ m})^2} = 27\text{ cd}$

10. **Distance of a Light Source** Suppose that a lightbulb illuminating your desk provides only half the illuminance that it should. If it is currently 1.0 m away, how far should it be to provide the correct illuminance?

    Illumination depends on $1/d^2$,

    so $\frac{E_i}{E_f} = \frac{d_f^2}{d_i^2} = \frac{1}{2}$

    $\frac{d_f^2}{(1.0\text{ m})^2} = \frac{1}{2}$

    $d_f = \sqrt{\frac{1}{2}}\text{ m}$

    $= 0.71\text{ m}$

11. **Distance of Light Travel** How far does light travel in the time it takes sound to travel 1 cm in air at 20°C?

    Sound velocity is 343 m/s, so sound takes 3×10^{-5} s to travel 1 cm. In that time, light travels 9 km.

    $v_{sound} = 343\text{ m/s}$

    $t_{sound} = \frac{d}{v_{sound}}$

    $= \frac{1\times10^{-2}\text{ m}}{343\text{ m/s}}$

    $= 3\times10^{-5}\text{ s}$

    $v_{light} = 3.00\times10^{8}\text{ m/s}$

    $d_{light} = v_{light}t_{sound}$

    $= (3.00\times10^{8}\text{ m/s})(3\times10^{-5}\text{ s})$

    $= 9\times10^{3}\text{ m} = 9\text{ km}$

12. **Distance of Light Travel** The distance to the Moon can be found with the help of mirrors left on the Moon by astronauts. A pulse of light is sent to the Moon and returns to Earth in 2.562 s. Using the measured value of the speed of light to the same precision, calculate the distance from Earth to the Moon.

    $d = ct$

    $= (299{,}800{,}000\text{ m/s})\left(\frac{1}{2}\right)(2.562\text{ s})$

    $= 3.840\times10^{8}\text{ m}$

13. **Critical Thinking** Use the correct time taken for light to cross Earth's orbit, 16.5 min, and the diameter of Earth's orbit, 2.98×10^{11} m, to calculate the speed of light using Roemer's method. Does this method appear to be accurate? Why or why not?

    $v = \frac{d}{t} = \frac{3.0\times10^{11}}{(16\text{ min})(60\text{ s/min})}$

    $= 3.1\times10^{8}\text{ m/s}$

Practice Problems

16.2 The Wave Nature of Light pages 439–447

page 447

14. What is the frequency of oxygen's spectral line if its wavelength is 513 nm?

Use $\lambda = \frac{c}{f}$ and solve for f.

$$f = \frac{c}{\lambda}$$

$$= \frac{3.00\times10^{8}\text{ m/s}}{5.13\times10^{-7}\text{ m}}$$

$$= 5.85\times10^{14}\text{ Hz}$$

15. A hydrogen atom in a galaxy moving with a speed of 6.55×10^{6} m/s away from Earth emits light with a frequency of 6.16×10^{14} Hz. What frequency of light from that hydrogen atom would be observed by an astronomer on Earth?

The relative speed along the axis is much less than the speed of light. Thus, you can use the observed light frequency equation. Because the astronomer and the galaxy are moving away from each other, use the negative form of the observed light frequency equation.

$$f_{obs} = f\left(1 - \frac{v}{c}\right)$$

$$= (6.16\times10^{14}\text{ Hz})\left(1 - \left(\frac{6.55\times10^{6}\text{ m/s}}{3.00\times10^{8}\text{ m/s}}\right)\right)$$

$$= 6.03\times10^{14}\text{ Hz}$$

16. A hydrogen atom in a galaxy moving with a speed of 6.55×10^{16} m/s away from Earth emits light with a wavelength of 4.86×10^{-7} m. What wavelength would be observed on Earth from that hydrogen atom?

The relative speed along the axis is much less than the speed of light. Thus, you can use the observed Doppler shift equation. Because the astronomer and the galaxy are moving away from each other, use the positive form of the Doppler shift equation.

$$(\lambda_{obs} - \lambda) = +\frac{v}{c}\lambda$$

$$\lambda_{obs} = \lambda\left(1 + \frac{v}{c}\right)$$

$$= (4.86\times10^{-7}\text{ m})\left(1 + \left(\frac{6.55\times10^{6}\text{ m/s}}{3.00\times10^{8}\text{ m/s}}\right)\right)$$

$$= 4.97\times10^{-7}\text{ m}$$

17. An astronomer is looking at the spectrum of a galaxy and finds that it has an oxygen spectral line of 525 nm, while the laboratory value is measured at 513 nm. Calculate how fast the galaxy would be moving relative to Earth. Explain whether the galaxy is moving toward or away from Earth and how you know.

Assume that the relative speed along the axis is much less than the speed of light. Thus, you can use the Doppler shift equation.

$$(\lambda_{obs} - \lambda) = \pm\frac{v}{c}\lambda$$

The observed (apparent) wavelength appears to be longer than the known (actual) wavelength of the oxygen spectral line. This means that the astronomer and the galaxy are moving away from each other. So use the positive form of the Doppler shift equation.

$$(\lambda_{obs} - \lambda) = +\frac{v}{c}\lambda$$

Solve for the unknown variable.

$$v = c\,\frac{(\lambda_{obs} - \lambda)}{\lambda}$$

$$= (3.00\times10^{8}\text{ m/s})\left(\frac{(525\text{ nm} - 513\text{ nm})}{513\text{ nm}}\right)$$

$$= 7.02\times10^{6}\text{ m/s}$$

Section Review

16.2 The Wave Nature of Light pages 439–447

page 447

18. Addition of Light Colors What color of light must be combined with blue light to obtain white light?

yellow (a mixture of the other two primaries, red and green)

19. Combination of Pigments What primary pigment colors must be mixed to produce red? Explain how red results using color subtraction for pigment colors.

Yellow and magenta pigments are used to produce red. Yellow pigment subtracts blue and magenta pigment subtracts green, neither subtracts red so the mixture would reflect red.

20. Light and Pigment Interaction What color will a yellow banana appear to be when illuminated by each of the following?

a. white light

yellow

b. green and red light

yellow

c. blue light

black

21. Wave Properties of Light The speed of red light is slower in air and water than in a vacuum. The frequency, however, does not change when red light enters water. Does the wavelength change? If so, how?

Yes, because $v = \lambda f$ and $\lambda = v/f$, when v decreases, so does λ.

22. Polarization Describe a simple experiment that you could do to determine whether sunglasses in a store are polarizing.

See if the glasses reduce glare from the reflective surfaces, such as windows or roadways. Polarization of light allows photographers to photograph objects while eliminating glare.

23. Critical Thinking Astronomers have determined that Andromeda, a neighboring galaxy to our own galaxy, the Milky Way, is moving toward the Milky Way. Explain how they determined this. Can you think of a possible reason why Andromeda is moving toward our galaxy?

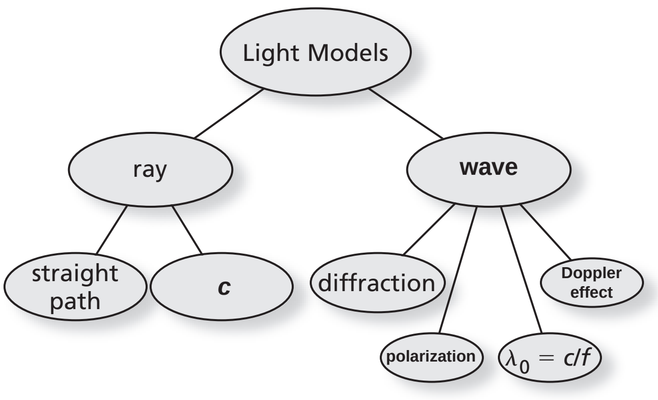
The spectral lines of the emissions of known atoms are blue-shifted in the light we see coming from Andromeda. Andromeda would be moving toward us due to gravitational attraction. This gravitational attraction could be due to the mass of the Milky Way or other objects located near the Milky Way.

Chapter Assessment

Concept Mapping

page 452

24. Complete the following concept map using the following terms: *wave, c, Doppler effect, polarization.*



Mastering Concepts

page 452

25. Sound does not travel through a vacuum. How do we know that light does? (16.1)

Light comes through the vacuum of space from the Sun.

26. Distinguish between a luminous source and an illuminated source. (16.1)

A luminous body emits light. An illuminated body is one on which light falls and is reflected.

27. Look carefully at an ordinary, frosted, incandescent bulb. Is it a luminous or an illuminated source? (16.1)

It is mainly illuminated. The filament is luminous; the frosted glass is illuminated. You barely can see the hot filament through the frosted glass.

28. Explain how you can see ordinary, nonluminous classroom objects. (16.1)

Ordinary nonluminous objects are illuminated by reflected light, allowing them to be seen.

29. Distinguish among transparent, translucent, and opaque objects. (16.1)

A transparent object is a material through which light can pass without distortion. A translucent object allows light to pass but distorts the light to the point where images are not discernable. An opaque object does not allow light to pass through.

30. To what is the illumination of a surface by a light source directly proportional? To what is it inversely proportional? (16.1)

The illumination on a surface is directly proportional to the intensity of the source and inversely proportional to the square of the distance of the surface from the source.

31. What did Galileo assume about the speed of light? (16.1)

The speed of light is very fast, but finite.

32. Why is the diffraction of sound waves more familiar in everyday experience than is the diffraction of light waves? (16.2)

Diffraction is most pronounced around obstacles approximately the same size as the wavelength of the wave. We are more accustomed to obstacles of the size that diffract the much larger wavelengths of sound.

33. What color of light has the shortest wavelength? (16.2)

Violet light has the shortest wavelength.

34. What is the range of the wavelengths of light, from shortest to longest? (16.2)

400 nm to 700 nm

35. Of what colors does white light consist? (16.2)

White light is a combination of all the colors, or at least the primary colors.

36. Why does an object appear to be black? (16.2)

An object appears to be black because little, if any, light is being reflected from it.

37. Can longitudinal waves be polarized? Explain. (16.2)

No. They have no vertical or horizontal components.

38. If a distant galaxy were to emit a spectral line in the green region of the light spectrum, would the observed wavelength on Earth shift toward red light or toward blue light? Explain. (16.2)

Because the galaxy is distant, it is most likely moving away from Earth. The wavelength actually would shift away from the wavelength of green light toward a longer red wavelength. If it

shifted toward the blue wavelength, the wavelength would be shorter, not longer. This would indicate the galaxy is getting closer to Earth, and no galaxy outside the Local Group has been discovered moving toward us.

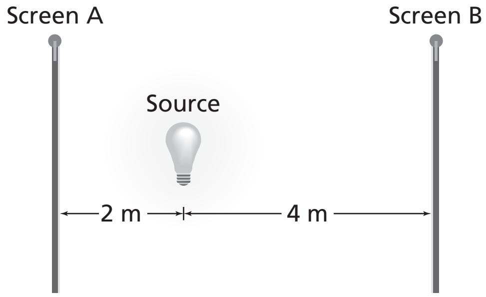
39. What happens to the wavelength of light as the frequency increases? (16.2)

As the frequency increases, the wavelength decreases.

Applying Concepts

page 452

40. A point source of light is 2.0 m from screen A and 4.0 m from screen B, as shown in **Figure 16-21.** How does the illuminance at screen B compare with the illuminance at screen A?



■ **Figure 16-21**

Illumination $E \propto I/r^2$; therefore, the illumination at screen B will be one-fourth of that at screen A because it is twice as far from the source.

41. Reading Lamp You have a small reading lamp that is 35 cm from the pages of a book. You decide to double the distance.

a. Is the illuminance at the book the same?

No.

b. If not, how much more or less is it?

Distance is doubled, so the illumination of the page is one-fourth as great.

42. Why are the insides of binoculars and cameras painted black?

The insides are painted black because black does not reflect any light, and thus there is no interference while observing or photographing objects.

43. Eye Sensitivity The eye is most sensitive to yellow-green light. Its sensitivity to red and blue light is less than 10 percent as great. Based on this knowledge, what color would you recommend that fire trucks and ambulances be painted? Why?

Fire trucks should be painted yellow-green, 550 nm, because less light has to be reflected to the eye for the fire truck to be seen.

44. Streetlight Color Some very efficient streetlights contain sodium vapor under high pressure. They produce light that is mainly yellow with some red. Should a community that has these lights buy dark blue police cars? Why or why not?

Blue pigment of a police car will absorb the red and yellow light. Dark blue police cars would not be very visible. If a community wants its police cars to be visible, they should buy yellow cars.

*Refer to **Figure 16-22** for problems 45 and 46.*

■ **Figure 16-22**

45. What happens to the illuminance at a book as the lamp is moved farther away from the book?

Illuminance decreases, as described by the inverse-square law.

46. What happens to the luminous intensity of the lamp as it is moved farther away from the book?

No change; distance does not affect the luminous intensity of the lamp.

47. Polarized Pictures Photographers often put polarizing filters over camera lenses to make clouds in the sky more visible. The clouds remain white, while the sky looks darker. Explain this based on your knowledge of polarized light.

Light scattered from the atmosphere is polarized, but light scattered from the clouds is not. By rotating the filter, the photographer can reduce the amount of polarized light reaching the film.

48. An apple is red because it reflects red light and absorbs blue and green light.

a. Why does red cellophane look red in reflected light?

Cellophane reflects red light and absorbs blue and green light.

b. Why does red cellophane make a white lightbulb look red when you hold the cellophane between your eye and the lightbulb?

Cellophane transmits red light.

c. What happens to the blue and green light?

Blue and green light are absorbed.

49. You put a piece of red cellophane over one flashlight and a piece of green cellophane over another. You shine the light beams on a white wall. What color will you see where the two flashlight beams overlap?

yellow

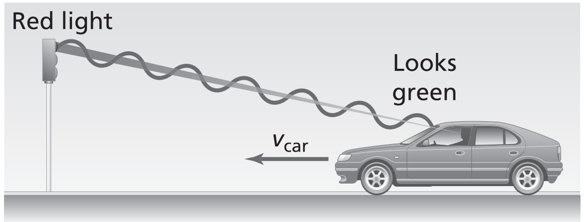
50. You now put both the red and green cellophane pieces over one of the flashlights in Problem 49. If you shine the flashlight beam on a white wall, what color will you see? Explain.

Black; almost no light would get through because the light transmitted through the first filter would be absorbed by the second.

51. If you have yellow, cyan, and magenta pigments, how can you make a blue pigment? Explain.

Mix cyan and magenta.

52. Traffic Violation Suppose that you are a traffic officer and you stop a driver for going through a red light. Further suppose that the driver draws a picture for you (**Figure 16-23**) and explains that the light looked green because of the Doppler effect when he went through it. Explain to him using the Doppler shift equation just how fast he would have had to be going for the red light (λ = 645 nm), to appear green (λ = 545 nm). *Hint: For the purpose of this problem, assume that the Doppler shift equation is valid at this speed.*



■ **Figure 16-23**

$$\left(\frac{645\text{ nm} - 545\text{ nm}}{645\text{ nm}}\right)(3.00\times10^{8}\text{ m/s}) = 4.65\times10^{7}\text{ m/s}$$

That is over 100 million mph. If he does not get a ticket for running a red light, he will get a ticket for speeding.

Mastering Problems

16.1 Illumination

page 453

Level 1

53. Find the illumination 4.0 m below a 405-lm lamp.

$$E = \frac{P}{4\pi d^2} = \frac{405\text{ lm}}{4\pi(4.0\text{ m})^2} = 2.0\text{ lx}$$

54. Light takes 1.28 s to travel from the Moon to Earth. What is the distance between them?

$$d = vt = (3.00\times10^{8}\text{ m/s})(1.28\text{ s}) = 3.84\times10^{8}\text{ m}$$

Level 2

55. A three-way bulb uses 50, 100, or 150 W of electric power to deliver 665, 1620, or 2285 lm in its three settings. The bulb is placed 80 cm above a sheet of paper. If an illumination of at least 175 lx is needed on the paper, what is the minimum setting that should be used?

$$E = \frac{P}{4\pi d^2}$$

$$P = 4\pi Ed^2 = 4\pi(175\ \text{lx})(0.80\ \text{m})^2$$

$$= 1.4\times10^3\ \text{lm}$$

Thus, the 100-W (1620-lm) setting is needed.

56. Earth's Speed Ole Roemer found that the average increased delay in the disappearance of Io from one orbit around Jupiter to the next is 13 s.

a. How far does light travel in 13 s?

3.9×10^9 **m**

b. Each orbit of Io takes 42.5 h. Earth travels the distance calculated in part **a** in 42.5 h. Find the speed of Earth in km/s.

$$v = \frac{d}{t}$$

$$= \left(\frac{3.9\times10^9\ \text{m}}{1.53\times10^5\ \text{s}}\right)\left(\frac{1\ \text{km}}{1000\ \text{m}}\right)$$

$$= 25\ \text{km/s}$$

c. Check to make sure that your answer for part **b** is reasonable. Calculate Earth's speed in orbit using the orbital radius, 1.5×10^8 km, and the period, 1.0 yr.

$$v = \frac{d}{t} = \left(\frac{2\pi(1.5\times10^8\ \text{km})}{365\ \text{d}}\right)\left(\frac{1\ \text{d}}{24\ \text{h}}\right)\left(\frac{1\ \text{h}}{3600\ \text{s}}\right)$$

$= 3.0\times10^1$ **km/s, so fairly accurate**

Level 3

57. A student wants to compare the luminous flux of a lightbulb with that of a 1750-lm lamp. The lightbulb and the lamp illuminate a sheet of paper equally. The 1750-lm lamp is 1.25 m away from the sheet of paper; the lightbulb is 1.08 m away. What is the lightbulb's luminous flux?

$$E = \frac{P}{4\pi d^2}$$

Since the illumination is equal,

$$E_1 = E_2$$

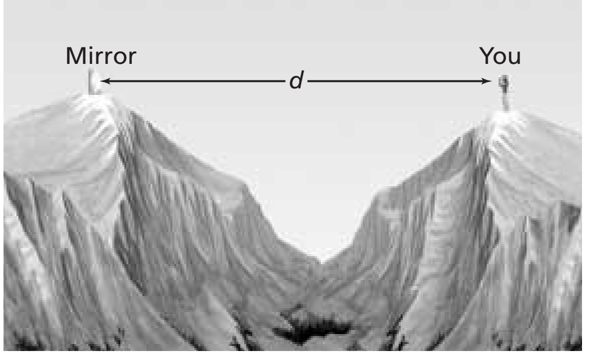
So $\frac{P_1}{{d_1}^2} = \frac{P_2}{{d_2}^2}$

or $P_2 = \frac{P_1{d_2}^2}{{d_1}^2}$

$$= \frac{(1750\ \text{lm})(1.08\ \text{m})^2}{(1.25\ \text{m})^2}$$

$$= 1.31\times10^3\ \text{lm}$$

58. Suppose that you wanted to measure the speed of light by putting a mirror on a distant mountain, setting off a camera flash, and measuring the time it takes the flash to reflect off the mirror and return to you, as shown in **Figure 16-24.** Without instruments, a person can detect a time interval of about 0.10 s. How many kilometers away would the mirror have to be? Compare this distance with that of some known distances.



■ **Figure 16-24**

$$d = vt$$

$$= (3.00\times10^8\ \text{m/s})(0.1\ \text{s})\left(\frac{1\ \text{km}}{1000\ \text{m}}\right)$$

$$= 3\times10^4\ \text{km}$$

The mirror would be half this distance, or 15,000 km away. Earth is 40,000 km in circumference, so this is three-eighths of the way around Earth.

16.2 The Wave Nature of Light
pages 453–454

Level 1

59. Convert 700 nm, the wavelength of red light, to meters.

$$(700\ \text{nm})\left(\frac{1\times10^{-9}\ \text{m}}{1\ \text{nm}}\right) = 7\times10^{-7}\ \text{m}$$

60. Galactic Motion How fast is a galaxy moving relative to Earth if a hydrogen spectral line of 486 nm is red-shifted to 491 nm?

Assume that the relative speed along the axis is much less than the speed of light. Thus, you can use the Doppler shift equation.

$$(\lambda_{app} - \lambda) = \pm\frac{v}{c}\lambda$$

The light is red-shifted, so the astronomer and the galaxy are moving away from each other. So use the positive form of the apparent light wavelength equation.

$$(\lambda_{app} - \lambda) = \pm\frac{v}{c}\lambda$$

Solve for the unknown variable.

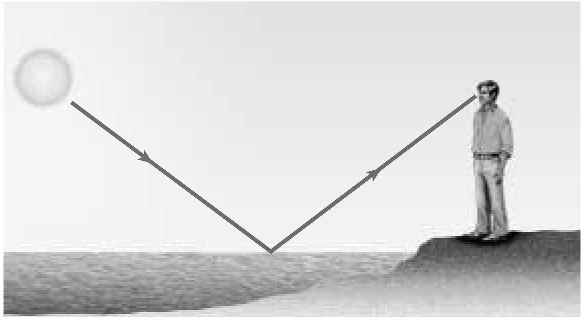
$$v = c\frac{(\lambda_{app} - \lambda)}{\lambda}$$

$$= (3.00\times10^8\ \text{m/s})\left(\frac{491\ \text{nm} - 486\ \text{nm}}{486\ \text{nm}}\right)$$

$$= 3.09\times10^6\ \text{m/s}$$

The original assumption was valid.

61. Suppose that you are facing due east at sunrise. Sunlight is reflected off the surface of a lake, as shown in **Figure 16-25.** Is the reflected light polarized? If so, in what direction?



■ **Figure 16-25**

The reflected light is partially polarized in the direction parallel to the surface of the lake and perpendicular to the path of travel of the light from the lake to your eyes.

Level 2

62. Polarizing Sunglasses In which direction should the transmission axis of polarizing sunglasses be oriented to cut the glare from the surface of a road: vertically or horizontally? Explain.

The transmission axis should be oriented vertically, since the light reflecting off the road will be partially polarized in the horizontal direction. A vertical transmission axis will filter horizontal waves.

63. Galactic Motion A hydrogen spectral line that is known to be 434 nm is red-shifted by 6.50 percent in light coming from a distant galaxy. How fast is the galaxy moving away from Earth?

Assume that the relative speed along the axis is much less than the speed of light. Thus, you can use the Doppler shift equation.

$$(\lambda_{app} - \lambda) = \pm\frac{v}{c}\lambda$$

The light is red-shifted, so the astronomer and the galaxy are moving away from each other. So use the positive form of the apparent light wavelength equation.

$$(\lambda_{app} - \lambda) = \pm\frac{v}{c}\lambda$$

Solve for the unknown variable.

$$v = c\frac{(\lambda_{app} - \lambda)}{\lambda}$$

$$= (3.00\times10^8\ \text{m/s})\left(\frac{(1.065)(434\ \text{nm}) - 434\ \text{nm}}{434\ \text{nm}}\right)$$

$$= 1.95\times10^7\ \text{m/s}$$

The original assumption was valid.

Level 3

64. For any spectral line, what would be an unrealistic value of the apparent wavelength for a galaxy moving away from Earth? Why?

An unrealistic value would make the galaxy seem to be moving away from us at a speed close to or greater than the speed of light, or $v \sim c$. If this were the

case, use of the low-speed Doppler shift equation would give a wavelength difference of $(\lambda_{app} - \lambda) = +\frac{c}{c}\lambda$. When solved, this would give an apparent wavelength of $\lambda_{app} = 2\lambda$. It would be twice as large as the actual wavelength. So any apparent wavelength close to or greater than twice the actual wavelength would be unrealistic.

Mixed Review

page 454

Level 1

65. Streetlight Illumination A streetlight contains two identical bulbs that are 3.3 m above the ground. If the community wants to save electrical energy by removing one bulb, how far from the ground should the streetlight be positioned to have the same illumination on the ground under the lamp?

$$E = \frac{P}{4\pi d^2}$$

If P is reduced by a factor of 2, so must d^2.

Thus, d is reduced by a factor of $\sqrt{2}$, becoming

$$\frac{(3.3\text{ m})}{\sqrt{2}} = 2.3\text{ m}$$

66. An octave in music is a doubling of frequency. Compare the number of octaves that correspond to the human hearing range to the number of octaves in the human vision range.

Humans hear over a range of about nine or ten octaves (20 Hz to 10,240 or 20,480 Hz); however, human vision is less than one "octave."

Level 2

67. A 10.0-cd point-source lamp and a 60.0-cd point-source lamp cast equal intensities on a wall. If the 10.0-cd lamp is 6.0 m from the wall, how far from the wall is the 60.0-cd lamp?

$E = \frac{I}{d^2}$ and since the intensities on the wall are equal, the wall is equally illuminated and

$$E_1 = E_2$$

$$\text{So } \frac{I_1}{{d_1}^2} = \frac{I_2}{{d_2}^2}$$

$$\text{or } d_2 = d_1\sqrt{\frac{I_2}{I_1}} = (6.0\text{ m})\sqrt{\frac{60.0\text{ cd}}{10.0\text{ cd}}}$$

$$= 15\text{ m}$$

68. Thunder and Lightning Explain why it takes 5 s to hear thunder when lightning is 1.6 km away.

The time for light to travel 1.6 km is a small fraction of a second (5.3 μs). The sound travels about 340 m/s, which is about one-fifth of the 1.6 km every second, and takes about 4.7 s to travel 1.6 km.

Level 3

69. Solar Rotation Because the Sun rotates on its axis, one edge of the Sun moves toward Earth and the other moves away. The Sun rotates approximately once every 25 days, and the diameter of the Sun is 1.4×10^9 m. Hydrogen on the Sun emits light of frequency 6.16×10^{14} Hz from the two sides of the Sun. What changes in wavelength are observed?

Speed of rotation is equal to circumference times period of rotation.

$$v_{rot} = \frac{(1.4\times10^9\text{ m})\pi}{(25\text{ days})(24\text{ h/day})(3600\text{ s/h})}$$

$$= 2.04\times10^3\text{ m/s}$$

$$\lambda = \frac{c}{f}$$

$$= \frac{3.00\times10^8\text{ m/s}}{6.16\times10^{14}\text{ Hz}}$$

$$= 4.87\times10^{-7}\text{ m}$$

$$\Delta\lambda = \pm\frac{v}{c}\lambda$$

$$\Delta\lambda = \pm\frac{v_{rot}}{c}\lambda$$

$$= \pm\frac{(2.04\times10^3\text{ m/s})}{(3.00\times10^8\text{ m/s})}(4.87\times10^{-7}\text{ m})$$

$$= \pm3.3\times10^{-12}\text{ m}$$

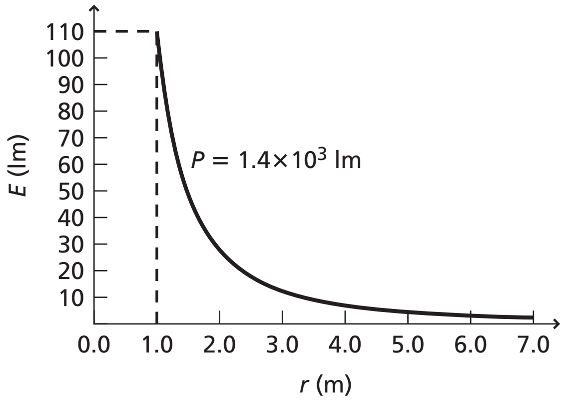
Thinking Critically

page 454

70. **Research** Why did Galileo's method for measuring the speed of light not work?

It was not precise enough. He was not able to measure the small time intervals involved in a terrestrial measurement.

71. **Make and Use Graphs** A 110-cd light source is 1.0 m from a screen. Determine the illumination on the screen originally and for every meter of increasing distance up to 7.0 m. Graph the data.



a. What is the shape of the graph?

hyperbola

b. What is the relationship between illuminance and distance shown by the graph?

inverse square

72. **Analyze and Conclude** If you were to drive at sunset in a city filled with buildings that have glass-covered walls, the setting Sun reflected off the building's walls might temporarily blind you. Would polarizing glasses solve this problem?

Yes. Light reflected off glass is partially polarized, so polarizing sunglasses will reduce much of the glare, if the sunglasses are aligned correctly.

Writing in Physics

page 454

73. Write an essay describing the history of human understanding of the speed of light. Include significant individuals and the contribution that each individual made.

Answers will vary.

74. Look up information on the SI unit *candela*, cd, and explain in your own words the standard that is used to set the value of 1 cd.

Answers will vary. Begin with the element thorium. Heat it to the melting point of platinum. At this temperature, the thorium will glow. Surround the thorium with an opaque material that can take the high temperature. Leave an opening that is one-sixtieth of a square centimeter in size. The candela is defined as the amount of steady flow of light energy that is emitted by the thorium through the opening under these conditions.

Cumulative Review

page 454

75. A 2.0-kg object is attached to a 1.5-m long string and swung in a vertical circle at a constant speed of 12 m/s. (Chapter 7)

a. What is the tension in the string when the object is at the bottom of its path?

$$F_{net} = \frac{mv^2}{r} = \frac{(2.0\ kg)(12\ m/s)^2}{1.5\ m}$$

$$= 1.9\times10^1\ N$$

$$F_g = mg = (2.0\ kg)(9.80\ m/s^2)$$

$$= 2.0\times10^2\ N$$

$$F_{net} = T - F_g$$

$$T = F_{net} + F_g$$

$$= 1.9\times10^2\ N + 0.20\times10^2\ N$$

$$= 2.1\times10^2\ N$$

b. What is the tension in the string when the object is at the top of its path?

$$F_{net} = T + F_g$$

$$T = F_{net} - F_g$$

$$= 1.9\times10^2\ N - 0.20\times10^2\ N$$

$$= 1.7\times10^2\ N$$

76. A space probe with a mass of 7.600×10^3 kg is traveling through space at 125 m/s. Mission control decides that a course correction of 30.0° is needed and instructs the probe to fire rockets perpendicular to its present direction of motion. If the gas expelled by the rockets has a speed of 3.200 km/s, what mass of gas should be released? (Chapter 9)

$$\tan 30.0° = \frac{m_g \Delta v_g}{m_p v_{p1}}$$

$$m_g = \frac{m_p v_{p1}(\tan 30.0°)}{\Delta v_g}$$

$$= \frac{(7.600\times10^3 \text{ kg})(125 \text{ m/s})(\tan 30.0°)}{3.200\times10^3 \text{ m/s}}$$

$$= 171 \text{ kg}$$

77. When a 60.0-cm-long guitar string is plucked in the middle, it plays a note of frequency 440 Hz. What is the speed of the waves on the string? (Chapter 14)

$$\lambda = 2L = 2(0.600 \text{ m}) = 1.20 \text{ m}$$

$$v = \lambda f = (1.20 \text{ m})(440 \text{ Hz}) = 530 \text{ m/s}$$

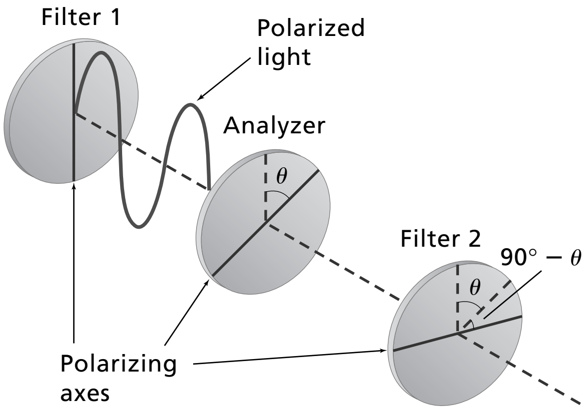
78. What is the wavelength of a sound wave with a frequency of 17,000 Hz in water at 25°C? (Chapter 15)

$$\lambda = \frac{v}{f} = \frac{1493 \text{ m/s}}{17{,}000 \text{ Hz}} = 0.0878 \text{ m} = 8.8 \text{ cm}$$

Challenge Problem

page 444

You place an analyzer filter between the two cross-polarized filters, such that its polarizing axis is not parallel to either of the two filters, as shown in the figure to the right.



1. You observe that some light passes through filter 2, though no light passed through filter 2 previous to inserting the analyzer filter. Why does this happen?

The analyzer filter allows some light to pass through, since its polarizing axis is not perpendicular to the polarizing axis of the first filter. The last polarizing filter now can pass light from the analyzer filter, since the polarizing axis of the analyzer filter is not perpendicular to the polarizing axis of the last polarizing filter.

2. The analyzer filter is placed at an angle of θ relative to the polarizing axes of filter 1. Derive an equation for the intensity of light coming out of filter 2 compared to the intensity of light coming out of filter 1.

I_1 is the light intensity out of the first filter, $I_{analyzer}$ is the light intensity out of the analyzer filter, and I_2 is the light intensity out of the last filter.

$$I_{analyzer} = I_1 \cos^2 \theta$$

$$I_2 = I_{analyzer} \cos^2(90° - \theta)$$

$$I_2 = I_1 \cos^2(\theta) \cos^2(90° - \theta)$$

CHAPTER

17 Reflection and Mirrors

Practice Problems

17.1 Reflection from Plane Mirrors pages 457–463

page 460

1. Explain why the reflection of light off ground glass changes from diffuse to specular if you spill water on it.

Water fills in the rough areas and makes the surface smoother.

2. If the angle of incidence of a ray of light is 42°, what is each of the following?

a. the angle of reflection

$\theta_r = \theta_i = 42°$

b. the angle the incident ray makes with the mirror

$\theta_{i,\ mirror} = 90° - \theta_i = 90° - 42° = 48°$

c. the angle between the incident ray and the reflected ray

$\theta_i + \theta_r = 2\theta_i = 84°$

3. If a light ray reflects off a plane mirror at an angle of 35° to the normal, what was the angle of incidence of the ray?

$\theta_i = \theta_r = 35°$

4. Light from a laser strikes a plane mirror at an angle of 38° to the normal. If the laser is moved so that the angle of incidence increases by 13°, what is the new angle of reflection?

$\theta_i = \theta_{i,\ initial} + 13°$

$= 38° + 13° = 51°$

$\theta_r = \theta_i = 51°$

5. Two plane mirrors are positioned at right angles to one another. A ray of light strikes one mirror at an angle of 30° to the normal. It then reflects toward the second mirror. What is the angle of reflection of the light ray off the second mirror?

$\theta_{r1} = \theta_{i1} = 30°$

$\theta_{i2} = 90° - \theta_{r1}$

$= 90° - 30° = 60°$

Section Review

17.1 Reflection from Plane Mirrors pages 457–463

page 463

6. Reflection A light ray strikes a flat, smooth, reflecting surface at an angle of 80° to the normal. What is the angle that the reflected ray makes with the surface of the mirror?

$\theta_r = \theta_i$

$= 80°$

$\theta_{r,\ mirror} = 90° - \theta_r$

$= 90° - 80°$

$= 10°$

7. Law of Reflection Explain how the law of reflection applies to diffuse reflection.

The law of reflection applies to individual rays of light. Rough surfaces make the light rays reflect in many different directions.

8. Reflecting Surfaces Categorize each of the following as a specular or a diffuse reflecting surface: paper, polished metal, window glass, rough metal, plastic milk jug, smooth water surface, and ground glass.

Specular: window glass, smooth water, polished metal. Diffuse: paper, rough metal, ground glass, plastic milk jug.

9. Image Properties A 50-cm-tall dog stands 3 m from a plane mirror and looks at its image. What is the image position, height, and type?

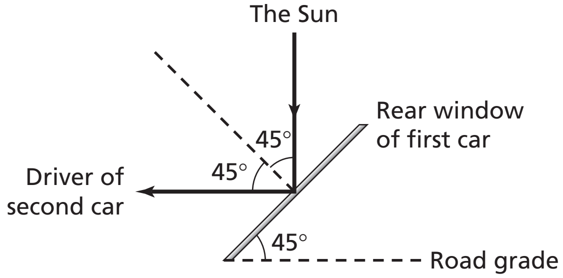
$d_i = d_o$

$= 3\ m$

$h_i = h_o$
$= 50$ cm

The image is virtual.

10. Image Diagram A car is following another car down a straight road. The first car has a rear window tilted 45°. Draw a ray diagram showing the position of the Sun that would cause sunlight to reflect into the eyes of the driver of the second car.



The Sun's position directly overhead would likely reflect light into the driver's eyes, according to the law of reflection.

11. Critical Thinking Explain how diffuse reflection of light off an object enables you to see an object from any angle.

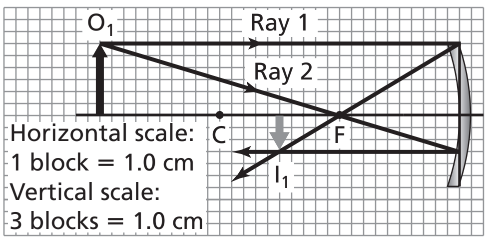
The incoming light reflects off the surface of the object in all directions. This enables you to view the object from any location.

Practice Problems

17.2 Curved Mirrors pages 464–473

page 469

12. Use a ray diagram, drawn to scale, to solve Example Problem 2.



13. An object is 36.0 cm in front of a concave mirror with a 16.0-cm focal length. Determine the image position.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(36.0 \text{ cm})(16.0 \text{ cm})}{36.0 \text{ cm} - 16.0 \text{ cm}}$$

$$= 28.8 \text{ cm}$$

14. A 3.0-cm-tall object is 20.0 cm from a 16.0-cm-radius concave mirror. Determine the image position and image height.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(20.0 \text{ cm})\left(\frac{16.0 \text{ cm}}{2}\right)}{20.0 \text{ cm} - \left(\frac{16.0 \text{ cm}}{2}\right)} = 13.3 \text{ cm}$$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o} = \frac{-(13.3 \text{ cm})(3.0 \text{ cm})}{20.0 \text{ cm}}$$

$$= -2.0 \text{ cm}$$

15. A concave mirror has a 7.0-cm focal length. A 2.4-cm-tall object is 16.0 cm from the mirror. Determine the image height.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(16.0 \text{ cm})(7.0 \text{ cm})}{16.0 \text{ cm} - 7.0 \text{ cm}}$$

$$= 12.4 \text{ cm}$$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(12.4 \text{ cm})(2.4 \text{ cm})}{16.0 \text{ cm}}$$

$$= -1.9 \text{ cm}$$

16. An object is near a concave mirror of 10.0-cm focal length. The image is 3.0 cm tall, inverted, and 16.0 cm from the mirror. What are the object position and object height?

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_o = \frac{d_i f}{d_i - f}$$

$$= \frac{(16.0\text{ cm})(10.0\text{ cm})}{16.0\text{ cm} - 10.0\text{ cm}}$$

$$= 26.7\text{ cm}$$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

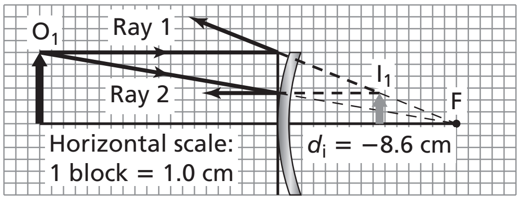
$$h_o = \frac{-d_o h_i}{d_i}$$

$$= \frac{-(26.7\text{ cm})(-3.0\text{ cm})}{16.0\text{ cm}}$$

$$= 5.0\text{ cm}$$

page 472

17. An object is located 20.0 cm in front of a convex mirror with a −15.0-cm focal length. Find the image position using both a scale diagram and the mirror equation.



$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

$$\text{so } d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(20.0\text{ cm})(-15.0\text{ cm})}{20.0\text{ cm} - (-15.0\text{ cm})}$$

$$= -8.57\text{ cm}$$

18. A convex mirror has a focal length of −13.0 cm. A lightbulb with a diameter of 6.0 cm is placed 60.0 cm from the mirror. What is the lightbulb's image position and diameter?

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(60.0\text{ cm})(-13.0\text{ cm})}{60.0\text{ cm} - (-13.0\text{ cm})}$$

$$= -10.7\text{ cm}$$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$m = \frac{-(-10.7\text{ cm})}{60.0\text{ cm}}$$

$$= +0.178$$

$$h_i = mh_o = (0.178)(6.0\text{ cm})$$

$$= 1.1\text{ cm}$$

19. A convex mirror is needed to produce an image that is three-fourths the size of an object and located 24 cm behind the mirror. What focal length should be specified?

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$f = \frac{d_o d_i}{d_o + d_i} \text{ and } m = \frac{-d_i}{d_o}$$

$$\text{so } d_o = \frac{-d_i}{m}$$

$d_i = -24$ **cm and** $m = 0.75$**, so**

$$d_o = \frac{-(-24\text{ cm})}{0.75}$$

$$= 32\text{ cm}$$

$$f = \frac{(32\text{ cm})(-24\text{ cm})}{32\text{ cm} + (-24\text{ cm})}$$

$$= -96\text{ cm}$$

20. A 7.6-cm-diameter ball is located 22.0 cm from a convex mirror with a radius of curvature of 60.0 cm. What are the ball's image position and diameter?

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(22.0\text{ cm})(-30.0\text{ cm})}{22.0\text{ cm} - (-30.0\text{ cm})}$$

$$= -12.7\text{ cm}$$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(-12.7\text{ cm})(7.6\text{ cm})}{22.0\text{ cm}}$$

$$= 4.4\text{ cm}$$

21. A 1.8-m-tall girl stands 2.4 m from a store's security mirror. Her image appears to be 0.36 m tall. What is the focal length of the mirror?

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$d_i = \frac{-d_o h_i}{h_o}$$

$$= \frac{-(2.4\text{ m})(0.36\text{ m})}{1.8\text{ m}}$$

$$= -0.48\text{ m}$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$f = \frac{d_i d_o}{d_i + d_o}$$

$$= \frac{(-0.48\text{ m})(2.4\text{ m})}{-0.48\text{ m} + 2.4\text{ m}}$$

$$= -0.60\text{ m}$$

Section Review

17.2 Curved Mirrors pages 464–473

page 473

22. Image Properties If you know the focal length of a concave mirror, where should you place an object so that its image is upright and larger compared to the object? Will this produce a real or virtual image?

You should place the object between the mirror and the focal point. The image will be virtual.

23. Magnification An object is placed 20.0 cm in front of a concave mirror with a focal length of 9.0 cm. What is the magnification of the image?

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(20.0\text{ cm})(9.0\text{ cm})}{20.0\text{ cm} - 9.0\text{ cm}}$$

$$= 16.4\text{ cm}$$

$$m = \frac{-d_i}{d_o}$$

$$= \frac{-16.4\text{ cm}}{20.0\text{ cm}}$$

$$= -0.82$$

24. Object Position The placement of an object in front of a concave mirror with a focal length of 12.0 cm forms a real image that is 22.3 cm from the mirror. What is the object position?

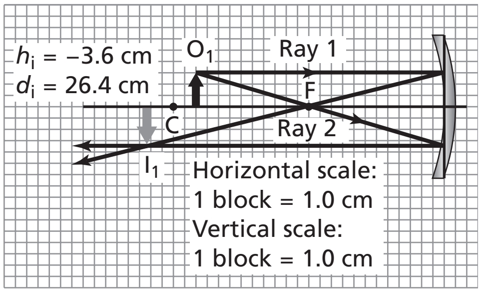
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_o = \frac{d_i f}{d_i - f}$$

$$= \frac{(22.3\text{ cm})(12.0\text{ cm})}{22.3\text{ cm} - 12.0\text{ cm}}$$

$$= 26.0\text{ cm}$$

25. Image Position and Height A 3.0-cm-tall object is placed 22.0 cm in front of a concave mirror having a focal length of 12.0 cm. Find the image position and height by drawing a ray diagram to scale. Verify your answer using the mirror and magnification equations.



$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$= \frac{(22.0 \text{ cm})(12.0 \text{ cm})}{22.0 \text{ cm} - 12.0 \text{ cm}}$

$= 26.4 \text{ cm}$

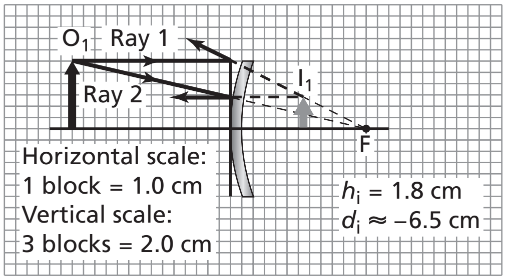
$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$

$h_i = \frac{-d_i h_o}{d_o}$

$= \frac{-(26.4 \text{ cm})(3.0 \text{ cm})}{22.0 \text{ cm}}$

$= -3.6 \text{ cm}$

26. Ray Diagram A 4.0-cm-tall object is located 14.0 cm from a convex mirror with a focal length of −12.0 cm. Draw a scale ray diagram showing the image position and height. Verify your answer using the mirror and magnification equations.



$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

$d_i = \frac{d_o f}{d_o - f}$

$= \frac{(14.0 \text{ cm})(-12.0 \text{ cm})}{14.0 \text{ cm} - (-12.0 \text{ cm})}$

$= -6.46 \text{ cm}$

$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$

$h_i = \frac{-d_i h_o}{d_o}$

$= \frac{-(-6.46 \text{ cm})(4.0 \text{ cm})}{14.0 \text{ cm}}$

$= 1.8 \text{ cm}$

27. Radius of Curvature A 6.0-cm-tall object is placed 16.4 cm from a convex mirror. If the image of the object is 2.8 cm tall, what is the radius of curvature of the mirror?

$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$

$d_i = \frac{-d_o h_i}{h_o}$

$= \frac{-(16.4 \text{ cm})(2.8 \text{ cm})}{6.0 \text{ cm}}$

$= -7.7 \text{ cm}$

$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

$f = \frac{d_o d_i}{d_o + d_i}$

$= \frac{(-7.7 \text{ cm})(16.4 \text{ cm})}{-7.7 \text{ cm} + 16.4 \text{ cm}}$

$= -14.5 \text{ cm}$

$r = 2|f|$

$= (2)(|-14.5 \text{ cm}|)$

$= 29 \text{ cm}$

28. Focal Length A convex mirror is used to produce an image that is two-thirds the size of an object and located 12 cm behind the mirror. What is the focal length of the mirror?

$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$

$d_o = \frac{-d_i}{m}$

$= \frac{-(-12 \text{ cm})}{\left(\frac{2}{3}\right)}$

$= 18 \text{ cm}$

$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

$f = \frac{d_o d_i}{d_o + d_i}$

$= \frac{(-12 \text{ cm})(18 \text{ cm})}{-12 \text{ cm} + 18 \text{ cm}}$

$= -36 \text{ cm}$

29. Critical Thinking Would spherical aberration be less for a mirror whose height, compared to its radius of curvature, is small or large? Explain.

It would be less for a mirror whose height is relatively small compared to

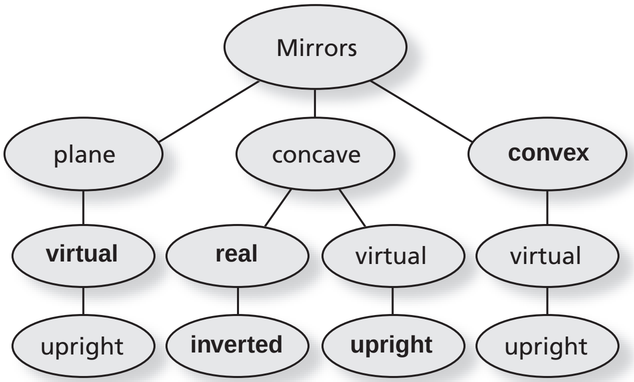
its radius of curvature; diverging light rays from an object that strike the mirror are more paraxial so they converge more closely to create an image that is not blurred.

Chapter Assessment

Concept Mapping

page 478

30. Complete the following concept map using the following terms: *convex, upright, inverted, real, virtual.*



Mastering Concepts

page 478

31. How does specular reflection differ from diffuse reflection? (17.1)

When parallel light is reflected from a smooth surface, the rays are reflected parallel to each other. The result is an image of the origin of the rays. When light is reflected from a rough surface, it is reflected in many different directions. The rays are diffused or scattered. No image of the source results.

32. What is meant by the phrase "normal to the surface"? (17.1)

any line that is perpendicular to the surface at any point

33. Where is the image produced by a plane mirror located? (17.1)

The image is on a line that is perpendicular to the mirror and the same distance behind the mirror as the object is in front of the mirror.

34. Describe the properties of a plane mirror. (17.1)

A plane mirror is a flat, smooth surface from which light is reflected by specular reflection. The images created by plane mirrors are virtual, upright, and as far behind the mirror as the object is in front of it.

35. A student believes that very sensitive photographic film can detect a virtual image. The student puts photographic film at the location of a virtual image. Does this attempt succeed? Explain. (17.1)

No, the rays do not converge at a virtual image. No image forms and the student would not get a picture. Some virtual images are behind the mirror.

36. How can you prove to someone that an image is a real image? (17.1)

Place a sheet of plain paper or photographic film at the image location and you should be able to find the image.

37. An object produces a virtual image in a concave mirror. Where is the object located? (17.2)

Object must be located between *F* and the mirror.

38. What is the defect that all concave spherical mirrors have and what causes it? (17.2)

Rays parallel to the axis that strike the edges of a concave spherical mirror are not reflected through the focal point. This effect is called spherical aberration.

39. What is the equation relating the focal point, object position, and image position? (17.2)

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

40. What is the relationship between the center of curvature and the focal length of a concave mirror? (17.2)

$C = 2f$

41. If you know the image position and object position relative to a curved mirror, how can you determine the mirror's magnification? (17.2)

The magnification is equal to the negative of the image distance divided by the object distance.

42. Why are convex mirrors used as rearview mirrors? (17.2)

Convex mirrors are used as rearview mirrors because they allow for a wide range of view, allowing the driver to see a much larger area than is afforded by ordinary mirrors.

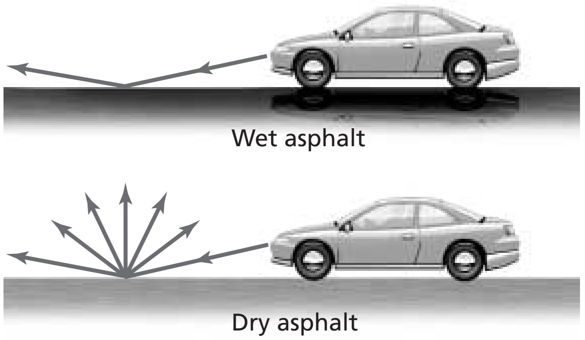
43. Why is it impossible for a convex mirror to form a real image? (17.2)

The light rays always diverge.

Applying Concepts

pages 478–479

44. **Wet Road** A dry road is more of a diffuse reflector than a wet road. Based on **Figure 17-16,** explain why a wet road appears blacker to a driver than a dry road does.



■ **Figure 17-16**

Less light is reflected back to the car from a wet road.

45. **Book Pages** Why is it desirable that the pages of a book be rough rather than smooth and glossy?

The smoother and glossier the pages are, the lesser the diffuse reflection of light and the greater the glare from the pages.

46. Locate and describe the physical properties of the image produced by a concave mirror when the object is located at the center of curvature.

The image will be at *C,* the center of curvature, inverted, real, and the same size as the object.

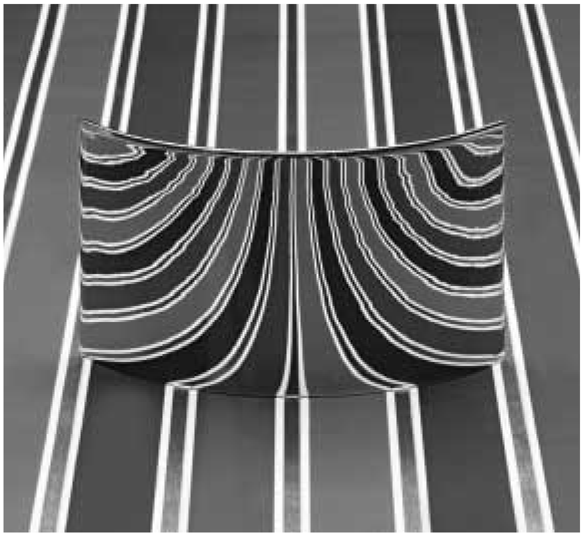
47. An object is located beyond the center of curvature of a spherical concave mirror. Locate and describe the physical properties of the image.

The image will be between *C* and *F,* and will be inverted, real, and smaller than the object.

48. **Telescope** You have to order a large concave mirror for a telescope that produces high-quality images. Should you order a spherical mirror or a parabolic mirror? Explain.

You should order a parabolic mirror to eliminate spherical aberrations.

49. Describe the properties of the image seen in the single convex mirror in **Figure 17-17.**



■ **Figure 17-17**

The image in a single convex mirror is always virtual, erect, smaller than the object, and located closer to the mirror than the object.

50. List all the possible arrangements in which you could use a spherical mirror, either concave or convex, to form a real image.

You can use only a concave mirror with the object beyond the focal point. A convex mirror will not form a real image.

51. List all possible arrangements in which you could use a spherical mirror, either concave or convex, to form an image that is smaller compared to the object.

You may use a concave mirror with the object beyond the center of curvature or a convex mirror with the object anywhere.

52. **Rearview Mirrors** The outside rearview mirrors of cars often carry the warning "Objects in the mirror are closer than they appear." What kind of mirrors are these and what advantage do they have?

Convex mirror; it provides a wider field of view.

Mastering Problems

17.1 Reflection from Plane Mirrors

page 479

Level 1

53. A ray of light strikes a mirror at an angle of 38° to the normal. What is the angle that the reflected angle makes with the normal?

$$\theta_r = \theta_i = 38°$$

54. A ray of light strikes a mirror at an angle of 53° to the normal.

a. What is the angle of reflection?

$$\theta_r = \theta_i = 53°$$

b. What is the angle between the incident ray and the reflected ray?

$$\theta = \theta_i + \theta_r = 53° + 53° = 106°$$

55. A ray of light incident upon a mirror makes an angle of 36° with the mirror. What is the angle between the incident ray and the reflected ray?

$$\theta_i = 90° - 36° = 54°$$

$$\theta_r = \theta_i = 54°$$

$$\theta = \theta_i + \theta_r = 54° + 54° = 108°$$

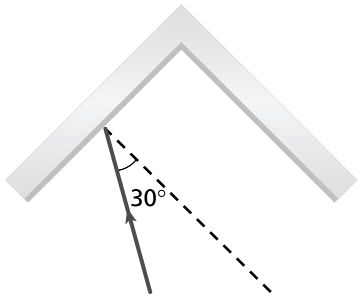
Level 2

56. **Picture in a Mirror** Penny wishes to take a picture of her image in a plane mirror, as shown in **Figure 17-18.** If the camera is 1.2 m in front of the mirror, at what distance should the camera lens be focused?

■ **Figure 17-18**

The image is 1.2 m behind the mirror, so the camera lens should be set to 2.4 m.

57. Two adjacent plane mirrors form a right angle, as shown in **Figure 17-19.** A light ray is incident upon one of the mirrors at an angle of 30° to the normal.



■ **Figure 17-19**

a. What is the angle at which the light ray is reflected from the other mirror?

Reflection from the first mirror:

$\theta_{r1} = \theta_{i1} = 30°$

Reflection from the second mirror:

$\theta_{i2} = 90° - \theta_{r1}$

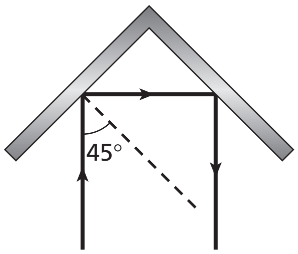
$= 90° - 30°$

$= 60°$

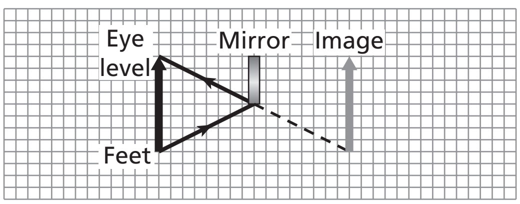
$\theta_{r2} = \theta_{i2}$

$= 60°$

b. A retroreflector is a device that reflects incoming light rays back in a direction opposite to that of the incident rays. Draw a diagram showing the angle of incidence on the first mirror for which the mirror system acts as a retroreflector.



58. Draw a ray diagram of a plane mirror to show that if you want to see yourself from your feet to the top of your head, the mirror must be at least half your height.



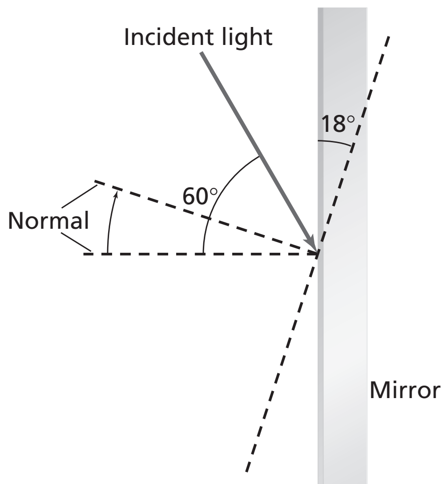
The ray from the top of the head hits the mirror halfway between the eyes and the top of the head. The ray from the feet hits the mirror halfway between the eyes and the feet. The distance between the point the two rays hit the mirror is half the total height.

Level 3

59. Two plane mirrors are connected at their sides so that they form a 45° angle between them. A light ray strikes one mirror at an angle of 30° to the normal and then reflects off the second mirror. Calculate the angle of reflection of the light ray off the second mirror.

Reflection from the first mirror is $\theta_{r,1} = \theta_{i,1} = 30°$. The angle the ray forms with the mirror is thus $90° - 30° = 60°$. Because the two mirrors form a 45° angle, the angle the ray reflecting off the first mirror forms with the second mirror is $180° - 60° - 45° = 75°$. The angle the ray forms with the second mirror is thus $\theta_{i,2} = 90° - 75° = 15°$. The angle of reflection from the second mirror is $\theta_{r,2} = \theta_{i,2} = 15°$.

60. A ray of light strikes a mirror at an angle of 60° to the normal. The mirror is then rotated 18° clockwise, as shown in **Figure 17-20.** What is the angle that the reflected ray makes with the mirror?



■ **Figure 17-20**

$\theta_i = \theta_{i,\,old} - 18°$

$= 60° - 18°$

$= 42°$

$\theta_r = \theta_i$

$= 42°$

$\theta_{r,\ mirror} = 90° - \theta_r$

$= 90° - 42°$

$= 48°$

17.2 Curved Mirrors

page 480

Level 1

61. A concave mirror has a focal length of 10.0 cm. What is its radius of curvature?

$r = 2f = 2(10.0\text{ cm}) = 20.0\text{ cm}$

62. An object located 18 cm from a convex mirror produces a virtual image 9 cm from the mirror. What is the magnification of the image?

$$m = \frac{-d_i}{d_o}$$

$$= \frac{-(-9\text{ cm})}{18\text{ cm}}$$

$$= 0.5$$

63. Fun House A boy is standing near a convex mirror in a fun house at a fair. He notices that his image appears to be 0.60 m tall. If the magnification of the mirror is $\frac{1}{3}$, what is the boy's height?

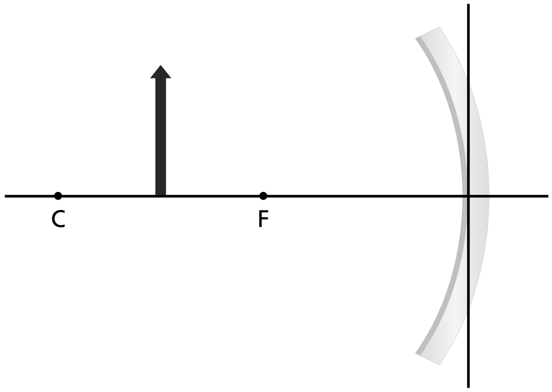
$$m = \frac{h_i}{h_o}$$

$$h_o = \frac{h_i}{m}$$

$$= \frac{0.60\text{ m}}{\left(\frac{1}{3}\right)}$$

$$= 1.8\text{ m}$$

64. Describe the image produced by the object in **Figure 17-21** as real or virtual, inverted or upright, and smaller or larger than the object.



■ **Figure 17-21**

real; inverted; larger

Level 2

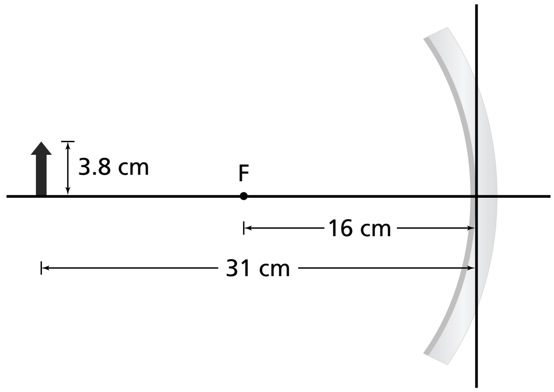
65. Star Image Light from a star is collected by a concave mirror. How far from the mirror is the image of the star if the radius of curvature is 150 cm?

Stars are far enough away that the light coming into the mirror can be considered to be parallel and parallel light will converge at the focal point.

Since $r = 2f$,

$$f = \frac{r}{2} = \frac{150\text{ cm}}{2} = 75\text{ cm}$$

66. Find the image position and height for the object shown in **Figure 17-22.**



■ **Figure 17-22**

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(31\text{ cm})(16\text{ cm})}{31\text{ cm} - 16\text{ cm}}$$

$= 33\ \text{cm}$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(33\ \text{cm})(3.8\ \text{cm})}{31\ \text{cm}}$$

$= -4.1\ \text{cm}$

67. Rearview Mirror How far does the image of a car appear behind a convex mirror, with a focal length of −6.0 m, when the car is 10.0 m from the mirror?

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(10.0\ \text{m})(-6.0\ \text{m})}{10.0\ \text{m} - (-6.0\ \text{m})}$$

$= -3.8\ \text{m}$

68. An object is 30.0 cm from a concave mirror of 15.0 cm focal length. The object is 1.8 cm tall. Use the mirror equation to find the image position. What is the image height?

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(30.0\ \text{cm})(15.0\ \text{cm})}{30.0\ \text{cm} - 15.0\ \text{cm}}$$

$= 30.0\ \text{cm}$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(30.0\ \text{cm})(1.8\ \text{cm})}{(30.0\ \text{cm})}$$

$= -1.8\ \text{cm}$

69. Dental Mirror A dentist uses a small mirror with a radius of 40 mm to locate a cavity in a patient's tooth. If the mirror is concave and is held 16 mm from the tooth, what is the magnification of the image?

$$f = \frac{r}{2} = \frac{(40\ \text{mm})}{2} = 20\ \text{mm}$$

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

$$d_i = \frac{d_o f}{d_o - f} = \frac{(16\ \text{mm})(20\ \text{mm})}{16\ \text{mm} - 20\ \text{mm}} = -80\ \text{mm}$$

$$m = \frac{-d_i}{d_o} = \frac{-(-80\ \text{mm})}{16\ \text{mm}} = 5$$

70. A 3.0-cm-tall object is 22.4 cm from a concave mirror. If the mirror has a radius of curvature of 34.0 cm, what are the image position and height?

$$f = \frac{r}{2}$$

$$= \frac{34.0\ \text{cm}}{2}$$

$= 17.0\ \text{cm}$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(22.4\ \text{cm})(17.0\ \text{cm})}{22.4\ \text{cm} - 17.0\ \text{cm}}$$

$= 70.5\ \text{cm}$

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(70.5\ \text{cm})(3.0\ \text{cm})}{22.4\ \text{cm}}$$

$= -9.4\ \text{cm}$

Level 3

71. Jeweler's Mirror A jeweler inspects a watch with a diameter of 3.0 cm by placing it 8.0 cm in front of a concave mirror of 12.0-cm focal length.

a. Where will the image of the watch appear?

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

$$d_i = \frac{d_o f}{d_o - f} = \frac{(8.0\text{ cm})(12.0\text{ cm})}{8.0\text{ cm} - 12.0\text{ cm}}$$

$$= -24\text{ cm}$$

b. What will be the diameter of the image?

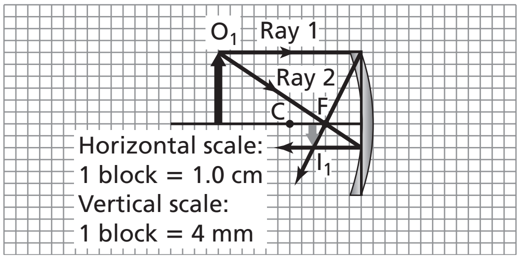
$$\frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o} = \frac{-(-24\text{ cm})(3.0\text{ cm})}{8.0\text{ cm}}$$

$$= 9.0\text{ cm}$$

72. Sunlight falls on a concave mirror and forms an image that is 3.0 cm from the mirror. An object that is 24 mm tall is placed 12.0 cm from the mirror.

a. Sketch the ray diagram to show the location of the image.



b. Use the mirror equation to calculate the image position.

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

$$d_i = \frac{f d_o}{d_o - f} = \frac{(3.0\text{ cm})(12.0\text{ cm})}{12.0\text{ cm} - 3.0\text{ cm}}$$

$$= 4.0\text{ cm}$$

c. How tall is the image?

$$m = \frac{-d_i}{d_o} = \frac{-4.0\text{ cm}}{12.0\text{ cm}} = -0.33$$

$$h_i = m h_o = (-0.33)(24\text{ mm})$$

$$= -8.0\text{ mm}$$

73. Shiny spheres that are placed on pedestals on a lawn are convex mirrors. One such sphere has a diameter of 40.0 cm. A 12-cm-tall robin sits in a tree that is 1.5 m from the sphere. Where is the image of the robin and how tall is the image?

$r = 20.0\text{ cm}, f = -10.0\text{ cm}$

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

$$d_i = \frac{f d_o}{d_o - f}$$

$$= \frac{(-10.0\text{ cm})(150\text{ cm})}{150\text{ cm} - (-10.0\text{ cm})} = -9.4\text{ cm}$$

$$m = \frac{-d_i}{d_o} = \frac{-(-9.4\text{ cm})}{150\text{ cm}} = +0.063$$

$$h_i = m h_o = (0.063)(12\text{ cm}) = 0.75\text{ cm}$$

Mixed Review

pages 480–481

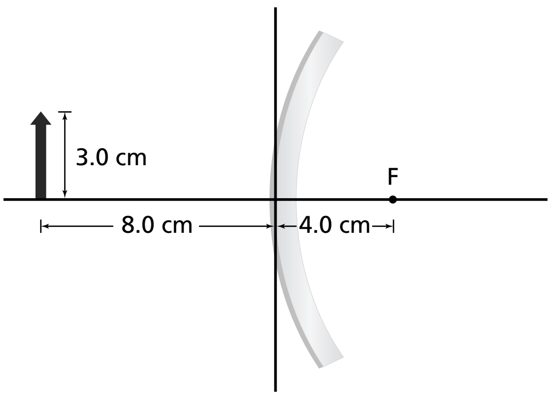
Level 1

74. A light ray strikes a plane mirror at an angle of 28° to the normal. If the light source is moved so that the angle of incidence increases by 34°, what is the new angle of reflection?

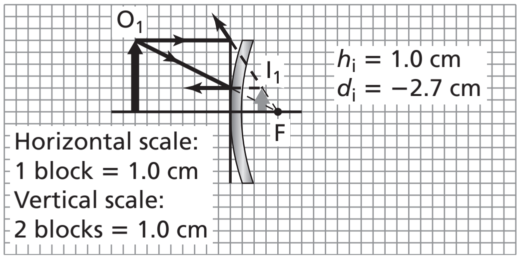
$$\theta_i = \theta_{i,\text{ initial}} + 34°$$
$$= 28° + 34°$$
$$= 62°$$

$$\theta_r = \theta_i$$
$$= 62°$$

75. Copy **Figure 17-23** on a sheet of paper. Draw rays on the diagram to determine the height and location of the image.



■ **Figure 17-23**



The image height is 1.0 cm, and its location is 2.7 cm from the mirror.

Level 2

76. An object is located 4.4 cm in front of a concave mirror with a 24.0-cm radius. Locate the image using the mirror equation.

$$f = \frac{r}{2} = \frac{24.0\text{ cm}}{2} = 12.0\text{ cm}$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f} = \frac{(4.4\text{ cm})(12.0\text{ cm})}{4.4\text{ cm} - 12.0\text{ cm}} = -6.9\text{ cm}$$

77. A concave mirror has a radius of curvature of 26.0 cm. An object that is 2.4 cm tall is placed 30.0 cm from the mirror.

a. Where is the image position?

$$f = \frac{r}{2} = \frac{26.0\text{ cm}}{2} = 13.0\text{ cm}$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f} = \frac{(30.0\text{ cm})(13.0\text{ cm})}{30.0\text{ cm} - 13.0\text{ cm}} = 22.9\text{ cm}$$

b. What is the image height?

$$m = \frac{h_i}{h_o}$$

$$h_i = \frac{-d_i h_o}{d_o} = \frac{-(22.9\text{ cm})(2.4\text{ cm})}{30.0\text{ cm}} = -1.8\text{ cm}$$

78. What is the radius of curvature of a concave mirror that magnifies an object by a factor of +3.2 when the object is placed 20.0 cm from the mirror?

$$m = \frac{h_i}{h_o}$$

$$d_i = -md_o = -(3.2)(20.0\text{ cm}) = -64\text{ cm}$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$f = \frac{d_o d_i}{d_o + d_i} = \frac{(20.0\text{ cm})(-64\text{ cm})}{20.0\text{ cm} + (-64\text{ cm})} = 29\text{ cm}$$

$$r = 2f = (2)(29\text{ cm}) = 58\text{ cm}$$

79. A convex mirror is needed to produce an image one-half the size of an object and located 36 cm behind the mirror. What focal length should the mirror have?

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$d_o = \frac{-d_i h_o}{h_i} = \frac{-(-36\text{ cm})h_o}{\left(\frac{h_o}{2}\right)} = 72\text{ cm}$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$f = \frac{d_o d_i}{d_o + d_i}$$

$$= \frac{(72\text{ cm})(-36\text{ cm})}{72\text{ cm} + (-36\text{ cm})}$$

$$= -72\text{ cm}$$

80. Surveillance Mirror A convenience store uses a surveillance mirror to monitor the store's aisles. Each mirror has a radius of curvature of 3.8 m.

a. What is the image position of a customer who stands 6.5 m in front of the mirror?

A mirror that is used for surveillance is a convex mirror. So the focal length is the negative of half the radius of curvature.

$$f = \frac{-r}{2}$$

$$= \frac{-3.8\text{ m}}{2}$$

$$= -1.9\text{ m}$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(6.5\text{ m})(-1.9\text{ m})}{6.5\text{ m} - (-1.9\text{ m})}$$

$$= -1.5\text{ m}$$

b. What is the image height of a customer who is 1.7 m tall?

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(-1.5\text{ m})(1.7\text{ m})}{6.5\text{ m}}$$

$$= 0.38\text{ m}$$

Level 3

81. Inspection Mirror A production-line inspector wants a mirror that produces an image that is upright with a magnification of 7.5 when it is located 14.0 mm from a machine part.

a. What kind of mirror would do this job?

An enlarged, upright image results only from a concave mirror, with the object inside the focal length.

b. What is its radius of curvature?

$$m = \frac{-d_i}{d_o}$$

$$d_i = -md_o = -(7.5)(14.0\text{ mm})$$

$$= -105\text{ mm}$$

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

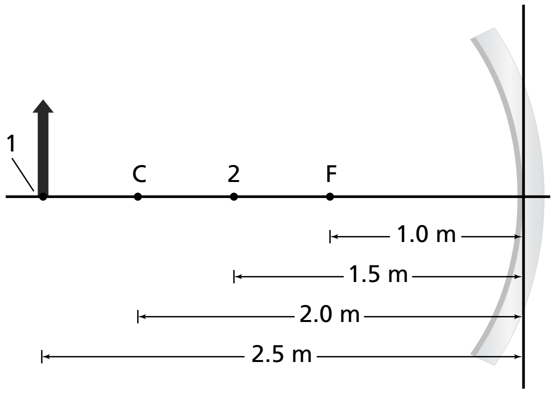
$$f = \frac{d_o d_i}{d_i + d_o} = \frac{(14.0\text{ mm})(-105\text{ mm})}{14.0\text{ mm} + (-105\text{ mm})}$$

$$= 16\text{ mm}$$

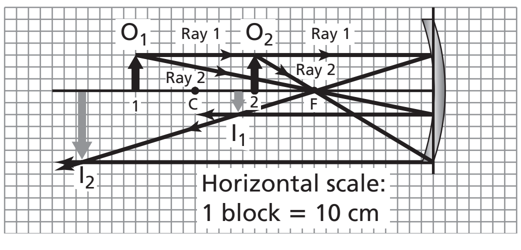
$$r = 2f = (2)(16\text{mm})$$

$$= 32\text{ mm}$$

82. The object in **Figure 17-24** moves from position 1 to position 2. Copy the diagram onto a sheet of paper. Draw rays showing how the image changes.



■ **Figure 17-24**



83. A ball is positioned 22 cm in front of a spherical mirror and forms a virtual image. If the spherical mirror is replaced with a plane mirror, the image appears 12 cm closer to the mirror. What kind of spherical mirror was used?

The object position for both mirrors is 22 cm. So, the image position for the plane mirror is −22 cm.

Because the spherical mirror forms a virtual image, the image is located behind the mirror. Thus, the image position for the spherical mirror is negative.

$$d_i = d_{i,\ plane} - 12\ cm$$

$$= -22\ cm - 12\ cm$$

$$= -34\ cm$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$f = \frac{d_o d_i}{d_o + d_i}$$

$$= \frac{(22\ cm)(-34\ cm)}{22\ cm + (-34\ cm)}$$

$$= 62\ cm$$

The focal length is positive, so the spherical mirror is a concave mirror.

84. A 1.6-m-tall girl stands 3.2 m from a convex mirror. What is the focal length of the mirror if her image appears to be 0.28 m tall?

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$d_i = \frac{-h_i d_o}{h_o}$$

$$= \frac{-(0.28\ m)(3.2\ m)}{1.6\ m}$$

$$= -0.56\ m$$

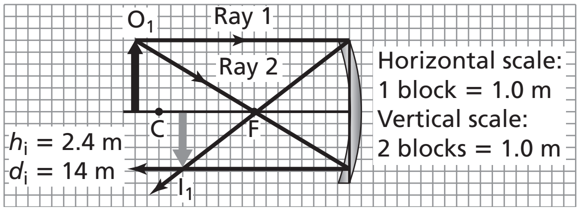
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$f = \frac{d_o d_i}{d_o + d_i}$$

$$= \frac{(3.2\ m)(-0.56\ m)}{3.2\ m + (-0.56\ m)}$$

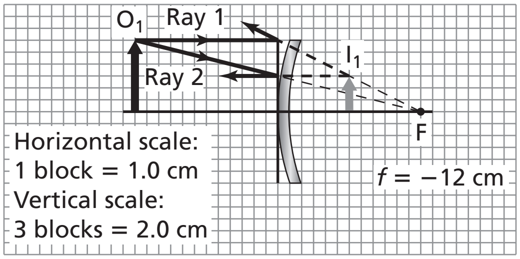
$$= -0.68\ m$$

85. Magic Trick A magician uses a concave mirror with a focal length of 8.0 m to make a 3.0-m-tall hidden object, located 18.0 m from the mirror, appear as a real image that is seen by his audience. Draw a scale ray diagram to find the height and location of the image.



The image is 2.4 m tall, and it is 14 m from the mirror.

86. A 4.0-cm-tall object is placed 12.0 cm from a convex mirror. If the image of the object is 2.0 cm tall, and the image is located at −6.0 cm, what is the focal length of the mirror? Draw a ray diagram to answer the question. Use the mirror equation and the magnification equation to verify your answer.



$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$f = \frac{d_o d_i}{d_o + d_i}$$

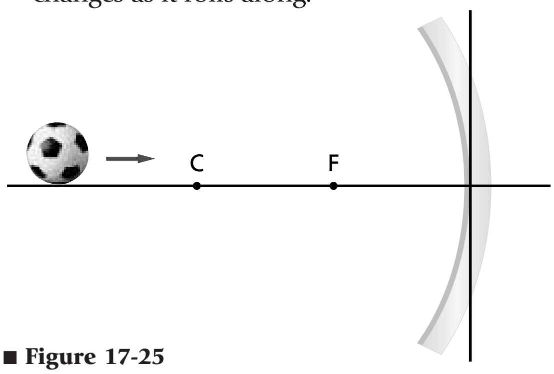
$$= \frac{(12.0\ cm)(-6.0\ cm)}{12.0\ cm + (-6.0\ cm)}$$

$$= -12\ cm$$

Thinking Critically

pages 481–482

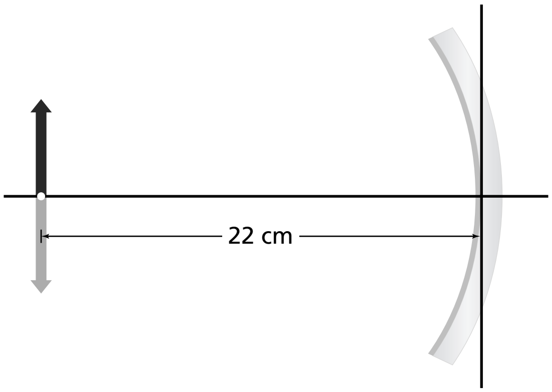
87. Apply Concepts The ball in **Figure 17-25** slowly rolls toward the concave mirror on the right. Describe how the size of the ball's image changes as it rolls along.



■ **Figure 17-25**

Beyond C, the image is smaller than the ball. As the ball rolls toward the mirror, the image size increases. The image is the same size as the ball when the ball is at C. The image size continues to increase until there is no image when the ball is at F. Past F, the size of the image decreases until it equals the ball's size when the ball touches the mirror.

88. Analyze and Conclude The object in **Figure 17-26** is located 22 cm from a concave mirror. What is the focal length of the mirror?



■ **Figure 17-26**

$$f = \frac{r}{2}$$
$$= \frac{d_o}{2}$$
$$= \frac{22\text{ cm}}{2}$$
$$= 11\text{ cm}$$

89. Use Equations Show that as the radius of curvature of a concave mirror increases to infinity, the mirror equation reduces to the relationship between the object position and the image position for a plane mirror.

As $f \rightarrow \infty$, $1/f \rightarrow 0$. The mirror equation then becomes $1/d_o = -1/d_i$, or $d_o = -d_i$.

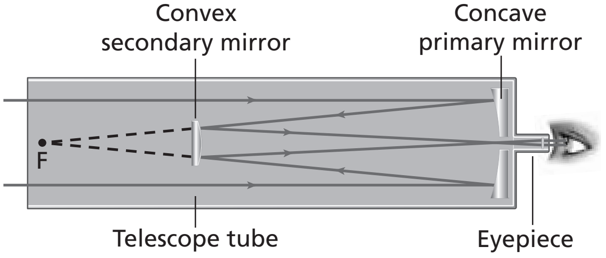
90. Analyze and Conclude An object is located 6.0 cm from a plane mirror. If the plane mirror is replaced with a concave mirror, the resulting image is 8.0 cm farther behind the mirror. Assuming that the object is located between the focal point and the concave mirror, what is the focal length of the concave mirror?

$$d_{i,\text{ initial}} = d_{o,\text{ initial}}$$
$$= 6.0\text{ cm}$$
$$d_i = d_{i,\text{ initial}} + (-8.0\text{ cm})$$
$$= -6.0\text{ cm} + (-8.0\text{ cm})$$
$$= -14.0\text{ cm}$$
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$
$$f = \frac{d_o d_i}{d_o + d_i}$$
$$f = \frac{(6.0\text{ cm})(-14.0\text{ cm})}{6.0\text{ cm} + (-14.0\text{ cm})}$$
$$f = 1.0\times10^1\text{ cm}$$

91. Analyze and Conclude The layout of the two-mirror system shown in Figure 17-11 is that of a Gregorian telescope. For this question, the larger concave mirror has a radius of curvature of 1.0 m, and the smaller mirror is located 0.75 m away. Why is the secondary mirror concave?

The smaller mirror is concave to produce a real image at the eyepiece that is upright. The light rays are inverted by the first concave mirror and then inverted again by the secondary concave mirror.

92. Analyze and Conclude An optical arrangement used in some telescopes is the Cassegrain focus, shown in **Figure 17-27.** This telescope uses a convex secondary mirror that is positioned between the primary mirror and the focal point of the primary mirror.



■ **Figure 17-27**

a. A single convex mirror produces only virtual images. Explain how the convex mirror in this telescope functions within the system of mirrors to produce real images.

The convex mirror is placed to intercept the rays from a concave mirror before they converge. The convex mirror places the point of convergence in the opposite direction back toward the concave mirror, and lengthens the total distance the light travels before converging. This effectively increases the focal length compared to using the concave mirror by itself, thus increasing the total magnification.

b. Are the images produced by the Cassegrain focus upright or inverted? How does this relate to the number of times that the light crosses?

Inverted; each time the light rays cross the image inverts.

Writing in Physics

page 482

93. Research a method used for grinding, polishing, and testing mirrors used in reflecting telescopes. You may report either on methods used by amateur astronomers who make their own telescope optics, or on a method used by a project at a national laboratory. Prepare a one-page report describing the method, and present it to the class.

Answers will vary depending on the mirrors and methods chosen by the students. Amateur methods usually involve rubbing two "blanks" against each other with varying grits between them. Methods used at national labs vary.

94. Mirrors reflect light because of their metallic coating. Research and write a summary of one of the following:

a. the different types of coatings used and the advantages and disadvantages of each

Answers will vary. Student answers should include information about shininess as well as tarnish resistance.

b. the precision optical polishing of aluminum to such a degree of smoothness that no glass is needed in the process of making a mirror

Answers will vary. Student answers might include information about deformation of a mirror from its own weight as size increases and how a mirror made of aluminum could impact this problem.

Cumulative Review

page 482

95. A child runs down the school hallway and then slides on the newly waxed floor. He was running at 4.7 m/s before he started sliding and he slid 6.2 m before stopping. What was the coefficient of friction of the waxed floor? (Chapter 11)

The work done by the waxed floor equals the child's initial kinetic energy.

$$KE = \frac{1}{2}mv^2 = W = Fd = \mu_k mgd$$

The mass of the child cancels out, giving

$$\mu_k = \frac{v^2}{2gd}$$

$$= \frac{(4.7\ \text{m/s})^2}{(2)(9.80\ \text{m/s}^2)(6.2\ \text{m})}$$

$$= 0.18$$

96. A 1.0 g piece of copper falls from a height of 1.0×10^4 m from an airplane to the ground. Because of air resistance it reaches the ground moving at a velocity of 70.0 m/s. Assuming that half of the energy lost by the piece was distributed as thermal energy to the copper, how much did it heat during the fall? (Chapter 12)

Potential energy of the piece

$$E = mgh$$

$$= (0.0010\ \text{kg})(9.80\ \text{m/s}^2)(1.0\times10^4\ \text{m})$$

$$= 9.8\ \text{J}$$

Final energy

$$E_f = \frac{1}{2}mv^2$$

$$= \frac{1}{2}(0.0010\ \text{kg})(70.0\ \text{m/s})^2$$

$$= 2.4\ \text{J}$$

Heat added to the piece

$$Q = \frac{1}{2}(E - E_f)$$

$$= \frac{1}{2}(9.8\ J - 2.4\ J)$$

$$= 3.7\ J$$

$$\Delta T = \frac{Q}{mc}$$

$$= \frac{3.7\ J}{(0.0010\ kg)(385\ J/kg°C)}$$

$$= 9.5°C$$

97. It is possible to lift a person who is sitting on a pillow made from a large sealed plastic garbage bag by blowing air into the bag through a soda straw. Suppose that the cross-sectional area of the person sitting on the bag is 0.25 m^2 and the person's weight is 600 N. The soda straw has a cross-sectional area of 2×10^{-5} m^2. With what pressure must you blow into the straw to lift the person that is sitting on the sealed garbage bag? (Chapter 13)

Apply Pascal's principle.

$$\Delta F_2 = \Delta F_1 \frac{A_1}{A_2}$$

$$= (600\ N)\left(\frac{2\times10^{-5}\ m^2}{0.25\ m^2}\right) = 0.048\ N$$

$$\Delta P = \frac{\Delta F_2}{A_2} = \frac{0.048\ N}{2\times10^{-5}\ m^2} = 2.4\ kPa$$

or 2 kPa to one significant digit

not a very large pressure at all

98. What would be the period of a 2.0-m-long pendulum on the Moon's surface? The Moon's mass is 7.34×10^{22} kg, and its radius is 1.74×10^6 m. What is the period of this pendulum on Earth? (Chapter 14)

$$g_m = \frac{Gm_m}{{d^2}_m}$$

$$= \frac{(6.67\times10^{-11}\ N\cdot m^2/kg^2)(7.34\times10^{22}\ kg)}{}$$

$$= 1.62\ m/s^2$$

$$T_{Moon} = 2\pi\sqrt{\frac{l}{g}} = 2\pi\sqrt{\frac{2.0\ m}{1.62\ m/s^2}} = 7.0\ s$$

$$T_{Earth} = 2\pi\sqrt{\frac{l}{g}} = 2\pi\sqrt{\frac{2.0\ m}{9.80\ m/s^2}} = 2.8\ s$$

99. Organ pipes An organ builder must design a pipe organ that will fit into a small space. (Chapter 15)

a. Should he design the instrument to have open pipes or closed pipes? Explain.

The resonant frequency of an open pipe is twice that of a closed pipe of the same length. Therefore, the pipes of a closed-pipe organ need be only half as long as open pipes to produce the same range of fundamental frequencies.

b. Will an organ constructed with open pipes sound the same as one constructed with closed pipes? Explain.

No. While the two organs will have the same fundamental tones, closed pipes produce only the odd harmonics, so they will have different timbres than open pipes.

100. Filters are added to flashlights so that one shines red light and the other shines green light. The beams are crossed. Explain in terms of waves why the light from both flashlights is yellow where the beams cross, but revert back to their original colors beyond the intersection point. (Chapter 16)

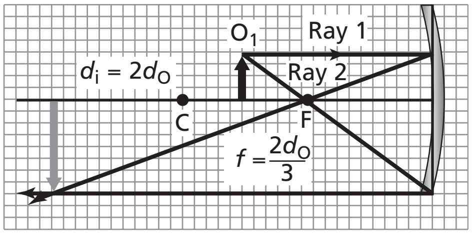
Waves can interfere, add, and then pass through unaffected. Chapter 14 showed the amplitude of waves adding. In this case, the waves retain their color information as they cross through each other.

Challenge Problem

page 470

An object of height h_o is located at d_o relative to a concave mirror with focal length f.

1. Draw and label a ray diagram showing the focal length and location of the object if the image is located twice as far from the mirror as the object. Prove your answer mathematically. Calculate the focal length as a function of object position for this placement.



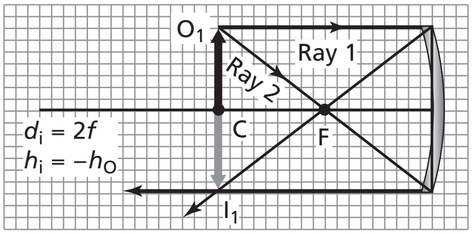
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$f = \frac{d_o d_i}{d_o + d_i}$$

$$= \frac{d_o(2d_o)}{d_o - 2d_o}$$

$$= \frac{2d_o}{3}$$

2. Draw and label a ray diagram showing the location of the object if the image is located twice as far from the mirror as the focal point. Prove your answer mathematically. Calculate the image height as a function of the object height for this placement.



$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_o = \frac{fd_i}{d_i - f}$$

$$= \frac{f(2f)}{2f - f}$$

$$= 2f$$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(2f)h_o}{2f}$$

$$= -h_o$$

3. Where should the object be located so that no image is formed?

The object should be placed at the focal point.

CHAPTER

18 Refraction and Lenses

Practice Problems

18.1 Refraction of Light pages 485–492

page 487

1. A laser beam in air is incident upon ethanol at an angle of incidence of 37.0°. What is the angle of refraction?

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin \theta_1}{n_2}\right)$$

$$= \sin^{-1}\left(\frac{(1.00)(\sin 37.0°)}{1.36}\right)$$

$$= 26.3°$$

2. Light in air is incident upon a piece of crown glass at an angle of incidence of 45.0°. What is the angle of refraction?

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin \theta_1}{n_2}\right)$$

$$= \sin^{-1}\left(\frac{(1.00)(\sin 45.0°)}{1.52}\right)$$

$$= 27.7°$$

3. Light passes from air into water at 30.0° to the normal. Find the angle of refraction.

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin \theta_1}{n_2}\right)$$

$$= \sin^{-1}\left(\frac{(1.00)(\sin 30.0°)}{1.33}\right)$$

$$= 22.1°$$

4. Light is incident upon a diamond facet at 45.0°. What is the angle of refraction?

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin \theta_1}{n_2}\right)$$

$$= \sin^{-1}\left(\frac{(1.00)(\sin 45.0°)}{2.42}\right) = 17.0°$$

5. A block of unknown material is submerged in water. Light in the water is incident on the block at an angle of incidence of 31°. The angle of refraction of the light in the block is 27°. What is the index of refraction of the material of the block?

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$n_2 = \frac{n_1 \sin \theta_1}{\sin \theta_2}$$

$$= \frac{(1.33)(\sin 31°)}{\sin 27°}$$

$$= 1.5$$

Section Review

18.1 Refraction of Light pages 485–492

page 492

6. **Index of Refraction** You notice that when a light ray enters a certain liquid from water, it is bent toward the normal, but when it enters the same liquid from crown glass, it is bent away from the normal. What can you conclude about the liquid's index of refraction?

$n_{water} < n_{liquid} < n_{crown\ glass}$, therefore, n_{liquid} must be between 1.33 and 1.52.

7. **Index of Refraction** A ray of light has an angle of incidence of 30.0° on a block of unknown material and an angle of refraction of 20.0°. What is the index of refraction of the material?

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$n_2 = \frac{n_1 \sin \theta_1}{\sin \theta_2}$$

$$= \frac{(1.00)(\sin 30.0°)}{\sin 20.0°}$$

$$= 1.46$$

8. Speed of Light Could an index of refraction ever be less than 1? What would this imply about the speed of light in that medium?

No, it would mean the speed of light in the medium is faster than it is in a vacuum.

9. Speed of Light What is the speed of light in chloroform (n = 1.51)?

$$n = \frac{c}{v}$$

$$v_{chloroform} = \frac{c}{n_{chloroform}}$$

$$= \frac{3.00\times10^8\ \text{m/s}}{1.51}$$

$$= 1.99\times10^8\ \text{m/s}$$

10. Total Internal Reflection If you were to use quartz and crown glass to make an optical fiber, which would you use for the cladding layer? Why?

crown glass because it has a lower index of refraction and would produce total internal reflection

11. Angle of Refraction A beam of light passes from water into polyethylene with n = 1.50. If θ_i = 57.5°, what is the angle of refraction in the polyethylene?

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin\theta_1}{n_2}\right)$$

$$= \sin^{-1}\left(\frac{(1.33)(\sin 57.5°)}{1.50}\right)$$

$$= 48.4°$$

12. Critical Angle Is there a critical angle for light traveling from glass to water? From water to glass?

Yes, because $n_{glass} > n_{water}$. No.

13. Dispersion Why can you see the image of the Sun just above the horizon when the Sun itself has already set?

because of bending of light rays in the atmosphere; refraction

14. Critical Thinking In what direction can you see a rainbow on a rainy late afternoon? Explain.

In the east, because the Sun sets in the west and sunlight must shine from behind you in order for you to see a rainbow.

Practice Problems

18.2 Convex and Concave Lenses pages 493–499

page 496

15. A 2.25-cm-tall object is 8.5 cm to the left of a convex lens of 5.5-cm focal length. Find the image position and height.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(8.5\ \text{cm})(5.5\ \text{cm})}{8.5\ \text{cm} - 5.5\ \text{cm}}$$

$$= 15.6\ \text{cm, or } 16\ \text{cm}$$

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(15.6\ \text{cm})(2.25\ \text{cm})}{8.5\ \text{cm}}$$

$$= -4.1\ \text{cm}$$

16. An object near a convex lens produces a 1.8-cm-tall real image that is 10.4 cm from the lens and inverted. If the focal length of the lens is 6.8 cm, what are the object position and height?

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_o = \frac{d_i f}{d_i - f}$$

$$= \frac{(10.4\ \text{cm})(6.8\ \text{cm})}{10.4\ \text{cm} - 6.8\ \text{cm}}$$

$$= 2.0\times10^1\ \text{cm}$$

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_o = \frac{-d_o h_i}{d_i}$$

$$= \frac{-(19.6\text{ cm})(-1.8\text{ cm})}{10.4\text{ cm}}$$

$$= 3.4\text{ cm}$$

17. An object is placed to the left of a convex lens with a 25-mm focal length so that its image is the same size as the object. What are the image and object positions?

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

with $d_o = d_i$ because

$$m = \frac{-d_i}{d_o} \text{ and } m = -1$$

Therefore,

$$\frac{1}{f} = \frac{2}{d_i}$$

$$d_i = 2f$$

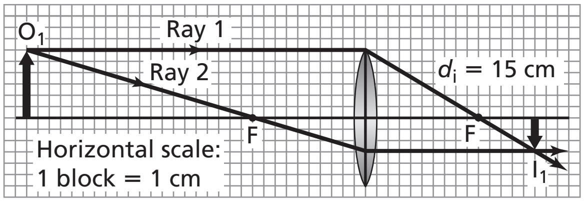
$$= 2(25\text{ mm})$$

$$= 5.0\times10^1\text{ mm}$$

$$d_o = d_i = 5.0\times10^1\text{ mm}$$

18. Use a scale ray diagram to find the image position of an object that is 30 cm to the left of a convex lens with a 10-cm focal length.

$$d_i = 15\text{ cm}$$



19. Calculate the image position and height of a 2.0-cm-tall object located 25 cm from a convex lens with a focal length of 5.0 cm. What is the orientation of the image?

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(25\text{ cm})(5.0\text{ cm})}{25\text{ cm} - 5.0\text{ cm}}$$

$$= 6.2\text{ cm}$$

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(6.2\text{ cm})(2.0\text{ cm})}{25\text{ cm}}$$

$$= -0.50\text{ cm (inverted image)}$$

page 497

20. A newspaper is held 6.0 cm from a convex lens of 20.0-cm focal length. Find the image position of the newsprint image.

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$\text{So } d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(6.0\text{ cm})(20.0\text{ cm})}{6.0\text{ cm} - 20.0\text{ cm}}$$

$$= -8.6\text{ cm}$$

21. A magnifying glass has a focal length of 12.0 cm. A coin, 2.0 cm in diameter, is placed 3.4 cm from the lens. Locate the image of the coin. What is the diameter of the image?

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(3.4\text{ cm})(12.0\text{ cm})}{3.4\text{ cm} - 12.0\text{ cm}}$$

$$= -4.7\text{ cm}$$

$$h_i = \frac{-h_o d_i}{d_o} = \frac{-(2.0\text{ cm})(-4.7\text{ cm})}{3.4\text{ cm}}$$

$$= 2.8\text{ cm}$$

22. A convex lens with a focal length of 22.0 cm is used to view a 15.0-cm-long pencil located 10.0 cm away. Find the height and orientation of the image.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(10.0\text{ cm})(22.0\text{ cm})}{10.0\text{ cm} - 22.0\text{ cm}}$$

$$= -18.3\text{ cm}$$

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(-18.3\text{ cm})(15.0\text{ cm})}{10.0\text{ cm}}$$

$$= 27.5\text{ cm (upright image)}$$

23. A stamp collector wants to magnify a stamp by 4.0 when the stamp is 3.5 cm from the lens. What focal length is needed for the lens?

$$m = \frac{-d_i}{d_o}$$

$$d_i = -md_o = -(4.0)(3.5\text{ cm})$$

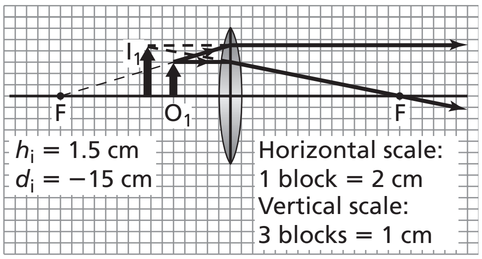
$$= -14\text{ cm}$$

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$f = \frac{d_o d_i}{d_o + d_i} = \frac{(3.5\text{ cm})(-14\text{ cm})}{3.5\text{ cm} + (-14\text{ cm})}$$

$$= 4.7\text{ cm}$$

24. A magnifier with a focal length of 30 cm is used to view a 1-cm-tall object. Use ray tracing to determine the location and size of the image when the magnifier is positioned 10 cm from the object.



The location should be about 15 cm on the same side of the lens (−15 cm) and the image should be upright and about 1.5 cm tall.

Section Review

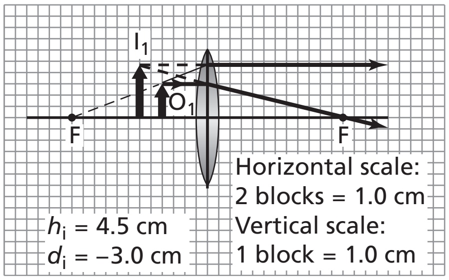
18.2 Convex and Concave Lenses pages 493–499

page 499

25. Magnification Magnifying glasses normally are used to produce images that are larger than the related objects, but they also can produce images that are smaller than the related objects. Explain.

If the object is located farther than twice the focal length from the lens, the size of the image is smaller than the size of the object.

26. Image Position and Height A 3.0-cm-tall object is located 2.0 cm from a convex lens having a focal length of 6.0 cm. Draw a ray diagram to determine the location and size of the image. Use the thin lens equation and the magnification equation to verify your answer.



$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(2.0\text{ cm})(6.0\text{ cm})}{2.0\text{ cm} - 6.0\text{ cm}}$$

$$= -3.0\text{ cm}$$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(-3.0\ \text{cm})(3.0\ \text{cm})}{2.0\ \text{cm}}$$

$$= 4.5\ \text{cm}$$

27. **Types of Lenses** The cross sections of four different thin lenses are shown in **Figure 18-16.**

■ **Figure 18-16**

a. Which of these lenses, if any, are convex, or converging, lenses?

Lenses a and c are converging.

b. Which of these lenses, if any, are concave, or diverging, lenses?

Lenses b and d are diverging.

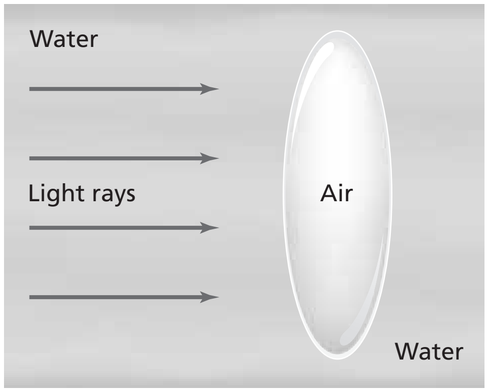
28. **Chromatic Aberration** All simple lenses have chromatic aberration. Explain, then, why you do not see this effect when you look through a microscope.

All precision optical instruments use a combination of lenses, called an achromatic lens, to minimize chromatic aberration.

29. **Chromatic Aberration** You shine white light through a convex lens onto a screen and adjust the distance of the screen from the lens to focus the red light. Which direction should you move the screen to focus the blue light?

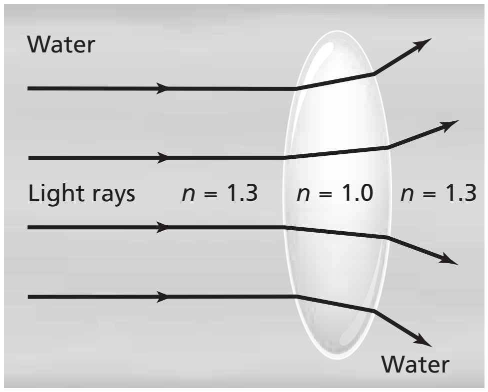
closer to the lens

30. **Critical Thinking** An air lens constructed of two watch glasses is placed in a tank of water. Copy **Figure 18-17** and draw the effect of this lens on parallel light rays incident on the lens.



■ **Figure 18-17**

The light rays will diverge.



Section Review

18.3 Applications of Lenses pages 500–503

page 503

31. **Refraction** Explain why the cornea is the primary focusing element in the eye.

The difference in index of refraction between the air and the cornea is greater than any other difference that light rays encounter when traveling toward the retina.

32. **Lens Types** Which type of lens, convex or concave, should a nearsighted person use? Which type should a farsighted person use?

A nearsighted person should use a concave lens. A farsighted person should use a convex lens.

33. **Focal Length** Suppose your camera is focused on a person who is 2 m away. You now want to focus it on a tree that is farther away. Should you move the lens closer to the film or farther away?

Closer; real images are always farther from the lens than the focal point. The farther away the object is, the closer the image is to the focal point.

34. **Image** Why is the image that you observe in a refracting telescope inverted?

After the light rays pass through the objective lens, they cross, forming an image that is inverted. The eyepiece maintains this orientation when it uses this image as its object.

35. **Prisms** What are three benefits of having prisms in binoculars?

The prisms extend the light's path length to make the binoculars more compact, invert light rays so that the viewer sees an upright image, and increase separation between objective lenses to improve the three-dimensional view.

36. **Critical Thinking** When you use the highest magnification on a microscope, the image is much darker than it is at lower magnifications. What are some possible reasons for the darker image? What could you do to obtain a brighter image?

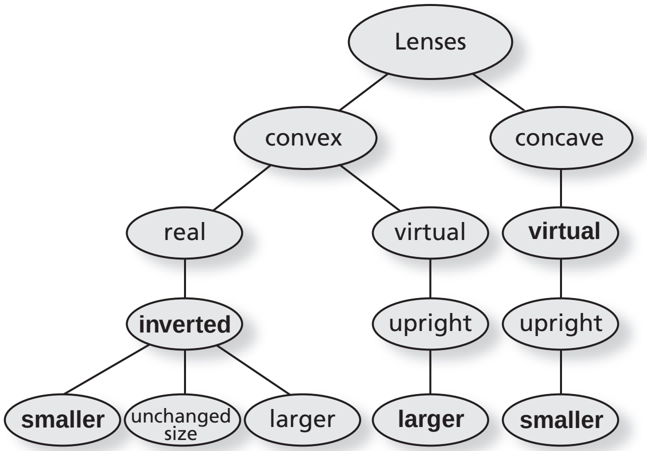
You are using the light that strikes only a small area of the object. A brighter lamp could be used.

Chapter Assessment

Concept Mapping

page 508

37. Complete the following concept map using the following terms: *inverted, larger, smaller, virtual.*



Mastering Concepts

page 508

38. How does the angle of incidence compare with the angle of refraction when a light ray passes from air into glass at a nonzero angle? (18.1)

The angle of incidence is larger than the angle of refraction, because air has a smaller index of refraction.

39. How does the angle of incidence compare with the angle of refraction when a light ray leaves glass and enters air at a nonzero angle? (18.1)

The angle of incidence is smaller than the angle of refraction, because glass has a larger index of refraction.

40. Regarding refraction, what is the critical angle? (18.1)

The term *critical angle* refers to the incident angle that causes the refracted ray to lie right along the boundary of the substance when a ray is passing from a region of higher index of refraction to a region of lower index of refraction. If the incident angle exceeds the critical angle, total internal reflection will occur.

41. Although the light coming from the Sun is refracted while passing through Earth's atmosphere, the light is not separated into its spectrum. What does this indicate about the speeds of different colors of light traveling through air? (18.1)

The speeds of the different colors of light traveling through air are the same.

42. Explain why the Moon looks red during a lunar eclipse. (18.1)

During a lunar eclipse, Earth blocks the Sun's rays from the Moon. However, sunlight refracting off Earth's atmosphere is directed inward toward the Moon. Because blue wavelengths of light are dispersed more, red wavelengths of light reflect off the Moon toward Earth.

43. How do the shapes of convex and concave lenses differ? (18.2)

Convex lenses are thicker at the center than at the edges. Concave lenses are thinner in the middle than at the edges.

44. Locate and describe the physical properties of the image produced by a convex lens when an object is placed some distance beyond 2F. (18.2)

It is a real image that is located between F and 2F, and that is inverted and smaller compared to the object.

45. What factor, other than the curvature of the surfaces of a lens, determines the location of the focal point of the lens? (18.2)

The index of refraction of the material from which the lens is made also determines the focus.

46. To project an image from a movie projector onto a screen, the film is placed between F and 2F of a converging lens. This arrangement produces an image that is inverted. Why does the filmed scene appear to be upright when the film is viewed? (18.2)

Another lens is included in the optics system of the projector to invert the image again. As a result, the image is upright compared to the original object.

47. Describe why precision optical instruments use achromatic lenses. (18.2)

All lenses have chromatic aberration, which means different wavelengths of light are bent at slightly different angles near their edges. An achromatic lens is a combination of two or more lenses with different indices of refraction that reduce this effect.

48. Describe how the eye focuses light. (18.3)

Light entering the eye is primarily focused by the cornea. Fine focusing occurs when muscles change the shape of the lens, allowing the eye to focus on either near or far objects.

49. What is the condition in which the focal length of the eye is too short to focus light on the retina? (18.3)

nearsightedness

50. What type of image is produced by the objective lens in a refracting telescope? (18.3)

real image, inverted

51. The prisms in binoculars increase the distance between the objective lenses. Why is this useful? (18.3)

It improves the three-dimensional view.

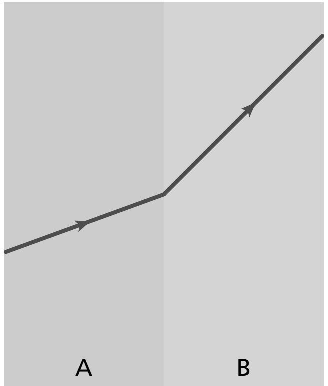
52. What is the purpose of a camera's reflex mirror? (18.3)

The reflex mirror diverts the image onto a prism so that it can be viewed before taking a photograph. When the shutter release button is pressed, the reflex mirror moves out of the way so that the lens focuses the image onto the film or other photodetector.

Applying Concepts

pages 508–509

53. Which substance, A or B, in **Figure 18-24** has a larger index of refraction? Explain.



■ **Figure 18-24**

The angle in substance A is smaller, so it has the larger index of refraction.

54. A light ray strikes the boundary between two transparent media. What is the angle of incidence for which there is no refraction?

An angle of incidence of 0° allows the light to go through unchanged. Or if the angle of incidence is greater than the critical angle there is total internal reflection.

55. How does the speed of light change as the index of refraction increases?

As the index of refraction of a material increases, the speed of light in that material decreases.

56. How does the size of the critical angle change as the index of refraction increases?

The critical angle decreases as the index of refraction increases.

57. Which pair of media, air and water or air and glass, has the smaller critical angle?

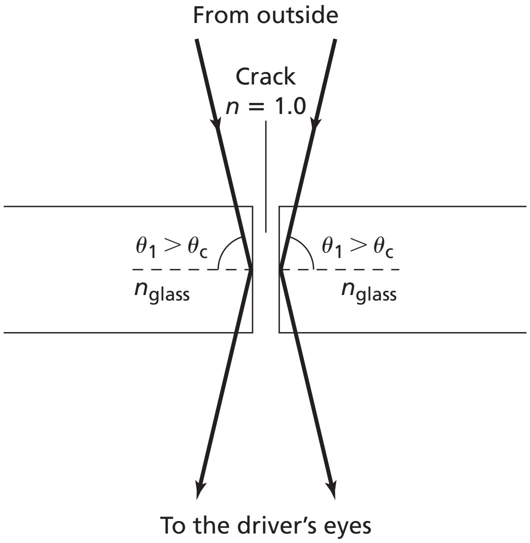
$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

$$\theta_{c,\ water/air} = \sin^{-1}\left(\frac{1.00}{1.33}\right) = 48.8°$$

$$\theta_{c,\ glass/air} = \sin^{-1}\left(\frac{1.00}{1.52}\right) = 41.1°$$

Air and glass have the smaller critical angle of 41.1°. The critical angle for air and water is 48.8°.

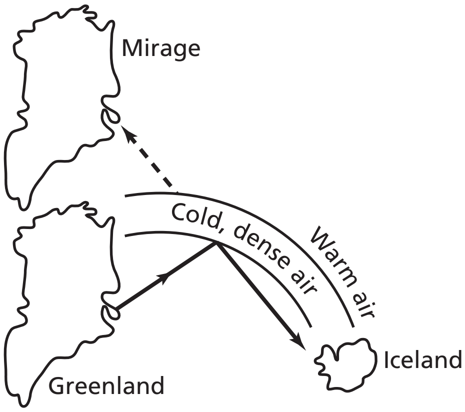
58. Cracked Windshield If you crack the windshield of your car, you will see a silvery line along the crack. The glass has separated at the crack, and there is air in the crack. The silvery line indicates that light is reflecting off the crack. Draw a ray diagram to explain why this occurs. What phenomenon does this illustrate?



This illustrates light reflected at angles larger than the critical angle, or total internal reflection.

59. Legendary Mirage According to legend, Eric the Red sailed from Iceland and discovered Greenland after he had seen the island in a mirage. Describe how the mirage might have occurred.

Even though Greenland is below the horizon, it is visible as a mirage due to the refraction of light.



60. A prism bends violet light more than it bends red light. Explain.

Violet light travels slower in a prism than red light does.

61. Rainbows Why would you never see a rainbow in the southern sky if you were in the northern hemisphere? In which direction should you look to see rainbows if you are in the southern hemisphere?

You can see a rainbow only when the Sun's rays come from behind you at an angle not greater than 42° with the horizon. When you are facing south in the northern hemisphere, the Sun is never behind you at an angle of 42° or less.

62. Suppose that **Figure 18-14** is redrawn with a lens of the same focal length but a larger diameter. Explain why the location of the image does not change. Would the image be affected in any way?

The location of the image depends on the focal length of the lens and the distance of the object from the lens. Therefore, the location of the image doesn't change.

63. A swimmer uses a magnifying glass to observe a small object on the bottom of a swimming pool. She discovers that the magnifying glass does not magnify the object very well. Explain why the magnifying glass is not functioning as it would in air.

The magnification is much less in water than in air. The difference in the indices of refraction for water and glass is much less than the difference for air and glass.

64. Why is there chromatic aberration for light that goes through a lens but not for light that reflects from a mirror?

Chromatic aberration for lenses is due to the dispersion of light (different wavelengths of light have different speeds in the lens and refract with slightly different angles). Mirrors reflect, and reflection is independent of wavelength.

65. When subjected to bright sunlight, the pupils of your eyes are smaller than when they are subjected to dimmer light. Explain why your eyes can focus better in bright light.

Eyes can focus better in bright light because rays that are refracted into larger angles are cut off by the iris. Therefore, all rays converge at a narrow angle, so there is less spherical aberration.

66. Binoculars The objective lenses in binoculars form real images that are upright compared to their objects. Where are the images located relative to the eyepiece lenses?

Each side of the binoculars is like a refracting telescope. Therefore, the objective lens image must be between the eyepiece lens and its focal point to magnify the image.

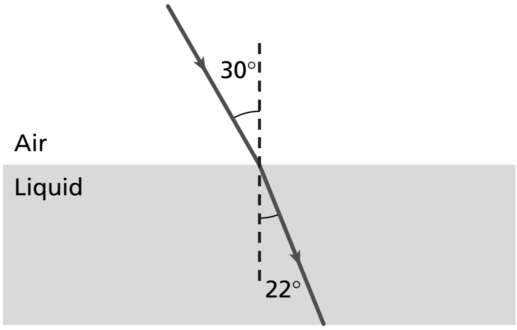
Mastering Problems

18.1 Refraction of Light

pages 509–510

Level 1

67. A ray of light travels from air into a liquid, as shown in **Figure 18-25.** The ray is incident upon the liquid at an angle of 30.0°. The angle of refraction is 22.0°.



■ **Figure 18-25**

a. Using Snell's law, calculate the index of refraction of the liquid.

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$n_2 = \frac{n_1 \sin \theta_1}{\sin \theta_2}$$

$$= \frac{(1.00)(\sin 30.0°)}{\sin 22.0°}$$

$$= 1.33$$

b. Compare the calculated index of refraction to those in Table 18-1. What might the liquid be?

water

68. Light travels from flint glass into ethanol. The angle of refraction in the ethanol is 25.0°. What is the angle of incidence in the glass?

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\theta_1 = \sin^{-1}\left(\frac{n_2 \sin \theta_2}{n_1}\right)$$

$$= \sin^{-1}\left(\frac{(1.36)(\sin 25.0°)}{1.62}\right)$$

$$= 20.8°$$

69. A beam of light strikes the flat, glass side of a water-filled aquarium at an angle of 40.0° to the normal. For glass, $n = 1.50$.

a. At what angle does the beam enter the glass?

$$n_A \sin \theta_A = n_g \sin \theta_g$$

$$\theta_g = \sin^{-1}\left(\frac{n_A \sin \theta_A}{n_g}\right)$$

$$= \sin^{-1}\left(\frac{(1.00)(\sin 40.0°)}{1.50}\right)$$

$$= 25.4°$$

b. At what angle does the beam enter the water?

$$n_g \sin \theta_g = n_w \sin \theta_w$$

$$\theta_w = \sin^{-1}\left(\frac{n_g \sin \theta_g}{n_w}\right)$$

$$= \sin^{-1}\left(\frac{(1.50)(\sin 25.4°)}{1.33}\right)$$

$$= 28.9°$$

70. Refer to Table 18-1. Use the index of refraction of diamond to calculate the speed of light in diamond.

$$n = \frac{c}{v}$$

$$v_{diamond} = \frac{c}{n_{diamond}}$$

$$= \frac{3.00\times10^8 \text{ m/s}}{2.42}$$

$$= 1.24\times10^8 \text{ m/s}$$

71. Refer to Table 18-1. Find the critical angle for a diamond in air.

$$\theta_{c,\ diamond/air} = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

$$= \sin^{-1}\left(\frac{1.00}{2.42}\right)$$

$$= 24.4°$$

Level 2

72. Aquarium Tank A thick sheet of plastic, $n = 1.500$, is used as the side of an aquarium tank. Light reflected from a fish in the water has an angle of incidence of 35.0°. At what angle does the light enter the air?

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$n_{water} \sin \theta_{water} = n_{plastic} \sin \theta_{plastic}$$

$$\theta_{plastic} = \sin^{-1}\left(\frac{n_{water} \sin \theta_{water}}{n_{plastic}}\right)$$

$$= \sin^{-1}\left(\frac{(1.33)(\sin 35.0°)}{1.500}\right)$$

$$= 30.57°$$

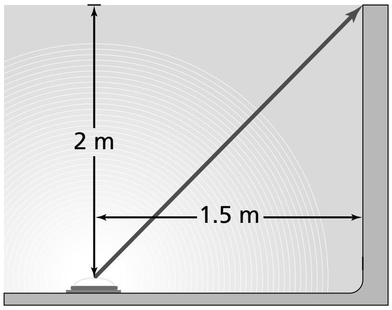
$$n_{plastic} \sin \theta_{plastic} = n_{air} \sin \theta_{air}$$

$$\theta_{air} = \sin^{-1}\left(\frac{n_{plastic} \sin \theta_{plastic}}{n_{air}}\right)$$

$$= \sin^{-1}\left(\frac{(1.500)(\sin 30.57°)}{1.00}\right)$$

$$= 49.7°$$

73. Swimming-Pool Lights A light source is located 2.0 m below the surface of a swimming pool and 1.5 m from one edge of the pool, as shown in **Figure 18-26.** The pool is filled to the top with water.



■ **Figure 18-26**

a. At what angle does the light reaching the edge of the pool leave the water?

$$\theta_i = \tan^{-1}\left(\frac{1.5 \text{ m}}{2.0 \text{ m}}\right)$$

$$= 37°$$

Then find the angle in air.

$$n_A \sin \theta_A = n_w \sin \theta_w$$

$$\theta_A = \sin^{-1}\left(\frac{n_w \sin \theta_w}{n_A}\right)$$

$$= \sin^{-1}\left(\frac{(1.33)(\sin 37°)}{1.00}\right)$$

$$= 53°$$

b. Does this cause the light viewed from this angle to appear deeper or shallower than it actually is?

$$\tan 53° = \frac{\text{side opposite}}{\text{side adjacent}}$$

$$\text{side adjacent} = \frac{\text{side opposite}}{\tan 53°}$$

$$= \frac{1.5 \text{ m}}{\tan 53°}$$

$$= 1.1 \text{ m, shallower}$$

74. A diamond's index of refraction for red light, 656 nm, is 2.410, while that for blue light, 434 nm, is 2.450. Suppose that white light is incident on the diamond at 30.0°. Find the angles of refraction for red and blue light.

$$n_A \sin \theta_A = n_d \sin \theta_d$$

$$\theta_d = \sin^{-1}\left(\frac{n_A \sin \theta_A}{n_d}\right)$$

For red light

$$\theta_d = \sin^{-1}\left(\frac{(1.00)(\sin 30.0°)}{2.410}\right)$$

$$= 12.0°$$

For blue light

$$\theta_d = \sin^{-1}\left(\frac{(1.00)(\sin 30.0°)}{2.450}\right)$$

$$= 11.8°$$

75. The index of refraction of crown glass is 1.53 for violet light, and it is 1.51 for red light.

a. What is the speed of violet light in crown glass?

$$v = \frac{c}{n} = \frac{3.00\times10^8 \text{ m/s}}{1.53}$$

$$= 1.96\times10^8 \text{ m/s}$$

b. What is the speed of red light in crown glass?

$$v = \frac{c}{n} = \frac{3.00\times10^8 \text{ m/s}}{1.51}$$

$$= 1.99\times10^8 \text{ m/s}$$

76. The critical angle for a special glass in air is 41.0°. What is the critical angle if the glass is immersed in water?

$$\sin \theta_{c,\text{ air}} = \frac{n_A}{n_g}$$

$$n_g = \frac{n_A}{\sin \theta_{c,\text{ air}}} = \frac{1.00}{\sin 41.0°} = 1.524$$

$$\sin \theta_{c,\text{ water}} = \frac{n_w}{n_g}$$

$$\theta_{c,\text{ water}} = \sin^{-1}\left(\frac{n_w}{n_g}\right)$$

$$= \sin^{-1}\left(\frac{1.33}{1.524}\right)$$

$$= 60.8°$$

Level 3

77. A ray of light in a tank of water has an angle of incidence of 55.0°. What is the angle of refraction in air?

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

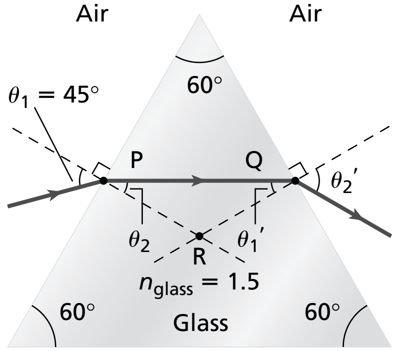
$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin \theta_1}{n_2}\right)$$

$$= \sin^{-1}\left(\frac{(1.33)(\sin 55.0°)}{1.00}\right)$$

$$= \sin^{-1}(1.09)$$

The value $\sin \theta_2 = 1.09$ is not defined. Therefore, total internal reflection occurs.

78. The ray of light shown in **Figure 18-27** is incident upon a 60°-60°-60° glass prism, $n = 1.5$.



■ **Figure 18-27**

a. Using Snell's law of refraction, determine the angle, θ_2, to the nearest degree.

$$n_{air} \sin \theta_1 = n_{glass} \sin \theta_2$$

$$\theta_2 = \sin^{-1}\left(\frac{n_{air} \sin \theta_1}{n_{glass}}\right)$$

$$= \sin^{-1}\left(\frac{1.00 \sin 45°}{1.5}\right)$$

$$= 28°$$

b. Using elementary geometry, determine the value of θ_1'.

$$\theta_P = 90° - 28° = 62°$$

$$\theta_Q = 180° - 62° - 60° = 58°$$

$$\theta_1' = 90° - 58° = 32°$$

c. Determine θ_2'.

$$n_{air} \sin \theta_2' = n_{glass} \sin \theta_1'$$

$$\theta_2' = \sin^{-1}\left(\frac{n_{glass} \sin \theta_1'}{n_{air}}\right)$$

$$= \sin^{-1}\left(\frac{(1.5)(\sin 32°)}{1.00}\right)$$

$$= 53°$$

79. The speed of light in a clear plastic is 1.90×10^8 m/s. A ray of light strikes the plastic at an angle of 22.0°. At what angle is the ray refracted?

$n_{air} \sin \theta_{air} = n_p \sin \theta_p$ **and** $n_p = \frac{c}{v_p}$**, so**

$$n_{air} \sin \theta_{air} = \frac{c}{v_p} \sin \theta_p$$

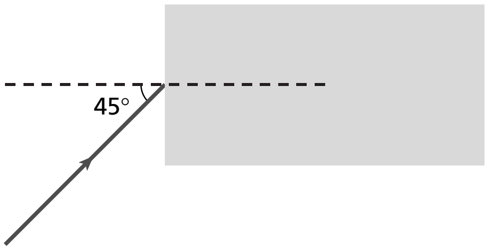
$$\sin \theta_p = \frac{v_p n_{air} \sin \theta_{air}}{c}$$

$$\theta_p = \sin^{-1}\left(\frac{v_p n_{air} \sin \theta_{air}}{c}\right)$$

$$= \sin^{-1}\left(\frac{(1.90\times10^8 \text{ m/s})(1.00)(\sin 22.0°)}{3.00\times10^8 \text{ m/s}}\right)$$

$$= 13.7°$$

80. A light ray enters a block of crown glass, as illustrated in **Figure 18-28.** Use a ray diagram to trace the path of the ray until it leaves the glass.



■ **Figure 18-28**

$$n_A \sin \theta_A = n_g \sin \theta_g$$

$$\theta_g = \sin^{-1}\left(\frac{n_A \sin \theta_A}{n_g}\right)$$

$$= \sin^{-1}\left(\frac{(1.00)(\sin 45°)}{1.52}\right)$$

$$= 28°$$

Find the critical angle for crown glass.

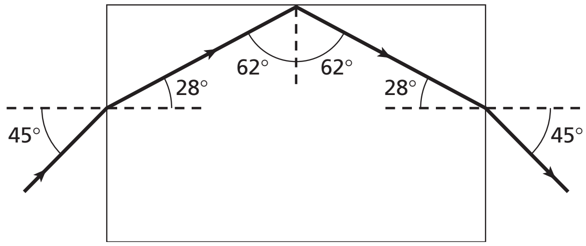
$$\sin \theta_c = \frac{n_A}{n_g}$$

$$\theta_c = \sin^{-1}\left(\frac{n_A}{n_g}\right)$$

$$= \sin^{-1}\left(\frac{1.00}{1.52}\right)$$

$$= 41.1°$$

When the light ray in the glass strikes the surface at a 62° angle, total internal reflection occurs.



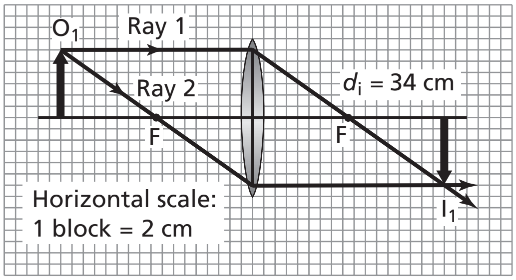
18.2 Convex and Concave Lenses

page 510

Level 1

81. The focal length of a convex lens is 17 cm. A candle is placed 34 cm in front of the lens. Make a ray diagram to locate the image.

$d_i = 34$ **cm**



82. A converging lens has a focal length of 25.5 cm. If it is placed 72.5 cm from an object, at what distance from the lens will the image be?

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(72.5 \text{ cm})(25.5 \text{ cm})}{72.5 \text{ cm} - 25.5 \text{ cm}}$$

$$= 39.3 \text{ cm}$$

The image is 39.3 cm from the lens.

83. If an object is 10.0 cm from a converging lens that has a focal length of 5.00 cm, how far from the lens will the image be?

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(10.0 \text{ cm})(5.00 \text{ cm})}{10.0 \text{ cm} - 5.00 \text{ cm}}$$

$$= 10.0 \text{ cm}$$

Level 2

84. A convex lens is needed to produce an image that is 0.75 times the size of the object and located 24 cm from the lens on the other side. What focal length should be specified?

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$d_o = \frac{-d_i}{m}$$

$$= \frac{-(24 \text{ cm})}{-0.75}$$

$$= 32 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

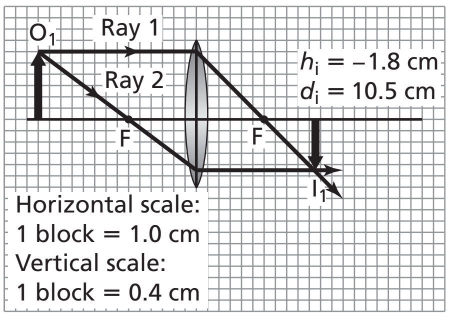
$$f = \frac{d_o d_i}{d_o + d_i}$$

$$= \frac{(32 \text{ cm})(24 \text{ cm})}{32 \text{ cm} + 24 \text{ cm}}$$

$$= 14 \text{ cm}$$

85. An object is located 14.0 cm from a convex lens that has a focal length of 6.0 cm. The object is 2.4 cm high.

a. Draw a ray diagram to determine the location, size, and orientation of the image.



b. Solve the problem mathematically.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(14.0\text{ cm})(6.0\text{ cm})}{14.0\text{ cm} - 6.0\text{ cm}}$$

$$= 10.5\text{ cm}$$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(10.5\text{ cm})(2.4\text{ cm})}{14.0\text{ cm}}$$

= −1.8 cm, so the image is inverted

86. A 3.0-cm-tall object is placed 22 cm in front of a converging lens. A real image is formed 11 cm from the lens. What is the size of the image?

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(11\text{ cm})(3.0\text{ cm})}{22\text{ cm}}$$

$$= -1.5\text{ cm}$$

The image is 1.5 cm tall.

Level 3

87. A 3.0-cm-tall object is placed 15.0 cm in front of a converging lens. A real image is formed 10.0 cm from the lens.

a. What is the focal length of the lens?

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$f = \frac{d_o d_i}{d_o + d_i}$$

$$= \frac{(15.0\text{ cm})(10.0\text{ cm})}{15.0\text{ cm} + 10.0\text{ cm}}$$

$$= 6.00\text{ cm}$$

b. If the original lens is replaced with a lens having twice the focal length, what are the image position, size, and orientation?

$$f_{new} = 2f$$

$$= 2(6.00\text{ cm})$$

$$= 12.0\text{ cm}$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_{i,\text{ new}} = \frac{d_o f_{new}}{d_o - f_{new}}$$

$$= \frac{(15.0\text{ cm})(12.0\text{ cm})}{15.0\text{ cm} - 12.0\text{ cm}}$$

$$= 60.0\text{ cm}$$

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_{i,\text{ new}} = \frac{-d_{i,\text{ new}} h_o}{d_o}$$

$$= \frac{-(60.0\text{ cm})(3.0\text{ cm})}{15\text{ cm}}$$

$$= -12\text{ cm}$$

The image is inverted compared to the object.

88. A diverging lens has a focal length of 15.0 cm. An object placed near it forms a 2.0-cm-high image at a distance of 5.0 cm from the lens.

a. What are the object position and object height?

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_o = \frac{d_i f}{d_i - f}$$

$$= \frac{(-5.0\text{ cm})(-15.0\text{ cm})}{-5.0\text{ cm} - (-15.0\text{ cm})}$$

$$= 7.5\text{ cm}$$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_o = \frac{-d_o h_i}{d_i}$$

$$= \frac{-(7.5\text{ cm})(2.0\text{ cm})}{-5.0\text{ cm}}$$

$$= 3.0\text{ cm}$$

b. The diverging lens is now replaced by a converging lens with the same focal length. What are the image position, height, and orientation? Is it a virtual image or a real image?

$$f_{new} = -f = -(-15.0\text{ cm}) = 15.0\text{ cm}$$

$$\frac{1}{f_{new}} = \frac{1}{d_o} + \frac{1}{d_{i,\,new}}$$

$$d_{i,\,new} = \frac{d_o f_{new}}{d_o - f_{new}} = \frac{(7.5\text{ cm})(15\text{ cm})}{7.5\text{ cm} - 15\text{ cm}} = -15\text{ cm}$$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_{i,\,new} = \frac{-d_{i,\,new}h_o}{d_o} = \frac{-(-15\text{ cm})(3.0\text{ cm})}{7.5\text{ cm}} = 6.0\text{ cm}$$

This is a virtual image that is upright compared to the object.

18.3 Applications of Lenses

pages 510–511

Level 1

89. Camera Lenses Camera lenses are described in terms of their focal length. A 50.0-mm lens has a focal length of 50.0 mm.

a. A camera with a 50.0-mm lens is focused on an object 3.0 m away. What is the image position?

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$\text{So } d_i = \frac{d_o f}{d_o - f} = \frac{(3.0\times10^3\text{ mm})(50.0\text{ mm})}{3.0\times10^3\text{ mm} - 50.0\text{ mm}} = 51\text{ mm}$$

b. A 1000.0-mm lens is focused on an object 125 m away. What is the image position?

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$\text{So } d_i = \frac{d_o f}{d_o - f} = \frac{(125\text{ m})(1.0000\text{ m})}{125\text{ m} - 1.00\text{ m}} = 1.01\text{ m} = 1.01\times10^3\text{ mm}$$

90. Eyeglasses To clearly read a book 25 cm away, a farsighted girl needs the image to be 45 cm from her eyes. What focal length is needed for the lenses in her eyeglasses?

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$\text{So } f = \frac{d_o d_i}{d_o + d_i} = \frac{(25\text{ cm})(-45\text{ cm})}{25\text{ cm} + (-45\text{ cm})} = 56\text{ cm}$$

Level 2

91. Copy Machine The convex lens of a copy machine has a focal length of 25.0 cm. A letter to be copied is placed 40.0 cm from the lens.

a. How far from the lens is the copy paper?

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$d_i = \frac{d_o f}{d_o - f} = \frac{(40.0\text{ cm})(25.0\text{ cm})}{40.0\text{ cm} - 25.0\text{ cm}} = 66.7\text{ cm}$$

b. How much larger will the copy be?

$$\frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o} = \frac{-(66.7\text{ cm})(h_o)}{40.0\text{ cm}} = -1.67h_o$$

The copy is enlarged and inverted.

92. **Camera** A camera lens with a focal length of 35 mm is used to photograph a distant object. How far from the lens is the real image of the object? Explain.

35 mm; for a distant object, d_o can be considered at ∞, thus $1/d_o$ is zero. According to the thin lens equation, $d_i = f$.

Level 3

93. **Microscope** A slide of an onion cell is placed 12 mm from the objective lens of a microscope. The focal length of the objective lens is 10.0 mm.

a. How far from the lens is the image formed?

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

So $d_i = \frac{d_o f}{d_o - f}$

$$= \frac{(12\text{ mm})(10.0\text{ mm})}{12\text{ mm} - 10.0\text{ mm}}$$

$$= 6.0\times10^1\text{ mm}$$

b. What is the magnification of this image?

$$m_o = \frac{-d_i}{d_o} = \frac{-6.0\times10^1\text{ mm}}{12\text{ mm}} = -5.0$$

c. The real image formed is located 10.0 mm beneath the eyepiece lens. If the focal length of the eyepiece is 20.0 mm, where does the final image appear?

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(10.0\text{ mm})(20.0\text{ mm})}{10.0\text{ mm} - 20.0\text{ mm}}$$

$= -20.0$ **mm, or 20.0 mm beneath the eyepiece**

d. What is the final magnification of this compound system?

$$m_e = \frac{-d_i}{d_o} = \frac{-(-20.0\text{ mm})}{10.0\text{ mm}} = 2.00$$

$$m_{total} = m_o m_e = (-5.0)(2.00)$$

$$= -1.0\times10^1$$

94. **Telescope** The optical system of a toy refracting telescope consists of a converging objective lens with a focal length of 20.0 cm, located 25.0 cm from a converging eyepiece lens with a focal length of 4.05 cm. The telescope is used to view a 10.0-cm-high object, located 425 cm from the objective lens.

a. What are the image position, height, and orientation as formed by the objective lens? Is this a real or virtual image?

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(425\text{ cm})(20.0\text{ cm})}{425\text{ cm} - 20.0\text{ cm}}$$

$$= 21.0\text{ cm}$$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(21.0\text{ cm})(10.0\text{ cm})}{425\text{ cm}}$$

$$= -0.494\text{ cm}$$

This is a real image that is inverted compared to the object.

b. The objective lens image becomes the object for the eyepiece lens. What are the image position, height, and orientation that a person sees when looking into the telescope? Is this a real or virtual image?

$$d_{o,\text{ new}} = 25.0\text{ cm} - d_i$$

$$= 25.0\text{ cm} - 21.0\text{ cm}$$

$$= 4.0\text{ cm}$$

$$\frac{1}{f_{new}} = \frac{1}{d_{o,\text{ new}}} = \frac{1}{d_{i,\text{ new}}}$$

$$d_{i,\text{ new}} = \frac{d_{o,\text{ new}} f_{new}}{d_{o,\text{ new}} - f_{new}}$$

$$= \frac{(4.0\text{ cm})(4.05\text{ cm})}{4.0\text{ cm} - 4.05\text{ cm}}$$

$$= -3.2\times10^2\text{ cm}$$

$$h_{o,\,new} = h_i$$
$$= -0.494\text{ cm}$$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_{i,\,new} = \frac{-d_{i,\,new}h_{o,\,new}}{d_{o,\,new}}$$
$$= \frac{-(-3.2\times10^2\text{ cm})(-0.494\text{ cm})}{4.0\text{ cm}}$$
$$= -4.0\times10^1\text{ cm}$$

This is a virtual image that is inverted compared to the object.

c. What is the magnification of the telescope?

$$m = \frac{h_{i,\,new}}{h_o}$$
$$= \frac{-4.0\times10^1\text{ cm}}{10.0\text{ cm}}$$
$$= -4.0$$

Mixed Review

pages 511–512

Level 1

95. A block of glass has a critical angle of 45.0°. What is its index of refraction?

$$\sin\theta_c = \frac{n_2}{n_1}$$

$$n_1 = \frac{n_2}{\sin\theta_c},\ n_2 = 1.00\text{ for air}$$

$$n_1 = \frac{1.00}{\sin 45.0°}$$
$$= 1.41$$

96. Find the speed of light in antimony trioxide if it has an index of refraction of 2.35.

$$n = \frac{c}{v}$$

$$v = \frac{c}{n}$$
$$= \frac{3.00\times10^8\text{ m/s}}{2.35}$$
$$= 1.28\times10^8\text{ m/s}$$

97. A 3.0-cm-tall object is placed 20 cm in front of a converging lens. A real image is formed 10 cm from the lens. What is the focal length of the lens?

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$f = \frac{d_o d_i}{d_o + d_i}$$
$$= \frac{(20\text{ cm})(10\text{ cm})}{20\text{ cm} + 10\text{ cm}}$$
$$= 7\text{ cm}$$

Level 2

98. Derive $n = \sin\theta_1/\sin\theta_2$ from the general form of Snell's law of refraction, $n_1 \sin\theta_1 = n_2 \sin\theta_2$. State any assumptions and restrictions.

The angle of incidence must be in air. If we let substance 1 be air, then n_1 = 1.000. Let $n_2 = n$. Therefore,

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\sin\theta_1 = n\sin\theta_2$$

$$\frac{\sin\theta_1}{\sin\theta_2} = n$$

99. **Astronomy** How many more minutes would it take light from the Sun to reach Earth if the space between them were filled with water rather than a vacuum? The Sun is 1.5×10^8 km from Earth.

Time through vacuum

$$t = \frac{d}{c} = \frac{(1.5\times10^8\text{ km})(1000\text{ m/1 km})}{3.00\times10^8\text{ m/s}}$$
$$= 5.0\times10^2\text{ s}$$

Speed through water

$$v = \frac{c}{n} = \frac{3.00\times10^8\text{ m/s}}{1.33}$$
$$= 2.26\times10^8\text{ m/s}$$

Time through water

$$t = \frac{d}{v} = \frac{(1.5\times10^8\text{ km})(1000\text{ m/1 km})}{2.26\times10^8\text{ m/s}}$$
$$= 660\text{ s}$$

$$\Delta t = 660\text{ s} - 500\text{ s} = 160\text{ s}$$
$$= (160\text{ s})(1\text{ min/60 s}) = 2.7\text{ min}$$

100. What is the focal length of the lenses in your eyes when you read a book that is 35.0 cm from them? The distance from each lens to the retina is 0.19 mm.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

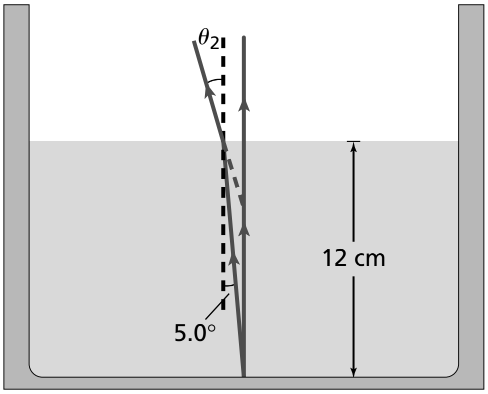
$$f = \frac{d_o d_i}{d_o + d_i}$$

$$= \frac{(350\text{ mm})(0.19\text{ mm})}{350\text{ mm} + 0.19\text{ mm}}$$

$$= 0.19\text{ mm}$$

Level 3

101. Apparent Depth Sunlight reflects diffusively off the bottom of an aquarium. **Figure 18-29** shows two of the many light rays that would reflect diffusively from a point off the bottom of the tank and travel to the surface. The light rays refract into the air as shown. The red dashed line extending back from the refracted light ray is a sight line that intersects with the vertical ray at the location where an observer would see the image of the bottom of the tank.



■ **Figure 18-29**

a. Compute the direction that the refracted ray will travel above the surface of the water.

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin\theta_1}{n_2}\right)$$

$$= \sin^{-1}\left(\frac{(1.33)(\sin 5.0°)}{1.0}\right)$$

$$= 6.7°$$

b. At what depth does the bottom of the tank appear to be if you look into the water? Divide this apparent depth into the true depth and compare it to the index of refraction.

Using right triangle geometry, (actual depth)(tan θ_1) = (apparent depth)(tan θ_2)

$$\text{apparent depth} = (12\text{ cm})\left(\frac{\tan 5.0°}{\tan 6.7°}\right)$$

$$= 8.9\text{ cm}$$

The refracted rays appear to intersect 8.9 cm below the surface; this is the apparent depth.

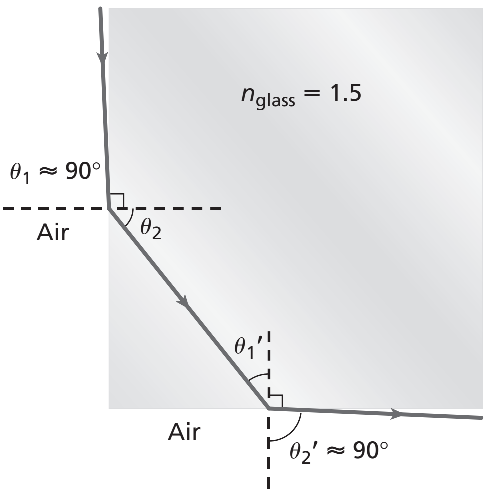
$$\frac{\text{apparent depth}}{\text{true depth}} = \frac{8.9\text{ cm}}{12\text{ cm}} = 0.74$$

Also, $$\frac{n_{air}}{n_{water}} = \frac{1.0}{1.33} = 0.75$$

Therefore,

$$\frac{\text{apparent depth}}{\text{true depth}} = \frac{n_{air}}{n_{water}}$$

102. It is impossible to see through adjacent sides of a square block of glass with an index of refraction of 1.5. The side adjacent to the side that an observer is looking through acts as a mirror. **Figure 18-30** shows the limiting case for the adjacent side to not act like a mirror. Use your knowledge of geometry and critical angles to show that this ray configuration is not achievable when $n_{glass} = 1.5$.



■ **Figure 18-30**

The light ray enters the glass at an angle θ_1 and is refracted to an angle θ_2.

$$\theta_2 = \sin^{-1}\left(\frac{n_A \sin \theta_A}{n_g}\right)$$

$$= \sin^{-1}\left(\frac{(1.00)(\sin 90°)}{1.5}\right)$$

$$= 42°$$

Therefore, $\theta_1{}' = 48°$.

But the critical angle for glass is

$$\theta_c = \sin^{-1}\left(\frac{n_A}{n_g}\right)$$

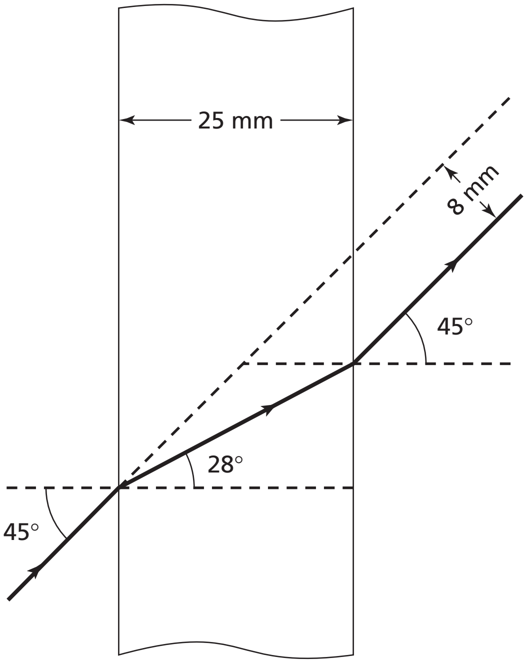
$$= \sin^{-1}\left(\frac{1.00}{1.5}\right)$$

$$= 42°$$

Because $\theta_1{}' > \theta_c$, the light reflects back into the glass and one cannot see out of an adjacent side.

103. Bank Teller Window A 25-mm-thick sheet of plastic, $n = 1.5$, is used in a bank teller's window. A ray of light strikes the sheet at an angle of 45°. The ray leaves the sheet at 45°, but at a different location. Use a ray diagram to find the distance between the ray that leaves and the one that would have left if the plastic were not there.

8 mm



Thinking Critically

page 512

104. Recognize Spatial Relationships White light traveling through air ($n = 1.0003$) enters a slab of glass, incident at exactly 45°. For dense flint glass, $n = 1.7708$ for blue light ($\lambda = 435.8$ nm) and $n = 1.7273$ for red light ($\lambda = 643.8$ nm). What is the angular dispersion of the red and blue light?

Find the angles of refraction for red and blue light, and find the difference in those angles in degrees.

Use Snell's law, $n_1 \sin \theta_1 = n_2 \sin \theta_2$.

Thus, $\theta_2 = \sin^{-1}\left(\frac{n_1 \sin \theta_1}{n_2}\right)$

For red light

$$\theta_2 = \sin^{-1}\left(\frac{(1.0003)(\sin 45.000°)}{1.7273}\right)$$

$$= 24.173°$$

For blue light

$$\theta_2 = \sin^{-1}\left(\frac{(1.0003)(\sin 45.000°)}{1.7708}\right)$$

$$= 23.543°$$

Difference

$$24.173° - 23.543° = 0.630°$$

105. Compare and Contrast Find the critical angle for ice ($n = 1.31$). In a very cold world, would fiber-optic cables made of ice or those made of glass do a better job of keeping light inside the cable? Explain.

$$\sin \theta_c = \frac{n_{air}}{n_{ice}}$$

$$\theta_c = \sin^{-1}\left(\frac{n_{air}}{n_{ice}}\right) = \sin^{-1}\left(\frac{1.00}{1.31}\right) = 49.8°$$

In comparison, the critical angle for glass, $n = 1.54$, is 40.5°. The larger critical angle means that fewer rays would be totally internally reflected in an ice core than in a glass core. Thus, they would not be able to transmit as much light. Fiber optic cables made of glass would work better.

106. Recognize Cause and Effect Your lab partner used a convex lens to produce an image with d_i = 25 cm and h_i = 4.0 cm. You are examining a concave lens with a focal length of −15 cm. You place the concave lens between the convex lens and the original image, 10 cm from the image. To your surprise, you see a real image on the wall that is larger than the object. You are told that the image from the convex lens is now the object for the concave lens, and because it is on the opposite side of the concave lens, it is a virtual object. Use these hints to find the new image position and image height and to predict whether the concave lens changed the orientation of the original image.

The new $d_o = -10$ cm. Thus,

$$d_i = \frac{fd_o}{d_o - f} = \frac{(-15\text{ cm})(-10\text{ cm})}{-10\text{ cm} - (-15\text{ cm})}$$

$$= +30\text{ cm}$$

$$m = \frac{-d_i}{d_o} = \frac{-30\text{ cm}}{-10\text{ cm}} = +3$$

$$h_i = mh_o = (3)(4.0\text{ cm}) = 10\text{ cm}$$

The image orientation is not changed.

107. Define Operationally Name and describe the effect that causes the rainbow-colored fringe commonly seen at the edges of a spot of white light from a slide or overhead projector.

The light that passes through a lens near the edges of the lens is slightly dispersed, since the edges of a lens resemble a prism and refract different wavelengths of light at slightly different angles. The result is that white light is dispersed into its spectrum. The effect is called chromatic aberration.

108. Think Critically A lens is used to project the image of an object onto a screen. Suppose that you cover the right half of the lens. What will happen to the image?

It will get dimmer, because fewer light rays will converge, but you will see a complete image.

Writing in Physics

page 512

109. The process of accommodation, whereby muscles surrounding the lens in the eye contract or relax to enable the eye to focus on close or distant objects, varies for different species. Investigate this effect for different animals. Prepare a report for the class showing how this fine focusing is accomplished for different eye mechanisms.

Answers will vary depending on the animals selected by the students.

110. Investigate the lens system used in an optical instrument such as an overhead projector or a particular camera or telescope. Prepare a graphics display for the class explaining how the instrument forms images.

Answers will vary. Students may find that it is necessary to simplify their chosen system for explanation purposes.

Cumulative Review

page 512

111. If you drop a 2.0 kg bag of lead shot from a height of 1.5 m, you could assume that half of the potential energy will be converted into thermal energy in the lead. The other half would go to thermal energy in the floor. How many times would you have to drop the bag to heat it by 10°C? (Chapter 12)

$$PE = mgh$$

$$= (2.0\text{ kg})(9.80\text{ m/s}^2)(1.5\text{ m})$$

$$= 29.4\text{ J}$$

To heat the bag

$$Q = mC\Delta T$$

$$= (2.0\text{ kg})(130\text{ J/kg}\cdot\text{°C})(10\text{°C})$$

$$= 2600\text{ J}$$

$$N = \frac{Q}{\frac{1}{2}PE} = \frac{2600\text{ J}}{\frac{1}{2}(29.4\text{ J})}$$

$$= 180\text{ times}$$

112. A blacksmith puts an iron hoop or tire on the outer rim of a wooden carriage wheel by heating the hoop so that it expands to a diameter greater than the wooden wheel. When the hoop cools, it contracts to hold the rim in place. If a blacksmith has a wooden wheel with a 1.0000-m diameter and wants to put a rim with a 0.9950-m diameter on the wheel, what is the minimum temperature change the iron must experience? ($\alpha_{iron} = 12\times10^{-6}/°C$) (Chapter 13)

$\Delta L = \alpha_{iron} L\Delta T$ where L is the diameter of the iron hoop. We want ΔL greater than 0.0050 m.

Therefore,

$$\Delta T = \frac{\Delta L}{\alpha_{iron}L}$$

$$= \frac{0.0050}{(12\times10^{-6}/°C)(0.9950\text{ m})}$$

$$= 420°C$$

Actually he would heat it much hotter to give room to fit over the wheel easily.

113. A car sounds its horn as it approaches a pedestrian in a crosswalk. What does the pedestrian hear as the car brakes to allow him to cross the street? (Chapter 15)

The pitch of the horn heard by the pedestrian will decrease as the car slows down.

114. Suppose that you could stand on the surface of the Sun and weigh yourself. Also suppose that you could measure the illuminance on your hand from the Sun's visible spectrum produced at that position. Next, imagine yourself traveling to a position 1000 times farther away from the center of the Sun as you were when standing on its surface. (Chapter 16)

a. How would the force of gravity on you from the Sun at the new position compare to what it was at the surface?

It is $\frac{1}{(1000)^2} = \frac{1}{1{,}000{,}000} = 1\times10^{-6}$ the value it was originally.

b. How would the illuminance on your hand from the Sun at the new position compare to what it was when you were standing on its surface? (For simplicity, assume that the Sun is a point source at both positions.)

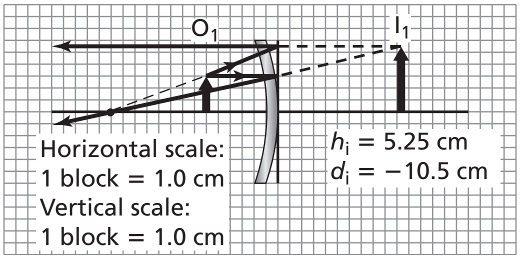
It is $\frac{1}{1000^2} = \frac{1}{1{,}000{,}000} = 1\times10^{-6}$ the value it was originally.

c. Compare the effect of distance upon the gravitational force and illuminance.

They both follow the inverse square law of distance.

115. **Beautician's Mirror** The nose of a customer who is trying some face powder is 3.00-cm high and is located 6.00 cm in front of a concave mirror having a 14.0-cm focal length. Find the image position and height of the customer's nose by means of the following. (Chapter 17)

a. a ray diagram drawn to scale



b. the mirror and magnification equations

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(6.00\text{ cm})(14.0\text{ cm})}{6.00\text{ cm} - 14.0\text{ cm}}$$

$$= -10.5\text{ cm}$$

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(-10.5\text{ cm})(3.00\text{ cm})}{6.00\text{ cm}}$$

$$= 5.25\text{ cm}$$

Challenge Problem

page 501

As light enters the eye, it first encounters the air/cornea interface. Consider a ray of light that strikes the interface between the air and a person's cornea at an angle of 30.0° to the normal. The index of refraction of the cornea is approximately 1.4.

1. Use Snell's law to calculate the angle of refraction.

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin \theta_1}{n_2}\right)$$

$$= \sin^{-1}\left(\frac{(1.0)(\sin 30.0°)}{1.4}\right)$$

$$= 21°$$

2. What would the angle of refraction be if the person was swimming underwater?

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin \theta_1}{n_2}\right)$$

$$= \sin^{-1}\left(\frac{(1.33)(\sin 30.0°)}{1.4}\right)$$

$$= 28°$$

3. Is the refraction greater in air or in water? Does this mean that objects under water seem closer or more distant than they would in air?

Refraction is greater in air because the angle to the normal is smaller. Objects seem closer in water.

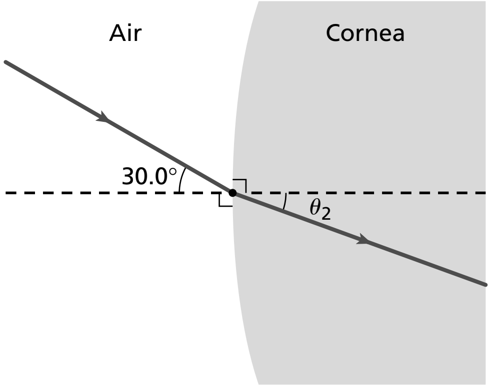
4. If you want the angle of refraction for the light ray in water to be the same as it is for air, what should the new angle of incidence be?

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\theta_1 = \sin^{-1}\left(\frac{n_2 \sin \theta_2}{n_1}\right)$$

$$= \sin^{-1}\left(\frac{(1.4)(\sin 21°)}{1.33}\right)$$

$$= 22°$$



CHAPTER 19

Interference and Diffraction

Practice Problems

19.1 Interference pages 515–523

page 519

1. Violet light falls on two slits separated by 1.90×10^{-5} m. A first-order bright band appears 13.2 mm from the central bright band on a screen 0.600 m from the slits. What is λ?

$$\lambda = \frac{xd}{L}$$

$$= \frac{(13.2\times10^{-3}\text{ m})(1.90\times10^{-5}\text{ m})}{0.600\text{ m}}$$

$$= 418\text{ nm}$$

2. Yellow-orange light from a sodium lamp of wavelength 596 nm is aimed at two slits that are separated by 1.90×10^{-5} m. What is the distance from the central band to the first-order yellow band if the screen is 0.600 m from the slits?

$$x = \frac{\lambda L}{d}$$

$$= \frac{(13.2\times10^{-3}\text{ m})(1.90\times10^{-5}\text{ m})}{0.600\text{ m}}$$

$$= 1.88\times10^{-2}\text{ m} = 18.8\text{ mm}$$

3. In a double-slit experiment, physics students use a laser with $\lambda = 632.8$ nm. A student places the screen 1.000 m from the slits and finds the first-order bright band 65.5 mm from the central line. What is the slit separation?

$$\lambda = \frac{xd}{L}$$

$$d = \frac{\lambda L}{x}$$

$$= \frac{(632.8\times10^{-9}\text{ m})(1.000\text{ m})}{65.5\times10^{-3}\text{ m}}$$

$$= 9.66\times10^{-6}\text{ m} = 9.66\ \mu\text{m}$$

4. Yellow-orange light with a wavelength of 596 nm passes through two slits that are separated by 2.25×10^{-5} m and makes an interference pattern on a screen. If the distance from the central line to the first-order yellow band is 2.00×10^{-2} m, how far is the screen from the slits?

$$\lambda = \frac{xd}{L}$$

$$L = \frac{xd}{\lambda}$$

$$= \frac{(2.00\times10^{-2}\text{ m})(2.25\times10^{-5}\text{ m})}{596\times10^{-9}\text{ m}}$$

$$= 0.755\text{ m}$$

page 522

5. In the situation in Example Problem 2, what would be the thinnest film that would create a reflected red ($\lambda = 635$ nm) band?

$$2t = \left(m + \frac{1}{2}\right)\frac{\lambda}{n_{oil}}$$

For the thinnest film, $m = 0$.

$$t = \left(\frac{1}{4}\right)\frac{\lambda}{n_{oil}}$$

$$= \frac{635\text{ nm}}{(4)(1.45)}$$

$$= 109\text{ nm}$$

6. A glass lens has a nonreflective coating placed on it. If a film of magnesium fluoride, $n = 1.38$, is placed on the glass, $n = 1.52$, how thick should the layer be to keep yellow-green light from being reflected?

Because $n_{film} > n_{air}$, there is a phase inversion on the first reflection.
Because $n_{glass} > n_{film}$, there is a phase inversion on the second reflection.
For destructive interference to keep yellow-green from being reflected:

$$2t = \left(m + \frac{1}{2}\right)\frac{\lambda}{n_{film}}$$

For the thinnest film, $m = 0$.

$$t = \left(\frac{1}{4}\right)\frac{\lambda}{n_{film}}$$

$$= \frac{555\ nm}{(4)(1.38)}$$

$$= 101\ nm$$

7. A silicon solar cell has a nonreflective coating placed on it. If a film of sodium monoxide, $n = 1.45$, is placed on the silicon, $n = 3.5$, how thick should the layer be to keep yellow-green light ($\lambda = 555$ nm) from being reflected?

Because $n_{film} > n_{air}$, there is a phase inversion on the first reflection. Because $n_{silicon} > n_{film}$, there is a phase inversion on the second reflection. For destructive interference to keep yellow-green from being reflected:

$$2t = \left(m + \frac{1}{2}\right)\frac{\lambda}{n_{film}}$$

For the thinnest film, $m = 0$.

$$t = \left(\frac{1}{4}\right)\frac{\lambda}{n_{film}}$$

$$= \frac{555\ nm}{(4)(1.45)}$$

$$= 95.7\ nm$$

8. You can observe thin-film interference by dipping a bubble wand into some bubble solution and holding the wand in the air. What is the thickness of the thinnest soap film at which you would see a black stripe if the light illuminating the film has a wavelength of 521 nm? Use $n = 1.33$.

Because $n_{film} > n_{air}$, there is a phase change on the first reflection. Because $n_{air} < n_{film}$, there is no phase change on the second reflection. For destructive interference to get a black stripe

$$2t = \frac{m\lambda}{n_{film}}$$

For the thinnest film, $m = 1$.

$$t = \frac{\lambda}{2n_{film}}$$

$$= \frac{521\ nm}{(2)(1.33)}$$

$$= 196\ nm$$

9. What is the thinnest soap film ($n = 1.33$) for which light of wavelength 521 nm will constructively interfere with itself?

For constructive interference

$$2t = \left(m + \frac{1}{2}\right)\frac{\lambda}{n_{film}}$$

For the thinnest film, $m = 0$.

$$t = \left(\frac{1}{4}\right)\frac{\lambda}{n_{film}}$$

$$= \frac{521\ nm}{(4)(1.33)}$$

$$= 97.9\ nm$$

Section Review

19.1 Interference pages 515–523

page 523

10. Film Thickness Lucien is blowing bubbles and holds the bubble wand up so that a soap film is suspended vertically in the air. What is the second thinnest width of the soap film at which he could expect to see a bright stripe if the light illuminating the film has a wavelength of 575 nm? Assume the soap solution has an index of refraction of 1.33.

There is one phase inversion, so constructive interference will be when

$$2t = \left(m + \frac{1}{2}\right)\frac{\lambda}{n_{film}}$$

For the second thinnest thickness, $m = 1$.

$$t = \left(\frac{3}{4}\right)\frac{\lambda}{n_{film}}$$

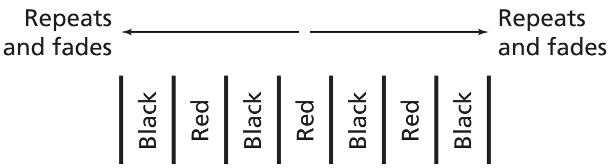
$$= \frac{(3)(575\ nm)}{(4)(1.33)}$$

$$= 324\ nm$$

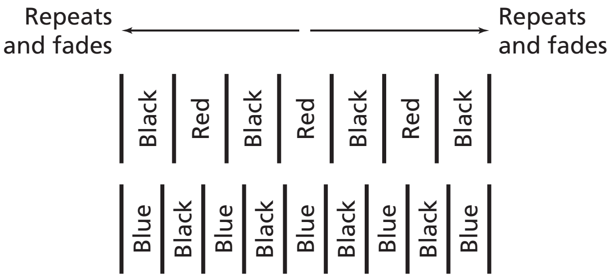
11. Bright and Dark Patterns Two very narrow slits are cut close to each other in a large piece of cardboard. They are illuminated by monochromatic red light. A sheet of white paper is placed far from the slits, and a pattern of bright and dark bands is seen on the paper. Describe how a wave behaves when it encounters a slit, and explain why some regions are bright while others are dark.

When a wave encounters a slit, the wave bends. Light is diffracted by the slits. Light from one slit interferes with light from the other. If interference is constructive, there is a bright band; if destructive, the region is dark.

12. Interference Patterns Sketch the pattern described in problem 11.



13. Interference Patterns Sketch what happens to the pattern in problem 11 when the red light is replaced by blue light.



The light bands become more closely spaced.

14. Film Thickness A plastic reflecting film ($n = 1.83$) is placed on an auto glass window ($n = 1.52$).

a. What is the thinnest film that will reflect yellow-green light?

Because $n_{film} > n_{air}$, there is a phase change on the first reflection. Because $n_{glass} < n_{film}$, there is not a phase change on the second reflection. For constructive interference to reflect yellow-green light:

$$2t = \left(m + \frac{1}{2}\right)\frac{\lambda}{n_{film}}$$

For the thinnest film, $m = 0$.

$$t = \left(\frac{1}{4}\right)\frac{\lambda_{color}}{n_{film}} = \frac{555\ \text{nm}}{(4)(1.83)} = 75.8\ \text{nm}$$

b. Unfortunately, a film this thin cannot be manufactured. What is the next-thinnest film that will produce the same effect?

For the next thinnest film, $m = 1$.

$$t = \left(\frac{3}{4}\right)\frac{\lambda_{color}}{n_{film}} = \frac{(3)(555\ \text{nm})}{(4)(1.83)} = 227\ \text{nm}$$

15. Critical Thinking The equation for wavelength from a double-slit experiment uses the simplification that θ is small so that $\sin\theta \approx \tan\theta$. Up to what angle is this a good approximation when your data has two significant figures? Would the maximum angle for a valid approximation increase or decrease as you increase the precision of your angle measurement?

$\sin\theta = \tan\theta$ to two significant digits up to 9.9°. An increase in the precision of the measurement reduces this angle to 2.99°.

Practice Problems

19.2 Diffraction pages 524–531

page 526

16. Monochromatic green light of wavelength 546 nm falls on a single slit with a width of 0.095 mm. The slit is located 75 cm from a screen. How wide will the central bright band be?

$\lambda = \frac{x_{min}w}{L}$

$x_{min} = \frac{\lambda L}{w}$

$= \frac{(5.46\times10^{-7}\ m)(0.75\ m)}{9.5\times10^{-5}\ m}$

= 4.3 mm

17. Yellow light with a wavelength of 589 nm passes through a slit of width 0.110 mm and makes a pattern on a screen. If the width of the central bright band is 2.60×10^{-2} m, how far is it from the slits to the screen?

$2x_1 = \frac{2\lambda L}{w}$

$L = \frac{(2x_1)w}{2\lambda}$

$= \frac{(2.60\times10^{-2}\ m)(0.110\times10^{-3}\ m)}{(2)(589\times10^{-9}\ m)}$

= 2.43 m

18. Light from a He-Ne laser (λ = 632.8 nm) falls on a slit of unknown width. A pattern is formed on a screen 1.15 m away, on which the central bright band is 15 mm wide. How wide is the slit?

$2x_1 = \frac{2\lambda L}{w}$

$w = \frac{2\lambda L}{2x_1}$

$= \frac{(2)(632.8\times10^{-9}\ m)(1.15\ m)}{15\times10^{-3}\ m}$

$= 9.7\times10^{-5}$ **m**

$= 97\ \mu$**m**

19. Yellow light falls on a single slit 0.0295 mm wide. On a screen that is 60.0 cm away, the central bright band is 24.0 mm wide. What is the wavelength of the light?

$2x_1 = \frac{2\lambda L}{w}$

$\lambda = \frac{(2x_1)w}{2L}$

$= \frac{(24.0\times10^{-3}\ m)(0.0295\times10^{-3}\ m)}{(2)(60.0\times10^{-2}\ m)}$

$= 5.90\times10^{2}$ **nm**

20. White light falls on a single slit that is 0.050 mm wide. A screen is placed 1.00 m away. A student first puts a blue-violet filter (λ = 441 nm) over the slit, then a red filter (λ = 622 nm). The student measures the width of the central bright band.

a. Which filter produced the wider band?

Red, because central peak width is proportional to wavelength.

b. Calculate the width of the central bright band for each of the two filters.

$2x_1 = \frac{2\lambda L}{w}$

For blue,

$2x_1 = \frac{2(4.41\times10^{-7}\ m)(1.00\ m)}{5.0\times10^{-5}\ m}$

= 18 mm

For red,

$2x_1 = \frac{2(6.22\times10^{-7}\ m)(1.00\ m)}{5.0\times10^{-5}\ m}$

= 25 mm

page 529

21. White light shines through a grating onto a screen. Describe the pattern that is produced.

A full spectrum of color is seen. Because of the variety of wavelengths, dark fringes of one wavelength would be filled by bright fringes of another color.

22. If blue light of wavelength 434 nm shines on a diffraction grating and the spacing of the resulting lines on a screen that is 1.05 m away is 0.55 m, what is the spacing between the slits in the grating?

$\lambda = d \sin\theta$

$d = \frac{\lambda}{\sin\theta}$ **where** $\theta = \tan^{-1}\left(\frac{x}{L}\right)$

$= \frac{\lambda}{\sin\left(\tan^{-1}\left(\frac{x}{L}\right)\right)}$

$= \frac{434\times10^{-9}}{\sin\left(\tan^{-1}\left(\frac{0.55\ m}{1.05\ m}\right)\right)}$

$= 9.4\times10^{-7}$ **m**

23. A diffraction grating with slits separated by 8.60×10^{-7} m is illuminated by violet light with a wavelength of 421 nm. If the screen is 80.0 cm from the grating, what is the separation of the lines in the diffraction pattern?

$$\lambda = d \sin \theta$$

$$\sin \theta = \frac{\lambda}{d}$$

$$\tan \theta = \frac{x}{L}$$

$$x = L \tan \theta$$

$$= L \tan \left(\sin^{-1}\left(\frac{\lambda}{d}\right)\right)$$

$$= (0.800 \text{ m})\left(\tan \left(\sin^{-1}\left(\frac{421\times10^{-9} \text{ m}}{8.60\times10^{-7} \text{ m}}\right)\right)\right)$$

$$= 0.449 \text{ m}$$

24. Blue light shines on the DVD in Example Problem 3. If the dots produced on a wall that is 0.65 m away are separated by 58.0 cm, what is the wavelength of the light?

$$\lambda = d \sin \theta = d \sin \left(\tan^{-1}\left(\frac{x}{L}\right)\right)$$

$$= (7.41\times10^{-7} \text{ m})\left(\sin \left(\tan^{-1}\left(\frac{0.58 \text{ m}}{0.65 \text{ m}}\right)\right)\right)$$

$$= 490 \text{ nm}$$

25. Light of wavelength 632 nm passes through a diffraction grating and creates a pattern on a screen that is 0.55 m away. If the first bright band is 5.6 cm from the central bright band, how many slits per centimeter does the grating have?

$$\lambda = d \sin \theta$$

There is one slit per distance d, so $\frac{1}{d}$ gives slits per centimeter.

$$d = \frac{\lambda}{\sin \theta} = \frac{\lambda}{\sin \left(\tan^{-1}\left(\frac{x}{L}\right)\right)}$$

$$= \frac{632\times10^{-9} \text{ m}}{\sin \left(\tan^{-1}\left(\frac{0.056 \text{ m}}{0.55 \text{ m}}\right)\right)}$$

$$= 6.2\times10^{-6} \text{ m} = 6.2\times10^{-4} \text{ cm}$$

$$\frac{1 \text{ slit}}{6.2\times10^{-4} \text{ cm}} = 1.6\times10^{3} \text{ slits/cm}$$

Section Review

19.2 Diffraction pages 524–531

page 531

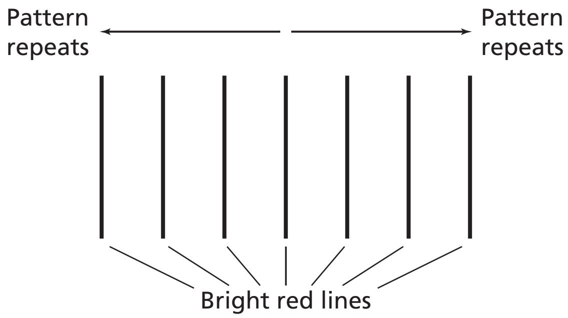
26. Distance Between First-Order Dark Bands Monochromatic green light of wavelength 546 nm falls on a single slit of width 0.080 mm. The slit is located 68.0 cm from a screen. What is the separation of the first dark bands on each side of the central bright band?

$$2x_{min} = \frac{2\lambda L}{w}$$

$$= \frac{(2)(546\times10^{-9} \text{ m})(68.0\times10^{-2} \text{ m})}{0.080\times10^{-3} \text{ m}}$$

$$= 9.3 \text{ mm}$$

27. Diffraction Patterns Many narrow slits are close to each other and equally spaced in a large piece of cardboard. They are illuminated by monochromatic red light. A sheet of white paper is placed far from the slits, and a pattern of bright and dark bands is visible on the paper. Sketch the pattern that would be seen on the screen.



Band spacing is exactly the same as in the pattern produced by the two slits, but now light bands are much thinner and separated by wider dark bands.

28. Line Spacing You shine a red laser light through one diffraction grating and form a pattern of red dots on a screen. Then you substitute a second diffraction grating for the first one, forming a different pattern. The dots produced by the first grating are spread out more than those produced by the second. Which grating has more lines per millimeter?

$\lambda \approx \frac{xd}{L}$, so the greater the dot spacings, x, the narrower the slit spacing, d, and thus more lines per millimeter.

29. **Rayleigh Criterion** The brightest star in the winter sky in the northern hemisphere is Sirius. In reality, Sirius is a system of two stars that orbit each other. If the *Hubble Space Telescope* (diameter 2.4 m) is pointed at the Sirius system, which is 8.44 light-years from Earth, what is the minimum separation there would need to be between the stars in order for the telescope to be able to resolve them? Assume that the average light coming from the stars has a wavelength of 550 nm.

$$x_{obj} = \frac{1.22\lambda L_{obj}}{D}$$

$$= \frac{1.22(330\times10^{-9}\text{ m})(7.99\times10^{16}\text{ m})}{2.4\text{ m}}$$

$$= 2.2\times10^{10}\text{ m}$$

30. **Critical Thinking** You are shown a spectrometer, but do not know whether it produces its spectrum with a prism or a grating. By looking at a white-light spectrum, how could you tell?

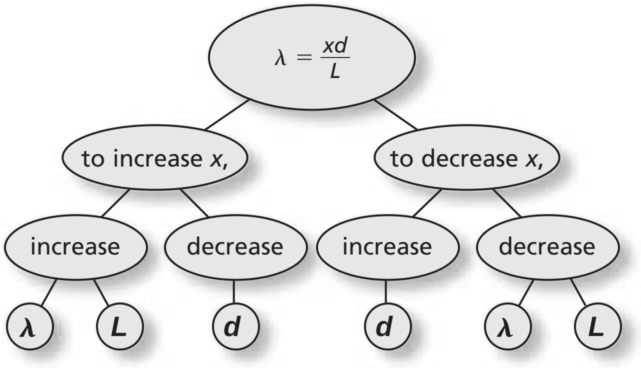
Determine if the violet or the red end of the spectrum makes the largest angle with the direction of the beam of incident white light. A prism bends the violet end of the spectrum the most, whereas a grating diffracts red wavelengths the most.

Chapter Assessment

Concept Mapping

page 536

31. Monochromatic light of wavelength λ illuminates two slits in a Young's double-slit experiment setup that are separated by a distance, d. A pattern is projected onto a screen a distance, L, away from the slits. Complete the following concept map using λ, L, and d to indicate how you could vary them to produce the indicated change in the spacing between adjacent bright bands, x.



Mastering Concepts

page 536

32. Why is it important that monochromatic light was used to make the interference pattern in Young's interference experiment? (19.1)

When monochromatic light is used, you get a sharp interference pattern; if you use white light, you get sets of colored bands.

33. Explain why the position of the central bright band of a double-slit interference pattern cannot be used to determine the wavelength of the light waves. (19.1)

All wavelengths produce the line in the same place.

34. Describe how you could use light of a known wave-length to find the distance between two slits. (19.1)

Let the light fall on the double slit, and let the interference pattern fall on a sheet of paper. Measure the spacings between the bright bands, x, and use the equation $d = \frac{\lambda L}{x}$.

35. Describe in your own words what happens in thin-film interference when a dark band is produced by light shining on a soap film suspended in air. Make sure you include in your explanation how the wavelength of the light and thickness of the film are related. (19.1)

When the light strikes the front of the film, some reflects off this surface and some passes through the film and reflects off the back surface of the film. When light reflects off a medium with a higher index of refraction, it undergoes a phase shift of one-half wavelength; this happens to the light that initially reflects. In order for a dark band to be produced, the two light rays must be one-half wavelength out of phase. If the thickness of the film is such that the ray reflecting off the back surface goes through a whole number of cycles while passing through the film, the light rays arriving at your eye will be out of phase and destructively interfere. Remember that the wavelength is altered by the index of refraction of the film, so that the thickness of the film must equal a multiple of half a wavelength of the light, divided by the film's index of refraction.

36. White light shines through a diffraction grating. Are the resulting red lines spaced more closely or farther apart than the resulting violet lines? Why? (19.2)

The spacing is directly proportional to the wavelength, and because red light has a longer wavelength than violet, the red lines will be spaced farther apart than the violet lines.

37. Why do diffraction gratings have large numbers of slits? Why are these slits so close together? (19.2)

The large number of grooves in diffraction gratings increases the intensity of the diffraction patterns. The grooves are close together, producing sharper images of light.

38. Why would a telescope with a small diameter not be able to resolve the images of two closely spaced stars? (19.2)

Small apertures have large diffraction patterns that limit resolution.

39. For a given diffraction grating, which color of visible light produces a bright line closest to the central bright band? (19.2)

violet light, the color with the smallest wavelength

Applying Concepts

page 536

40. For each of the following examples, indicate whether the color is produced by thin-film interference, refraction, or the presence of pigments.

a. soap bubbles

interference

b. rose petals

pigments

c. oil films

interference

d. a rainbow

refraction

41. How can you tell whether a pattern is produced by a single slit or a double slit?

A double-slit interference pattern consists of equally spaced lines of almost equal brightness. A single-slit diffraction pattern has a bright, broad central band and dimmer side bands.

42. Describe the changes in a single-slit diffraction pattern as the width of the slit is decreased.

The bands get wider and dimmer.

43. **Science Fair** At a science fair, one exhibition is a very large soap film that has a fairly consistent width. It is illuminated by a light with a wavelength of 432 nm, and nearly the entire surface appears to be a lovely shade of purple. What would you see in the following situations?

a. the film thickness was doubled

complete destructive interference

b. the film thickness was increased by half a wavelength of the illuminating light

complete constructive interference

c. the film thickness was decreased by one quarter of a wavelength of the illuminating light

complete destructive interference

44. What are the differences in the characteristics of the diffraction patterns formed by diffraction gratings containing 10^4 lines/cm and 10^5 lines/cm?

The lines in the diffraction pattern are narrower for the 10^5 lines/cm grating.

45. Laser Pointer Challenge You have two laser pointers, a red one and a green one. Your friends Mark and Carlos disagree about which has the longer wavelength. Mark insists that red light has a longer wavelength, while Carlos is sure that green has the longer wavelength. You have a diffraction grating handy. Describe what demonstration you would do with this equipment and how you would explain the results to Carlos and Mark to settle their disagreement.

Shine each laser pointer through the grating onto a nearby wall. The color with the longer wavelength will produce dots with a greater spacing on the wall because the spacing is directly proportional to the wavelength. (Mark is correct; red light has a longer wavelength than green light.)

46. Optical Microscope Why is blue light used for illumination in an optical microscope?

Less diffraction results from the short wavelength of blue light.

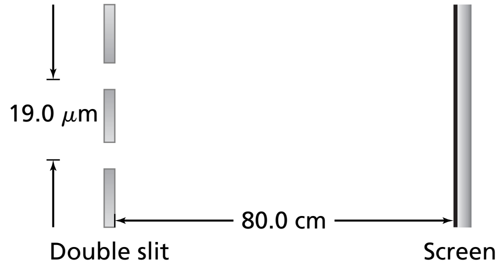
Mastering Problems

19.1 Interference

pages 536–537

Level 1

47. Light falls on a pair of slits 19.0 μm apart and 80.0 cm from a screen, as shown in **Figure 19-17.** The first-order bright band is 1.90 cm from the central bright band. What is the wavelength of the light?



■ **Figure 19-17** (Not to scale)

$$\lambda = \frac{xd}{L}$$

$$= \frac{(19.0\times10^{-6}\text{ m})(1.90\times10^{-2}\text{ m})}{80.0\times10^{-2}\text{ m}}$$

$$= 451\text{ nm}$$

48. Oil Slick After a short spring shower, Tom and Ann take their dog for a walk and notice a thin film of oil (n = 1.45) on a puddle of water, producing different colors. What is the minimum thickness of a place where the oil creates constructive interference for light with a wavelength of 545 nm?

There is one phase inversion, so constructive interference will be when

$$2t = \left(m + \frac{1}{2}\right)\frac{\lambda}{n_{\text{film}}}$$

For the minimum thickness, $m = 0$.

$$t = \left(\frac{1}{4}\right)\frac{\lambda}{n_{\text{film}}}$$

$$= \frac{545\text{ nm}}{(4)(1.45)}$$

$$= 94.0\text{ nm}$$

Level 2

49. Light of wavelength 542 nm falls on a double slit. First-order bright bands appear 4.00 cm from the central bright band. The screen is 1.20 m from the slits. How far apart are the slits?

$$\lambda = \frac{xd}{L}$$

$$d = \frac{\lambda L}{x}$$

$$= \frac{(5.42\times10^{-7}\text{ m})(1.20\text{ m})}{4.00\times10^{-2}\text{ m}}$$

$$= 16.3\ \mu\text{m}$$

50. Insulation Film Winter is approaching and Alejandro is helping to cover the windows in his home with thin sheets of clear plastic (n = 1.81) to keep the drafts out. After the plastic is taped up around the windows such that there is air between the plastic and the glass panes, the plastic is heated with a hair dryer to shrink-wrap the window. The thickness of the plastic is altered during this process. Alejandro notices a place on the plastic where there is a blue stripe of color. He realizes that this is created by thin-film interference. What are three possible thicknesses of the portion of the plastic where the blue stripe is produced if the wavelength of the light is 4.40×10^2 nm?

There is one phase inversion, so constructive interference will be when

$$2t = \left(m + \frac{1}{2}\right)\frac{\lambda}{n_{film}}$$

Three possible thicknesses occur at m = 0, 1, and 2.

$$t = \left(\frac{1}{4}\right)\frac{\lambda}{n_{film}} \text{ for } m = 0$$

$$= \frac{4.40\times10^2 \text{ nm}}{(4)(1.81)}$$

$$= 60.8 \text{ nm}$$

$$t = \left(\frac{3}{4}\right)\frac{\lambda}{n_{film}} \text{ for } m = 1$$

$$= \frac{(3)(4.40\times10^2 \text{ nm})}{(4)(1.81)}$$

$$= 182 \text{ nm}$$

$$t = \left(\frac{5}{4}\right)\frac{\lambda}{n_{film}} \text{ for } m = 2$$

$$= \frac{(5)(4.40\times10^2 \text{ nm})}{(4)(1.81)}$$

$$= 304 \text{ nm}$$

Level 3

51. Samir shines a red laser pointer through three different double-slit setups. In setup A, the slits are separated by 0.150 mm and the screen is 0.60 m away from the slits. In setup B, the slits are separated by 0.175 mm and the screen is 0.80 m away. Setup C has the slits separated by 0.150 mm and the screen a distance of 0.80 m away. Rank the three setups according to the separation between the central bright band and the first-order bright band, from least to most separation. Specifically indicate any ties.

$$\lambda = \frac{xd}{L}$$

$$x = \frac{\lambda L}{d}$$

Because λ is the same for each setup, calculate $\frac{x}{\lambda}$ to compare the setups.

$$\frac{x}{\lambda} = \frac{L}{d}$$

Setup A:

$$= \frac{0.60 \text{ m}}{1.50\times10^{-4} \text{ m}}$$

$$= 4.0\times10^3$$

Setup B:

$$= \frac{0.80 \text{ m}}{1.75\times10^{-4} \text{ m}}$$

$$= 4.6\times10^3$$

Setup C:

$$= \frac{0.80 \text{ m}}{1.50\times10^{-4} \text{ m}}$$

$$= 5.3\times10^3$$

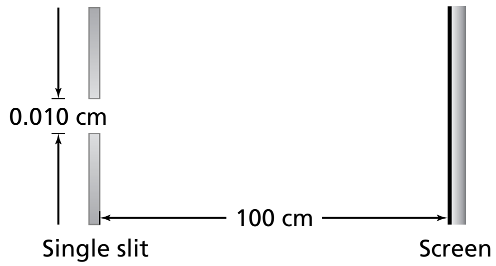
$$x_C > x_B > x_A$$

19.2 Diffraction

page 537

Level 1

52. Monochromatic light passes through a single slit with a width of 0.010 cm and falls on a screen 100 cm away, as shown in **Figure 19-18.** If the width of the central band is 1.20 cm, what is the wavelength of the light?



■ **Figure 19-18** (Not to scale)

$$2x_1 = \frac{2\lambda L}{w}$$

$$\lambda = \frac{xw}{L}$$

$$= \frac{(0.60\text{ cm})(0.010\text{ cm})}{100\text{ cm}}$$

$$= 600\text{ nm}$$

53. A good diffraction grating has 2.5×10^3 lines per cm. What is the distance between two lines in the grating?

$$d = \frac{1}{2.5\times10^3\text{ lines/cm}}$$

$$= 4.0\times10^{-4}\text{ cm}$$

Level 2

54. Light with a wavelength of 4.5×10^{-5} cm passes through a single slit and falls on a screen 100 cm away. If the slit is 0.015 cm wide, what is the distance from the center of the pattern to the first dark band?

$$2x_1 = \frac{2\lambda L}{w}$$

$2x_1$ is the width of the bright band, so to get the distance from the center to the first dark band, divide by 2.

$$x_1 = \frac{\lambda L}{w}$$

$$= \frac{(4.5\times10^{-5}\text{ cm})(100\text{ m})}{0.015\text{ cm}}$$

$$= 0.3\text{ cm}$$

55. ***Hubble Space Telescope*** Suppose the *Hubble Space Telescope*, 2.4 m in diameter, is in orbit 1.0×10^5 m above Earth and is turned to view Earth, as shown in **Figure 19-19.** If you ignore the effect of the atmosphere, how large an object can the telescope resolve? Use $\lambda = 5.1\times10^{-7}$ m.

■ **Figure 19-19**

$$\frac{x_{obj}}{L_{obj}} = \frac{1.22\lambda}{D}$$

$$x_{obj} = \frac{1.22\lambda L_{obj}}{D}$$

$$= \frac{(1.22)(5.1\times10^{-7}\text{ m})(1.0\times10^5\text{ m})}{2.4\text{ m}}$$

$$= 2.6\times10^{-2}\text{ m}$$

$$= 2.6\text{ cm}$$

Level 3

56. Monochromatic light with a wavelength of 425 nm passes through a single slit and falls on a screen 75 cm away. If the central bright band is 0.60 cm wide, what is the width of the slit?

$$2x_1 = \frac{2\lambda L}{w}$$

$$w = \frac{2\lambda L}{2x_1} = \frac{\lambda L}{x_1}$$

$$x_1 = \left(\frac{1}{2}\right)(2x_1) = 0.30\text{ cm}$$

$$= \frac{(4.25\times10^{-5}\text{ cm})(75\text{ cm})}{0.30\text{ cm}}$$

$$= 1.1\times10^{-2}\text{ cm}$$

57. **Kaleidoscope** Jennifer is playing with a kaleidoscope from which the mirrors have been removed. The eyehole at the end is 7.0 mm in diameter. If she can just distinguish two bluish-purple specks on the other end of the kaleidoscope separated by 40 μm, what is the length of the kaleidoscope? Use $\lambda = 650$ nm and assume that the resolution is diffraction limited through the eyehole.

$$x_{obj} = \frac{1.22\lambda L_{obj}}{D}$$

$$L_{obj} = \frac{x_{obj}D}{1.22\lambda}$$

$$= \frac{(40\times10^{-6}\text{ m})(7.0\times10^{-3}\text{ m})}{(1.22)(650\times10^{-9}\text{ m})}$$

$$= 0.4\text{ m}$$

58. Spectroscope A spectroscope uses a grating with 12,000 lines/cm. Find the angles at which red light, 632 nm, and blue light, 421 nm, have first-order bright lines.

$$d = \frac{1}{12{,}000 \text{ lines/cm}} = 8.33\times10^{-5} \text{ cm}$$

$$\lambda = d \sin\theta$$

$$\sin\theta = \frac{\lambda}{d}$$

For red light,

$$\theta = \sin^{-1}\left(\frac{6.32\times10^{-5} \text{ cm}}{8.33\times10^{-5} \text{ cm}}\right)$$

$$= 49.3°$$

For blue light,

$$\theta = \sin^{-1}\left(\frac{4.21\times10^{-5} \text{ cm}}{8.33\times10^{-5} \text{ cm}}\right)$$

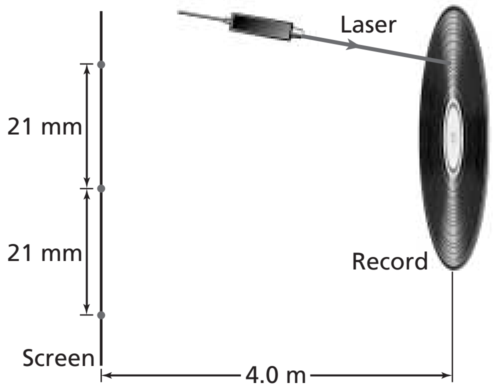
$$= 30.3°$$

Mixed Review

page 538

Level 1

59. Record Marie uses an old $33\frac{1}{3}$ rpm record as a diffraction grating. She shines a laser, λ = 632.8 nm, on the record, as shown in **Figure 19-20.** On a screen 4.0 m from the record, a series of red dots 21 mm apart are visible.



■ **Figure 19-20** (Not to scale)

a. How many ridges are there in a centimeter along the radius of the record?

$$\lambda = d \sin\theta$$

$$d = \frac{\lambda}{\sin\theta} = \frac{\lambda}{\sin\left(\tan^{-1}\left(\frac{x}{L}\right)\right)}$$

$$= \frac{632.8\times10^{-9} \text{ m}}{\sin\left(\tan^{-1}\left(\frac{21\times10^{3} \text{ m}}{4.0 \text{ m}}\right)\right)}$$

$$= 1.2\times10^{-4} \text{ m} = 1.2\times10^{-2} \text{ cm}$$

$$\frac{1}{d} = \frac{1}{1.2\times10^{-2} \text{ cm}} = 83 \text{ ridges/cm}$$

b. Marie checks her results by noting that the ridges represent a song that lasts 4.01 minutes and takes up 16 mm on the record. How many ridges should there be in a centimeter?

Number of ridges is

(4.01 min)(33.3 rev/min) = 134 ridges

$$\frac{134 \text{ ridges}}{1.6 \text{ cm}} = 84 \text{ ridges/cm}$$

Level 2

60. An anti-reflective coating, n = 1.2, is applied to a lens. If the thickness of the coating is 125 nm, what is (are) the color(s) of light for which complete destructive interference will occur? *Hint: Assume the lens is made out of glass.*

Because $n_{film} > n_{air}$, there is a phase inversion on the first reflection. Because $n_{lens} = 1.52 > n_{film}$, there is a phase inversion on the second reflection.

For destructive interference:

$$2d = \left(m + \frac{1}{2}\right)\frac{\lambda}{n_{film}}$$

$$\lambda = \frac{2dn_{film}}{\left(m + \frac{1}{2}\right)}$$

$$= \frac{(2)(125 \text{ nm})(1.2)}{\left(m + \frac{1}{2}\right)}$$

$$= \left(m + \frac{1}{2}\right)^{-1}(3.0\times10^{2} \text{ nm})$$

For $m = 0$

$$= \left(\frac{1}{2}\right)^{-1}(3.0\times10^{2} \text{ nm})$$

$$= 6.0\times10^{2} \text{ nm}$$

The light is reddish-orange. For other values of m, the wavelength is shorter than that of light.

Level 3

61. Camera When a camera with a 50-mm lens is set at f/8, its aperture has an opening 6.25 mm in diameter.

a. For light with $\lambda = 550$ nm, what is the resolution of the lens? The film is 50.0 mm from the lens.

$$x_{obj} = \frac{1.22\lambda L_{obj}}{D}$$

$$= \frac{(1.22)(5.5\times10^{-4}\text{ mm})(50.0\text{ mm})}{6.25\text{ mm}}$$

$$= 5.4\times10^{-3}\text{ mm}$$

b. The owner of a camera needs to decide which film to buy for it. The expensive one, called fine-grained film, has 200 grains/mm. The less costly, coarse-grained film has only 50 grains/mm. If the owner wants a grain to be no smaller than the width of the central bright spot calculated in part **a,** which film should he purchase?

Central bright band width

$$2x' = 10.7\times10^{-3}\text{ mm}$$

The 200 grains/mm film has $\frac{1}{200\text{ mm}}$ **between grains** $= 5\times10^{-3}$ **mm, so this film will work.**

The 50 grains/mm has $\frac{1}{50\text{ mm}}$ **between grains** $= 20\times10^{-3}$ **mm, so this film won't work.**

Thinking Critically

page 538

62. Apply Concepts Yellow light falls on a diffraction grating. On a screen behind the grating, you see three spots: one at zero degrees, where there is no diffraction, and one each at +30° and −30°. You now add a blue light of equal intensity that is in the same direction as the yellow light. What pattern of spots will you now see on the screen?

A green spot at 0°, yellow spots at +30° and −30°, and two blue spots slightly closer in.

63. Apply Concepts Blue light of wavelength λ passes through a single slit of width *w.* A diffraction pattern appears on a screen. If you now replace the blue light with a green light of wavelength 1.5λ, to what width should you change the slit to get the original pattern back?

The angle of diffraction depends on the ratio of slit width to wavelength. Thus, you would increase the width to 1.5*w*.

64. Analyze and Conclude At night, the pupil of a human eye has an aperture diameter of 8.0 mm. The diameter is smaller in daylight. An automobile's headlights are separated by 1.8 m.

a. Based upon Rayleigh's criterion, how far away can the human eye distinguish the two headlights at night? *Hint: Assume a wavelength of 525 nm.*

$$x_{obj} = \frac{1.22\lambda L_{obj}}{D}$$

$$L_{obj} = \frac{x_{obj}D}{1.22\lambda}$$

$$= \frac{(8.0\times10^{-3}\text{ m})(1.80\text{ m})}{(1.22)(5.25\times10^{-7}\text{ m})}$$

$$= 2.2\times10^{4}\text{ m} = 22\text{ km}$$

b. Can you actually see a car's headlights at the distance calculated in part **a?** Does diffraction limit your eyes' sensing ability? Hypothesize as to what might be the limiting factors.

No; a few hundred meters, not several kilometers, is the limit. Diffraction doesn't limit the sensing ability of your eyes. More probable factors are the refractive effects of the atmosphere, like those that cause stars to twinkle, or the limitations of the retina and the optic area of the brain to separate two dim sources.

Writing in Physics

page 538

65. Research and describe Thomas Young's contributions to physics. Evaluate the impact of his research on the scientific thought about the nature of light.

Student answers will vary. Answers should include Young's two-slit experiment that allowed him to precisely measure the wavelength of light.

66. Research and interpret the role of diffraction in medicine and astronomy. Describe at least two applications in each field.

Student answers will vary. Answers could include diffraction in telescopes and microscopes, as well as spectroscopy.

Cumulative Review

page 538

67. How much work must be done to push a 0.5-m^3 block of wood to the bottom of a 4-m-deep swimming pool? The density of wood is 500 kg/m^3. (Chapter 13)

The block would float, but to submerge it would require an extra force downward.

$$W = Fd$$

$$F = F_{buoyancy} - F_g$$

$$F_g = \rho V g = (500\ kg/m^3)(0.5\ m^3)(9.80\ m/s^2) = 2450\ N$$

$$F_{buoyancy} = \rho V g = (1000\ kg/m^3)(0.5\ m^3)(9.80\ m/s^2) = 4900\ N$$

$$\text{Work} = (4900\ N - 2450\ N)(4\ m) = 10\ kJ$$

68. What are the wavelengths of microwaves in an oven if their frequency is 2.4 GHz? (Chapter 14)

$$c = f\lambda$$

$$\lambda = \frac{c}{f} = \frac{3.00\times10^8\ m/s}{2.4\times10^9\ Hz} = 0.12\ m$$

69. Sound wave crests that are emitted by an airplane are 1.00 m apart in front of the plane, and 2.00 m apart behind the plane. (Chapter 15)

a. What is the wavelength of the sound in still air?

1.50 m

b. If the speed of sound is 330 m/s, what is the frequency of the source?

$$v = f\lambda$$

$$f = \frac{v}{\lambda} = \frac{330\ m/s}{1.50\ m} = 220\ Hz$$

c. What is the speed of the airplane?

The plane moves forward 0.50 m for every 1.50 m that the sound wave travels, so the plane's speed is one-third the speed of sound, or 110 m/s.

70. A concave mirror has a 48.0-cm radius. A 2.0-cm-tall object is placed 12.0 cm from the mirror. Calculate the image position and image height. (Chapter 17)

$$f = \frac{r}{2} = \frac{48.0\ cm}{2} = 24.0\ cm$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f} = \frac{(12.0\ cm)(24.0\ cm)}{12.0\ cm - 24.0\ cm} = -24.0\ cm$$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o} = \frac{-(-24.0\ cm)(2.0\ cm)}{12.0\ cm} = 4.0\ cm$$

71. The focal length of a convex lens is 21.0 cm. A 2.00-cm-tall candle is located 7.50 cm from the lens. Use the thin-lens equation to calculate the image position and image height. (Chapter 18)

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(7.50\text{ cm})(21.0\text{ cm})}{7.50\text{ cm} - 21.0\text{ cm}}$$

$$= -11.7\text{ cm}$$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

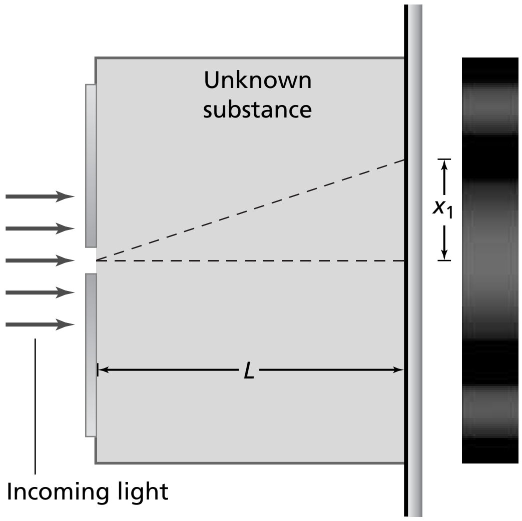
$$= \frac{-(-11.7\text{ cm})(2.00\text{ cm})}{7.50\text{ cm}}$$

$$= 3.11\text{ cm}$$

Challenge Problem

page 526

You have several unknown substances and wish to use a single-slit diffraction apparatus to determine what each one is. You decide to place a sample of an unknown substance in the region between the slit and the screen and use the data that you obtain to determine the identity of each substance by calculating its index of refraction.



1. Come up with a general formula for the index of refraction of an unknown substance in terms of the wavelength of the light, λ_{vacuum}, the width of the slit, w, the distance from the slit to the screen, L, and the distance between the central bright band and the first dark band, x_1.

Use (1) $\lambda = \frac{x_{min} w}{L}$, (2) $v_{substance} = \lambda f$, and (3) $n_{substance} = \frac{c}{v}$.

Combine (2) and (3).

$$n_{substance} = \frac{\lambda_{vacuum} f}{\lambda_{substance} f} = \frac{\lambda_{vacuum}}{\lambda_{substance}} \quad (4),$$

because the frequency remains constant as the light crosses a boundary.

Rewrite (1) in terms of a substance in the space between the slits and the screen.

$$\lambda_{substance} = \frac{x_{min} w}{L} \quad (5)$$

Combine (4) and (5) and solve for x.

$$n_{substance} = \frac{\lambda_{vacuum}}{\frac{x_{min} w}{L}}$$

$$x_{min} = \frac{\lambda_{vacuum} L}{n_{substance} w}$$

2. If the source you used had a wavelength of 634 nm, the slit width was 0.10 mm, the distance from the slit to the screen was 1.15 m, and you immersed the apparatus in water ($n_{substance} = 1.33$), then what would you expect the width of the center band to be?

$$x = \frac{\lambda_{vacuum} L}{n_{substance} d}$$

$$= \frac{(634\times10^{-9}\text{ m})(1.15\text{ m})}{(1.33)(0.10\times10^{-3}\text{ m})}$$

$$= 5.5\times10^{-3}\text{ m}$$

CHAPTER

20 Static Electricity

Section Review

20.1 Electric Charge pages 541–545

page 545

1. **Charged Objects** After a comb is rubbed on a wool sweater, it is able to pick up small pieces of paper. Why does the comb lose that ability after a few minutes?

   The comb loses its charge to its surroundings and becomes neutral once again.

2. **Types of Charge** In the experiments described earlier in this section, how could you find out which strip of tape, B or T, is positively charged?

   Bring a positively charged glass rod near the two strips of tape. The one that is repelled by the rod is positive.

3. **Types of Charge** A pith ball is a small sphere made of a light material, such as plastic foam, often coated with a layer of graphite or aluminum paint. How could you determine whether a pith ball that is suspended from an insulating thread is neutral, is charged positively, or is charged negatively?

   Bring an object of known charge, such as a negatively charged hard rubber rod, near the pith ball. If the pith ball is repelled, it has the same charge as the rod. If it is attracted, it may have the opposite charge or be neutral. To find out which, bring a positively charged glass rod near the pith ball. If they repel, the pith ball is positive; if they attract, the pith ball must be neutral.

4. **Charge Separation** A rubber rod can be charged negatively when it is rubbed with wool. What happens to the charge of the wool? Why?

   The wool becomes positively charged because it gives up electrons to the rubber rod.

5. **Conservation of Charge** An apple contains trillions of charged particles. Why don't two apples repel each other when they are brought together?

   Each apple contains equal numbers of positive and negative charges, so they appear neutral to each other.

6. **Charging a Conductor** Suppose you hang a long metal rod from silk threads so that the rod is isolated. You then touch a charged glass rod to one end of the metal rod. Describe the charges on the metal rod.

   The glass rod attracts electrons off the metal rod, so the metal becomes positively charged. The charge is distributed uniformly along the rod.

7. **Charging by Friction** You can charge a rubber rod negatively by rubbing it with wool. What happens when you rub a copper rod with wool?

   Because the copper is a conductor, it remains neutral as long as it is in contact with your hand.

8. **Critical Thinking** It once was proposed that electric charge is a type of fluid that flows from objects with an excess of the fluid to objects with a deficit. Why is the current two-charge model better than the single-fluid model?

   The two-charge model can better explain the phenomena of attraction and repulsion. It also explains how objects can become charged when they are rubbed together. The single-fluid model indicated that the charge should be equalized on objects that are in contact with each other.

Practice Problems

20.2 Electric Force pages 546–553

page 552

9. A negative charge of -2.0×10^{-4} C and a positive charge of 8.0×10^{-4} C are separated by 0.30 m. What is the force between the two charges?

$$F = \frac{Kq_Aq_B}{{d_{AB}}^2} = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(2.0\times10^{-4}\ \text{C})(8.0\times10^{-4}\ \text{C})}{(0.30\ \text{m})^2}$$

$$= 1.6\times10^4\ \text{N}$$

10. A negative charge of -6.0×10^{-6} C exerts an attractive force of 65 N on a second charge that is 0.050 m away. What is the magnitude of the second charge?

$$F = \frac{Kq_Aq_B}{{d_{AB}}^2}$$

$$q_B = \frac{F{d_{AB}}^2}{Kq_A} = \frac{(65\ \text{N})(0.050\ \text{m})^2}{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(6.0\times10^{-6}\ \text{C})}$$

$$= 3.0\times10^{-6}\ \text{C}$$

11. The charge on B in Example Problem 1 is replaced by a charge of $+3.00\ \mu$C. Diagram the new situation and find the net force on A.

Magnitudes of all forces remain the same. The direction changes to 42° above the $-x$ axis, or 138°.

12. Sphere A is located at the origin and has a charge of $+2.0\times10^{-6}$ C. Sphere B is located at +0.60 m on the *x*-axis and has a charge of -3.6×10^{-6} C. Sphere C is located at +0.80 m on the *x*-axis and has a charge of $+4.0\times10^{-6}$ C. Determine the net force on sphere A.

$$F_{\text{B on A}} = K\frac{q_Aq_B}{{d_{AB}}^2} = (9.0\times10^9\ \text{N·m}^2/\text{C}^2)\frac{(2.0\times10^{-6}\ \text{C})(3.6\times10^{-6}\ \text{C})}{(0.60\ \text{m})^2} = 0.18\ \text{N}$$

direction: toward the right

$$F_{\text{C on A}} = K\frac{q_Aq_C}{{d_{AC}}^2} = (9.0\times10^9\ \text{N·m}^2/\text{C}^2)\frac{(2.0\times10^{-6}\ \text{C})(4.0\times10^{-6}\ \text{C})}{(0.80\ \text{m})^2} = 0.1125 = \text{N}$$

direction: toward the left

$$F_{\text{net}} = F_{\text{B on A}} - F_{\text{C on A}} = (0.18\ \text{N}) - (0.1125\ \text{N}) = 0.068\ \text{N toward the right}$$

13. Determine the net force on sphere B in the previous problem.

$$F_{\text{A on B}} = K\frac{q_Aq_B}{{d_{AB}}^2}$$

$$F_{\text{C on B}} = K\frac{q_Aq_B}{{d_{AB}}^2}$$

$$F_{\text{net}} = F_{\text{C on B}} - F_{\text{A on B}}$$

$$= K\frac{q_Bq_C}{{d_{BC}}^2} - K\frac{q_Aq_B}{{d_{AB}}^2}$$

$$= (9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)\frac{(3.6\times10^{-6}\ \text{C})(4.0\times10^{-6}\ \text{C})}{(0.20\ \text{m})^2} - (9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)\frac{(2.0\times10^{-6}\ \text{C})(3.6\times10^{-6}\ \text{C})}{(0.60\ \text{m})^2}$$

= 3.1 N toward the right

Section Review

20.2 Electric Force pages 546–553

page 553

14. Force and Charge How are electric force and charge related? Describe the force when the charges are like charges and the force when the charges are opposite charges.

Electric force is directly related to each charge. It is repulsive between like charges and attractive between opposite charges.

15. Force and Distance How are electric force and distance related? How would the force change if the distance between two charges were tripled?

Electric force is inversely related to the square of the distance between charges. If the distance is tripled, the force will be one-ninth as great.

16. Electroscopes When an electroscope is charged, the leaves rise to a certain angle and remain at that angle. Why do they not rise farther?

As the leaves move farther apart, the electric force between them decreases until it is balanced by the gravitational force pulling down on the leaves.

17. Charging an Electroscope Explain how to charge an electroscope positively using

a. a positive rod.

Touch the positive rod to the electroscope. Negative charges will move to the rod, leaving the electroscope positively charged.

b. a negative rod.

Bring the negative rod near, but not touching the electroscope. Touch (ground) the electroscope with your finger, allowing electrons to be repelled off of the electroscope into your finger. Remove your finger and then remove the rod.

18. Attraction of Neutral Objects What two properties explain why a neutral object is attracted to both positively and negatively charged objects?

Charge separation, caused by the attraction of opposite charges and the repulsion of like charges, moves the opposite charges in the neutral body closer to the charged object and the like charges farther away. The inverse relation between force and distance means that the nearer, opposite charges will attract more than the more distant, like charges will repel. The overall effect is attraction.

19. Charging by Induction In an electroscope being charged by induction, what happens when the charging rod is moved away before the ground is removed from the knob?

Charge that had been pushed into the ground by the rod would return to the electroscope from the ground, leaving the electroscope neutral.

20. Electric Forces Two charged spheres are held a distance, *r*, apart. One sphere has a charge of $+3\mu$C, and the other sphere has a charge of $+9\mu$C. Compare the force of the $+3\mu$C sphere on the $+9\mu$C sphere with the force of the $+9\mu$C sphere on the $+3\mu$C sphere.

The forces are equal in magnitude and opposite in direction.

21. Critical Thinking Suppose that you are testing Coulomb's law using a small, positively charged plastic sphere and a large, positively charged metal sphere. According to Coulomb's law, the force depends on $1/r^2$, where r is the distance between the centers of the spheres. As the spheres get close together, the force is smaller than expected from Coulomb's law. Explain.

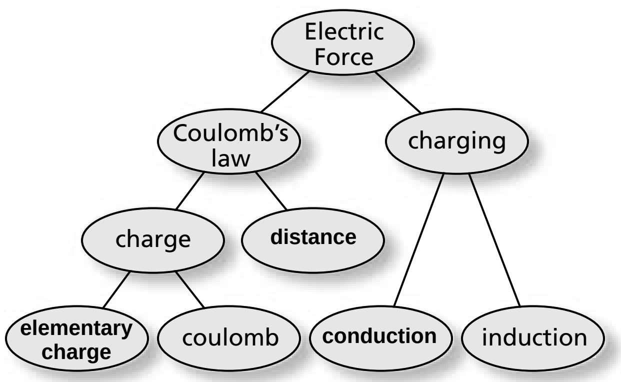
Some charges on the metal sphere will be repelled to the opposite side from the plastic sphere, making the effective distance between the charges greater than the distance between the spheres' centers.

Chapter Assessment

Concept Mapping

page 558

22. Complete the concept map below using the following terms: *conduction, distance, elementary charge.*



Mastering Concepts

page 558

23. If you comb your hair on a dry day, the comb can become positively charged. Can your hair remain neutral? Explain. (20.1)

No. By conservation of charge, your hair must become negatively charged.

24. List some insulators and conductors. (20.1)

Student answers will vary but may include dry air, wood, plastic, glass, cloth, and deionized water as insulators; and metals, tap water, and your body as conductors.

25. What property makes metal a good conductor and rubber a good insulator? (20.1)

Metals contain free electrons; rubber has bound electrons.

26. Laundry Why do socks taken from a clothes dryer sometimes cling to other clothes? (20.2)

They have been charged by contact as they rub against other clothes, and thus, are attracted to clothing that is neutral or has an opposite charge.

27. Compact Discs If you wipe a compact disc with a clean cloth, why does the CD then attract dust? (20.2)

Rubbing the CD charges it. Neutral particles, such as dust, are attracted to a charged object.

28. Coins The combined charge of all electrons in a nickel is hundreds of thousands of coulombs. Does this imply anything about the net charge on the coin? Explain. (20.2)

No. Net charge is the difference between positive and negative charges. The coin still can have a net charge of zero.

29. How does the distance between two charges impact the force between them? If the distance is decreased while the charges remain the same, what happens to the force? (20.2)

Electric force is inversely proportional to the distance squared. As distance decreases and charges remain the same, the force increases as the square of the distance.

30. Explain how to charge a conductor negatively if you have only a positively charged rod. (20.2)

Bring the conductor close to, but not touching, the rod. Ground the conductor in the presence of the charged rod; then, remove the ground before removing the charged rod. The conductor will have a net negative charge.

Applying Concepts

page 558

31. How does the charge of an electron differ from the charge of a proton? How are they similar?

The charge of the proton is exactly the same size as the electron, but has the opposite sign.

32. Using a charged rod and an electroscope, how can you find whether or not an object is a conductor?

Use a known insulator to hold one end of the object against the electroscope. Touch the other end with the charged rod. If the electroscope indicates a charge, the object is a conductor.

33. A charged rod is brought near a pile of tiny plastic spheres. Some of the spheres are attracted to the rod, but as soon as they touch the rod, they are flung off in different directions. Explain.

The natural spheres are initially attracted to the charged rod, but they acquire the same charge as the rod when they touch it. As a result, they are repelled from the rod.

34. **Lightning** Lightning usually occurs when a negative charge in a cloud is transported to Earth. If Earth is neutral, what provides the attractive force that pulls the electrons toward Earth?

The charge in the cloud repels electrons on Earth, causing a charge separation by induction. The side of Earth closest to the cloud is positive, resulting in an attractive force.

35. Explain what happens to the leaves of a positively charged electroscope when rods with the following charges are brought close to, but not touching, the electroscope.

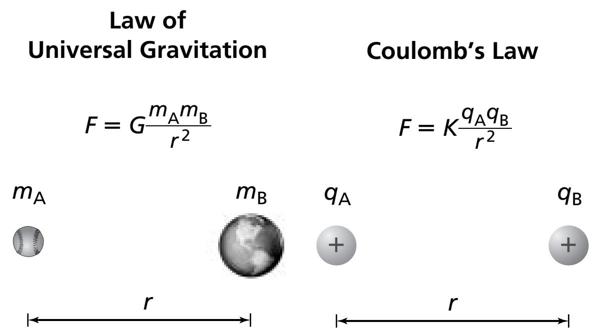
a. positive

The leaves will move farther apart.

b. negative

The leaves will drop slightly.

36. As shown in **Figure 20-13,** Coulomb's law and Newton's law of universal gravitation appear to be similar. In what ways are the electric and gravitational forces similar? How are they different?



■ **Figure 20-13** (Not to scale)

Similar: inverse-square dependence on distance, force proportional to product of two masses or two charges; different: only one sign of mass, so gravitational force is always attractive; two signs of charge, so electric force can be either attractive or repulsive.

37. The constant, *K*, in Coulomb's equation is much larger than the constant, *G*, in the universal gravitation equation. Of what significance is this?

The electric force is much larger than the gravitational force.

38. The text describes Coulomb's method for charging two spheres, A and B, so that the charge on B was exactly half the charge on A. Suggest a way that Coulomb could have placed a charge on sphere B that was exactly one-third the charge on sphere A.

After changing spheres A and B equally, sphere B is touched to two other equally sized balls that are touching each other. The charge on B will be divided equally among all three balls, leaving one-third the total charge on it.

39. Coulomb measured the deflection of sphere A when spheres A and B had equal charges and were a distance, *r*, apart. He then made the charge on B one-third the charge on A. How far apart would the two spheres then have had to be for A to have had the same deflection that it had before?

To have the same force with one-third the charge, the distance would have to be decreased such that $d^2 = 1/3$, or 0.58 times as far apart.

40. Two charged bodies exert a force of 0.145 N on each other. If they are moved so that they are one-fourth as far apart, what force is exerted?

$$F \propto \frac{1}{d^2} \text{ and } F \propto \frac{1}{\left(\frac{1}{4}\right)^2}, \text{ so } F = 16 \text{ times the original force.}$$

41. Electric forces between charges are enormous in comparison to gravitational forces. Yet, we normally do not sense electric forces between us and our surroundings, while we do sense gravitational interactions with Earth. Explain.

Gravitational forces only can be attractive. Electric forces can be either attractive or repulsive, and we can sense only their vector sums, which are generally small. The gravitational attraction to Earth is larger and more noticeable because of Earth's large mass.

Mastering Problems

20.2 Electric Force

page 559

Level 1

42. Two charges, q_A and q_B, are separated by a distance, r, and exert a force, F, on each other. Analyze Coulomb's law and identify what new force would exist under the following conditions.

a. q_A is doubled

$2q_A$, **then new force** $= 2F$

b. q_A and q_B are cut in half

$$\frac{1}{2}q_A \text{ and } \frac{1}{2}q_B, \text{ then new force} = \left(\frac{1}{2}\right)\left(\frac{1}{2}\right)F = \frac{1}{4}F$$

c. r is tripled

$$3d, \text{ then new force} = \frac{F}{(3)^2} = \frac{1}{9}F$$

d. r is cut in half

$$\frac{1}{2}d, \text{ then new force} = \frac{F}{\left(\frac{1}{2}\right)^2} = \frac{3}{4}F = 4F$$

e. q_A is tripled and r is doubled

$$3q_A \text{ and } 2d, \text{ then new force} = \frac{(3)F}{(2)^2} = \frac{3}{4}F$$

43. Lightning A strong lightning bolt transfers about 25 C to Earth. How many electrons are transferred?

$$(-25 \text{ C})\left(\frac{1 \text{ electron}}{-1.60\times10^{-19} \text{ C}}\right) = 1.6\times10^{20} \text{ electrons}$$

44. Atoms Two electrons in an atom are separated by 1.5×10^{-10} m, the typical size of an atom. What is the electric force between them?

$$F = \frac{Kq_Aq_B}{d^2} = \frac{(9.0\times10^9 \text{ N·m}^2/\text{C}^2)(1.60\times10^{-19} \text{ C})(1.60\times10^{-19} \text{ C})}{(1.5\times10^{-10} \text{ m})^2}$$

$$= 1.0\times10^{-8} \text{ N, away from each other}$$

45. A positive and a negative charge, each of magnitude 2.5×10^{-5} C, are separated by a distance of 15 cm. Find the force on each of the particles.

$$F = \frac{Kq_Aq_B}{d^2} = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(2.5\times10^{-5}\ \text{C})(2.5\times10^{-5}\ \text{C})}{(1.5\times10^{-1}\ \text{m})^2}$$

$= 2.5\times10^2$ **N, toward the other charge**

46. A force of 2.4×10^2 N exists between a positive charge of 8.0×10^{-5} C and a positive charge of 3.0×10^{-5} C. What distance separates the charges?

$$F = \frac{Kq_Aq_B}{d^2}$$

$$d = \sqrt{\frac{Kq_Aq_B}{F}} = \sqrt{\frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(8.0\times10^{-5}\ \text{C})(3.0\times10^{-5}\ \text{C})}{2.4\times10^2\ \text{N}}}$$

$= 0.30$ **m**

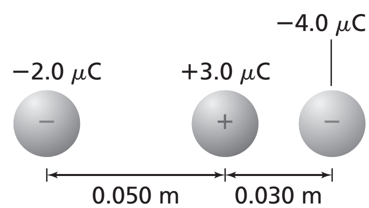
47. Two identical positive charges exert a repulsive force of 6.4×10^{-9} N when separated by a distance of 3.8×10^{-10} m. Calculate the charge of each.

$$F = \frac{Kq_Aq_B}{d^2} = \frac{Kq^2}{d^2}$$

$$q = \sqrt{\frac{Fd^2}{K}} = \sqrt{\frac{(6.4\times10^{-9}\ \text{N})(3.8\times10^{-10}\ \text{m})^2}{9.0\times10^9\ \text{N·m}^2/\text{C}^2}} = 3.2\times10^{-19}\ \text{C}$$

Level 2

48. A positive charge of 3.0 μC is pulled on by two negative charges. As shown in **Figure 20-14,** one negative charge, −2.0 μC, is 0.050 m to the west, and the other, −4.0 μC, is 0.030 m to the east. What total force is exerted on the positive charge?



■ **Figure 20-14**

$$F_1 = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(3.0\times10^{-6}\ \text{C})(2.0\times10^{-6}\ \text{C})}{(0.050\ \text{m})^2}$$

$= 22$ **N west**

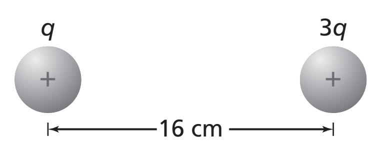
$$F_2 = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(3.0\times10^{-6}\ \text{C})(4.0\times10^{-6}\ \text{C})}{(0.030\ \text{m})^2}$$

$= 120$ **N east**

$$F_{net} = F_2 + F_1 = (1.2\times10^2\ \text{N}) - (2.2\times10^1\ \text{N})$$

$= 98$ **N, east**

49. **Figure 20-15** shows two positively charged spheres, one with three times the charge of the other. The spheres are 16 cm apart, and the force between them is 0.28 N. What are the charges on the two spheres?



■ **Figure 20-15**

$$F = K\frac{q_Aq_B}{d^2} = K\frac{q_A3q_A}{d^2}$$

$$q_A = \sqrt{\frac{Fd^2}{3K}} = \sqrt{\frac{(0.28\ \text{N})(0.16\ \text{m})^2}{3(9.0\times10^9\ \text{N·m}^2/\text{C}^2)}} = 5.2\times10^{-7}\ \text{C}$$

$$q_B = 3q_A = 1.5\times10^{-6}\ \text{C}$$

50. Charge in a Coin How many coulombs of charge are on the electrons in a nickel? Use the following method to find the answer.

a. Find the number of atoms in a nickel. A nickel has a mass of about 5 g. A nickel is 75 percent Cu and 25 percent Ni, so each mole of the coin's atoms will have a mass of about 62 g.

A coin is $\frac{5\ \text{g}}{62\ \text{g}} = 0.08$ mole.

Thus, it has $(0.08)(6.02\times10^{23}) = 5\times10^{22}$ atoms

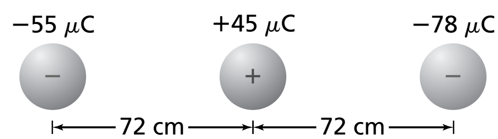
b. Find the number of electrons in the coin. On average, each atom has 28.75 electrons.

$(5\times10^{22}$ atoms)(28.75 electrons/atom) $= 1\times10^{24}$ electrons

c. Find the coulombs on the electrons.

$(1.6\times10^{-19}$ coulombs/electron)$(1\times10^{24}$ electrons) $= 2\times10^{5}$ coulombs

51. Three particles are placed in a line. The left particle has a charge of $-55\ \mu$C, the middle one has a charge of $+45\ \mu$C, and the right one has a charge of $-78\ \mu$C. The middle particle is 72 cm from each of the others, as shown in **Figure 20-16.**



■ **Figure 20-16**

a. Find the net force on the middle particle.

Let left be the negative direction

$$F_{net} = -F_l + (F_r) = -\frac{Kq_mq_l}{d^2} + \frac{Kq_mq_r}{d^2}$$

$$= \frac{-(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(45\times10^{-6}\ \text{C})(55\times10^{-6}\ \text{C})}{(0.72\ \text{m})^2} + \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(45\times10^{-6}\ \text{C})(78\times10^{-6}\ \text{C})}{(0.72\ \text{m})^2}$$

= 18 N, right

b. Find the net force on the right particle.

$$F_{net} = F_l + (-F_m) = +\frac{Kq_lq_r}{(2d)^2} - \frac{Kq_mq_r}{d^2}$$

$$= \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(55\times10^{-6}\ \text{C})(78\times10^{-6}\ \text{C})}{(2(0.72\ \text{m}))^2} + \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(45\times10^{-6}\ \text{C})(78\times10^{-6}\ \text{C})}{(0.72\ \text{m})^2}$$

= −42 N, left

Mixed Review

page 559

Level 1

52. A small metal sphere with charge 1.2×10^{-5} C is touched to an identical neutral sphere and then placed 0.15 m from the second sphere. What is the electric force between the two spheres?

The two spheres share the charge equally, so

$$F = K\frac{q_Aq_B}{d^2} = (9.0\times10^9\ \text{N·m}^2/\text{C}^2)\frac{(6.0\times10^{-6}\ \text{C})(6.0\times10^{-6}\ \text{C})}{(0.15\ \text{m})^2} = 14\ \text{N}$$

53. **Atoms** What is the electric force between an electron and a proton placed 5.3×10^{-11} m apart, the approximate radius of a hydrogen atom?

$$F = K\frac{q_Aq_B}{d^2} = (9.0\times10^9\ \text{N·m}^2/\text{C}^2)\frac{(1.60\times10^{-19}\ \text{C})(1.60\times10^{-19}\ \text{C})}{(5.3\times10^{-11}\ \text{m})^2} = 8.2\times10^{-8}\ \text{N}$$

54. A small sphere of charge 2.4 μC experiences a force of 0.36 N when a second sphere of unknown charge is placed 5.5 cm from it. What is the charge of the second sphere?

$$F = K\frac{q_Aq_B}{d^2}$$

$$q_B = \frac{Fd^2}{Kq_A} = \frac{(0.36\ \text{N})(5.5\times10^{-2}\ \text{m})^2}{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(2.4\times10^{-6}\ \text{C})} = 5.0\times10^{-8}\ \text{C}$$

55. Two identically charged spheres placed 12 cm apart have an electric force of 0.28 N between them. What is the charge of each sphere?

$$F = K\frac{q_Aq_B}{d^2}, \text{ where } q_A = q_B$$

$$q = \sqrt{\frac{Fd^2}{K}} = \sqrt{\frac{(0.28\ \text{N})(1.2\times10^{-1}\ \text{m})^2}{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)}}$$

$$= 6.7\times10^{-7}\ \text{C}$$

56. In an experiment using Coulomb's apparatus, a sphere with a charge of 3.6×10^{-8} C is 1.4 cm from a second sphere of unknown charge. The force between the spheres is 2.7×10^{-2} N. What is the charge of the second sphere?

$$F = K\frac{q_Aq_B}{d^2}$$

$$q_B = \frac{Fd^2}{Kq_A} = \sqrt{\frac{(2.7\times10^{-2}\ \text{N})(1.4\times10^{-2}\ \text{m})^2}{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(3.6\times10^{-8}\ \text{C})}}$$

$$= 1.6\times10^{-8}\ \text{C}$$

57. The force between a proton and an electron is 3.5×10^{-10} N. What is the distance between these two particles?

$$F = K\frac{q_Aq_B}{d^2}$$

$$d = \sqrt{K\frac{q_Aq_B}{F^2}}$$

$$= \sqrt{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)\frac{(1.60\times10^{-19}\ \text{C})(1.6\times10^{-19}\ \text{C})}{3.5\times10^{-10}\ \text{N}}} = 8.1\times10^{-10}\ \text{m}$$

Thinking Critically

page 560

58. Apply Concepts Calculate the ratio of the electric force to the gravitational force between the electron and the proton in a hydrogen atom.

$$\frac{F_e}{F_g} = \frac{K\frac{q_e q_p}{d^2}}{G\frac{m_e m_p}{d^2}} = \frac{Kq_e q_p}{Gm_e m_p}$$

$$= \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(1.60\times10^{-19}\ \text{C})^2}{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(9.11\times10^{-31}\ \text{kg})(1.67\times10^{-27}\ \text{kg})} = 2.3\times10^{39}$$

59. Analyze and Conclude Sphere A, with a charge of +64 μC, is positioned at the origin. A second sphere, B, with a charge of −16 μC, is placed at 11.00 m on the *x*-axis.

a. Where must a third sphere, C, of charge +12 μC be placed so there is no net force on it?

The attractive and repulsive forces must cancel, so

$$F_{AC} = K\frac{q_A q_C}{d_{AC}^2} = K\frac{q_B q_C}{d_{BC}^2} = F_{BC}, \text{ so}$$

$$\frac{q_A}{d_{AC}^2} = \frac{q_B}{d_{BC}^2}, \text{ and } 16d_{AC}^2 = 64d_{BC}^2, \text{ or}$$

$$d_{AC}^2 = 4d_{BC}^2, \text{ so } d_{AC} = 2d_{BC}$$

The third sphere must be placed at +2.00 m on the *x*-axis so it is twice as far from the first sphere as from the second sphere.

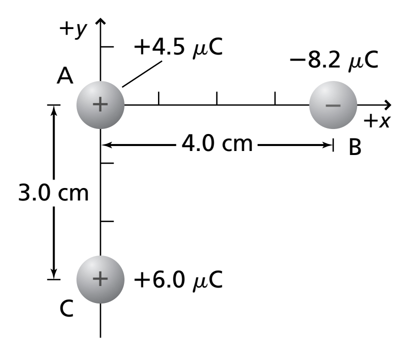
b. If the third sphere had a charge of +6 μC, where should it be placed?

The third charge, q_C, cancels from the equation, so it doesn't matter what its magnitude or sign is.

c. If the third sphere had a charge of −12 μC, where should it be placed?

As in part b, the magnitude and sign of the third charge, q_C, do not matter.

60. Three charged spheres are located at the positions shown in **Figure 20-17.** Find the total force on sphere B.



■ **Figure 20-17**

$$F_1 = F_{A\text{ on }B}$$

$$= \frac{Kq_A q_B}{d^2} = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(4.5\times10^{-6}\ \text{C})(-8.2\times10^{-6}\ \text{C})}{(0.040\ \text{m})^2}$$

$= -208\ \text{N} = 208\ \text{N}$, to left

The distance between the other two charges is

$$\sqrt{(0.040\ \text{m})^2 + (0.030\ \text{m})^2} = 0.050\ \text{m}$$

$$\theta_1 = \tan^{-1}\left(\frac{0.030\ \text{m}}{0.040\ \text{m}}\right)$$

= 37° below the negative *x*-axis, or 217° from the positive *x*-axis.

$$F_2 = F_{\text{C on B}}$$

$$= \frac{Kq_Cq_B}{d^2} = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C})(8.2\times10^{-6}\ \text{C})(6.0\times10^{-6}\ \text{C})}{(0.050\ \text{m})^2}$$

$= -177\ \text{N} = 177\ \text{N}$ at 217° from the positive *x*-axis (37° + 180°)

The components of F_2 are:

$F_{2x} = F_2 \cos\theta = (177\ \text{N})(\cos 217°) = -142\ \text{N} = 142\ \text{N}$ to the left

$F_{2y} = F_2 \sin\theta = (177\ \text{N})(\sin 217°) = -106\ \text{N} = 106\ \text{N}$ down

The components of the net (resultant) force are:

$F_{\text{net},\,x} = -208\ \text{N} - 142\ \text{N} = -350\ \text{N} = 350\ \text{N}$, to left

$F_{\text{net},\,y} = 106\ \text{N}$, down

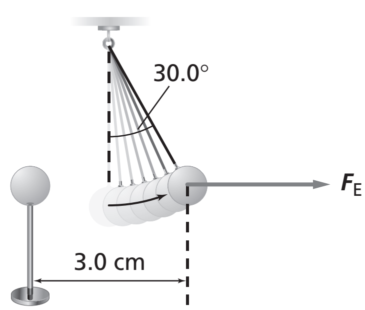
$$F_{\text{net}} = \sqrt{(350\ \text{N})^2 + (106\ \text{N})^2} = 366\ \text{N} = 3.7\times10^2\ \text{N}$$

$$\theta_2 = \tan^{-1}\left(\frac{106\ \text{N}}{350\ \text{N}}\right)$$

= 17° below the negative *x*-axis

$F_{\text{net}} = 3.7\times10^2\ \text{N}$ at 197° from the positive *x*-axis

61. The two pith balls in **Figure 20-18** each have a mass of 1.0 g and an equal charge. One pith ball is suspended by an insulating thread. The other is brought to 3.0 cm from the suspended ball. The suspended ball is now hanging with the thread forming an angle of 30.0° with the vertical. The ball is in equilibrium with F_E, F_g, and F_T. Calculate each of the following.



■ **Figure 20-18**

a. F_g on the suspended ball

$$F_g = mg = (1.0\times10^{-3}\ \text{kg})(9.80\ \text{m/s}^2) = 9.8\times10^{-3}\ \text{N}$$

b. F_E

$$\tan 30.0° = \frac{F_E}{F_g}$$

$$F_E = mg \tan 30.0°$$
$$= (1.0\times10^{-3}\ \text{kg})(9.80\ \text{m/s}^2)(\tan 30.0°)$$
$$= 5.7\times10^{-3}\ \text{N}$$

c. the charge on the balls

$$F = \frac{Kq_Aq_B}{d^2}$$

$$F = \frac{Kq^2}{d^2}$$

$$q = \sqrt{\frac{Fd^2}{K}} = \sqrt{\frac{(5.7\times10^{-3}\ \text{N})(3.0\times10^{-2}\ \text{m}^2)}{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)}} = 2.4\times10^{-8}\ \text{C}$$

62. Two charges, q_A and q_B, are at rest near a positive test charge, q_T, of 7.2 μC. The first charge, q_A, is a positive charge of 3.6 μC located 2.5 cm away from q_T at 35°; q_B is a negative charge of -6.6 μC located 6.8 cm away at 125°.

a. Determine the magnitude of each of the forces acting on q_T.

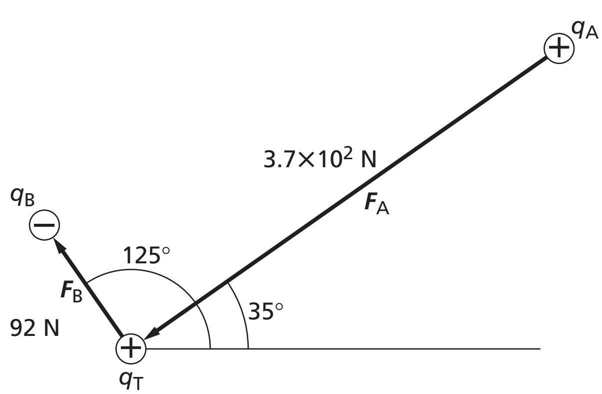
$$F_A = \frac{Kq_Tq_A}{d^2} = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(7.2\times10^{-6}\ \text{C})(3.6\times10^{-6}\ \text{C})}{(0.025\ \text{m})^2}$$

$= 3.7\times10^2$ **N, away (toward** q_T**)**

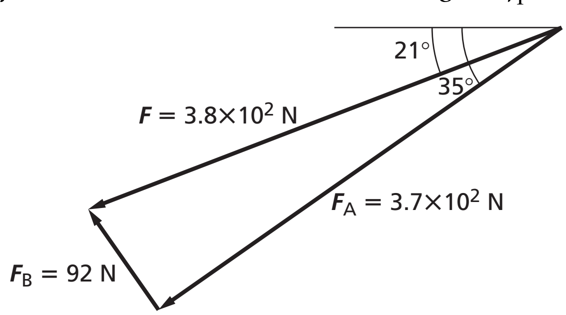
$$F_B = \frac{Kq_Tq_A}{d^2} = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(7.2\times10^{-6}\ \text{C})(6.6\times10^{-6}\ \text{C})}{(0.068\ \text{m})^2}$$

$= 92$ **N, toward (away from** q_T**)**

b. Sketch a force diagram.



c. Graphically determine the resultant force acting on q_T.



Writing in Physics

page 560

63. **History of Science** Research several devices that were used in the seventeenth and eighteenth centuries to study static electricity. Examples that you might consider include the Leyden jar and the Wimshurst machine. Discuss how they were constructed and how they worked.

Student answers will vary, but should include information such as the following. The Leyden jar, invented in the mid-1740s, was the earliest capacitor. It was used throughout the eighteenth and nineteenth centuries to store charges for electricity-related experiments and demonstrations. The Wimshurst machine was a device used in the nineteenth and early twentieth centuries to produce and discharge static charges. Wimshurst machines, which were replaced by the Van de Graaff generator in the twentieth century, used Leyden jars to store the charges prior to discharge.

64. In Chapter 13, you learned that forces exist between water molecules that cause water to be denser as a liquid between 0°C and 4°C than as a solid at 0°C. These forces are electrostatic in nature. Research electrostatic intermolecular forces, such as van der Waals forces and dipole-dipole forces, and describe their effects on matter.

Answers will vary, but students should describe the interactions between positive and negative charges at the molecular level. Students should note that the strength of these forces accounts for differences in melting and boiling points and for the unusual behavior of water between 0°C and 4°C.

Cumulative Review

page 560

65. Explain how a pendulum can be used to determine the acceleration of gravity. (Chapter 14)

Measure the length and period of the pendulum, and use the equation for the period of a pendulum to solve for *g*.

66. A submarine that is moving 12.0 m/s sends a sonar ping of frequency 1.50×10^3 Hz toward a seamount that is directly in front of the submarine. It receives the echo 1.800 s later. (Chapter 15)

a. How far is the submarine from the seamount?

$$d = vt = (1533\text{ m/s})(0.900\text{ s}) = 1380\text{ m}$$

b. What is the frequency of the sonar wave that strikes the seamount?

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right) = (1.50\times10^3\text{ Hz})\left(\frac{1533\text{ m/s} - 0.0\text{ m/s}}{1533\text{ m/s} - 12.0\text{ m/s}}\right)$$

$$= 1510\text{ Hz}$$

c. What is the frequency of the echo received by the submarine?

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right) = (1510\text{ Hz})\left(\frac{1533\text{ m/s} - (-12.0\text{ m/s})}{1533\text{ m/s} - 0.0\text{ m/s}}\right)$$

$$= 1520\text{ Hz}$$

67. **Security Mirror** A security mirror is used to produce an image that is three-fourths the size of an object and is located 12.0 cm behind the mirror. What is the focal length of the mirror? (Chapter 17)

$$m = \frac{-d_i}{d_o}$$

$$d_o = \frac{-d_i}{m} = \frac{-(-12.0\text{ cm})}{\frac{3}{4}} = 16.0\text{ cm}$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$f = \frac{d_o d_i}{d_o + d_i}$$

$$= \frac{(16.0\text{ cm})(-12.0\text{ cm})}{16.0\text{ cm} + (-12.0\text{ cm})}$$

$$= -48.0\text{ cm}$$

68. A 2.00-cm-tall object is located 20.0 cm away from a diverging lens with a focal length of 24.0 cm. What are the image position, height, and orientation? Is this a real or a virtual image? (Chapter 18)

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(20.0\text{ cm})(-24.0\text{ cm})}{20.0\text{ cm} - (-24.0\text{ cm})}$$

$$= -10.9\text{ cm}$$

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(-10.9\text{ cm})(2.00\text{ cm})}{20.0\text{ cm}}$$

$$= 1.09\text{ cm}$$

This is a virtual image that is upright in orientation, relative to the object.

69. Spectrometer A spectrometer contains a grating of 11,500 slits/cm. Find the angle at which light of wavelength 527 nm has a first-order bright band. (Chapter 19)

The number of centimeters per slit is the slit separation distance, *d*.

$$\frac{1\text{ slit}}{d} = 11{,}500\text{ slits/cm}$$

$$d = 8.70\times10^{-5}\text{ cm}$$

$$\lambda = d \sin\theta$$

$$\theta = \sin^{-1}\left(\frac{\lambda}{d}\right)$$

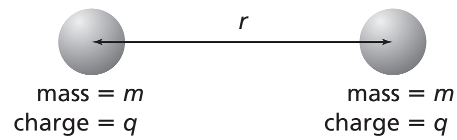
$$= \sin^{-1}\left(\frac{527\times10^{-9}\text{ m}}{8.70\times10^{-3}\text{ m}}\right)$$

$$= 0.00347°$$

Challenge Problem

page 552

As shown in the figure below, two spheres of equal mass, *m*, and equal positive charge, *q*, are a distance, *r*, apart.



■ **Figure 20-11**

1. Derive an expression for the charge, *q*, that must be on each sphere so that the spheres are in equilibrium; that is, so that the attractive and repulsive forces between them are balanced.

The attractive force is gravitation, and the repulsive force is electrostatic, so their expressions may be set equal.

$$F_g = G\frac{m_A m_B}{d^2} = K\frac{q_A q_B}{d^2} = F_e$$

The masses and charges are equal, and the distance cancels, so

$Gm^2 = Kq^2$, **and**

$$q = m\sqrt{\frac{G}{K}}$$

$$= m\sqrt{\frac{(6.67\times10^{-11}\text{ N·m}^2/\text{kg}^2)}{(9.0\times10^{9}\text{ N·m}^2/\text{C}^2)}}$$

$$= (8.61\times10^{-11}\text{ C/kg})m$$

2. If the distance between the spheres is doubled, how will that affect the expression for the value of *q* that you determined in the previous problem? Explain.

The distance does not affect the value of *q* because both forces are inversely related to the square of the distance, and the distance cancels out of the expression.

3. If the mass of each sphere is 1.50 kg, determine the charge on each sphere needed to maintain the equilibrium.

$$q = (8.61\times10^{-11}\text{ C/kg})(1.50\text{ kg})$$

$$= 1.29\times10^{-10}\text{ C}$$

CHAPTER

21 Electric Fields

Practice Problems

21.1 Creating and Measuring Electric Fields pages 563–568

page 565

1. A positive test charge of 5.0×10^{-6} C is in an electric field that exerts a force of 2.0×10^{-4} N on it. What is the magnitude of the electric field at the location of the test charge?

$$E = \frac{F}{q} = \frac{2.0\times10^{-4}\ \text{N}}{5.0\times10^{-6}\ \text{C}} = 4.0\times10^{1}\ \text{N/C}$$

2. A negative charge of 2.0×10^{-8} C experiences a force of 0.060 N to the right in an electric field. What are the field's magnitude and direction at that location?

$$E = \frac{F}{q} = \frac{0.060\ \text{N}}{2.0\times10^{-8}\ \text{C}} = 3.0\times10^{6}\ \text{N/C}$$

directed to the left

3. A positive charge of 3.0×10^{-7} C is located in a field of 27 N/C directed toward the south. What is the force acting on the charge?

$$E = \frac{F}{q}$$

$$F = Eq = (27\ \text{N/C})(3.0\times10^{-7}\ \text{C})$$

$$= 8.1\times10^{-6}\ \text{N}$$

4. A pith ball weighing 2.1×10^{-3} N is placed in a downward electric field of 6.5×10^{4} N/C. What charge (magnitude and sign) must be placed on the pith ball so that the electric force acting on it will suspend it against the force of gravity?

The electric force and the gravitational force algebraically sum to zero because the ball is suspended, i.e. not in motion:

$F_g + F_e = 0$, so $F_e = -F_g$

$$E = \frac{F_e}{q}$$

$$q = \frac{F_e}{E} = -\frac{F_g}{E} = -\frac{2.1\times10^{-3}\ \text{N}}{6.5\times10^{4}\ \text{N/C}}$$

$$= -3.2\times10^{-8}\ \text{C}$$

The electric force is upward (opposite the field), so the charge is negative.

5. You are probing the electric field of a charge of unknown magnitude and sign. You first map the field with a 1.0×10^{-6}-C test charge, then repeat your work with a 2.0×10^{-6}-C test charge.

a. Would you measure the same forces at the same place with the two test charges? Explain.

No. The force on the 2.0-μC charge would be twice that on the 1.0-μC charge.

b. Would you find the same field strengths? Explain.

Yes. You would divide the force by the strength of the test charge, so the results would be the same.

page 566

6. What is the magnitude of the electric field strength at a position that is 1.2 m from a point charge of 4.2×10^{-6} C?

$$E = \frac{F}{q'} = K\frac{q}{d^2}$$

$$= (9\times10^{9}\ \text{N·m}^2/\text{C}^2)\frac{(4.2\times10^{-6}\ \text{C})}{(1.2\ \text{m})^2}$$

$$= 2.6\times10^{4}\ \text{N/C}$$

7. What is the magnitude of the electric field strength at a distance twice as far from the point charge in problem 6?

Because the field strength varies as the square of the distance from the point charge, the new field strength will be one-fourth of the old field strength, or 6.5×10^{3} N/C.

8. What is the electric field at a position that is 1.6 m east of a point charge of $+7.2\times10^{-6}$ C?

$$E = \frac{F}{q'} = K\frac{q}{d^2}$$

$$= (9.0\times10^9\ \text{N·m}^2/\text{C}^2)\frac{(7.2\times10^{-6}\ \text{C})}{(1.6\ \text{m})^2}$$

$$= 2.5\times10^4\ \text{N/C}$$

The direction of the field is east (away from the positive point charge).

9. The electric field that is 0.25 m from a small sphere is 450 N/C toward the sphere. What is the charge on the sphere?

$$E = \frac{F}{q'} = K\frac{q}{d^2}$$

$$q = \frac{Ed^2}{K}$$

$$= \frac{(450\ \text{N/C})(0.25\ \text{m})^2}{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)} = -3.1\times10^{-9}\ \text{C}$$

The charge is negative, because the field is directed toward it.

10. How far from a point charge of $+2.4\times10^{-6}$ C must a test charge be placed to measure a field of 360 N/C?

$$E = \frac{F}{q'} = K\frac{q}{d^2}$$

$$d = \sqrt{\frac{Kq}{E}}$$

$$= \sqrt{\frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(2.4\times10^{-6}\ \text{C})}{360\ \text{N/C}}}$$

$$= 7.7\ \text{m}$$

Section Review

21.1 Creating and Measuring Electric Fields pages 563–568

page 568

11. Measuring Electric Fields Suppose you are asked to measure the electric field in space. How do you detect the field at a point? How do you determine the magnitude of the field? How do you choose the magnitude of the test charge? What do you do next?

To detect a field at a point, place a test charge at that point and determine if there is a force on it.

To determine the magnitude of the field, divide the magnitude of the force on the test charge by the magnitude of the test charge.

The magnitude of the test charge must be chosen so that it is very small compared to the magnitudes of the charges producing the field.

The next thing you should do is measure the direction of the force on the test charge. The direction of the field is the same as the direction of the force if the test charge is positive; otherwise, it is in the opposite direction.

12. Field Strength and Direction A positive test charge of magnitude 2.40×10^{-8} C experiences a force of 1.50×10^{-3} N toward the east. What is the electric field at the position of the test charge?

$$E = \frac{F}{q} = \frac{1.50\times10^{-3}\ \text{N east}}{2.40\times10^{-8}\ \text{C}}$$

$$= 6.25\times10^4\ \text{N/C east}$$

13. Field Lines In Figure 21-4, can you tell which charges are positive and which are negative? What would you add to complete the field lines?

No. The field lines must have arrowheads indicating their directions, from positive to negative charges.

14. Field Versus Force How does the electric field, *E*, at the test charge differ from the force, *F*, on it?

The field is a property of that region of space, and does not depend on the test charge used to measure it. The force depends on the magnitude and sign of the test charge.

15. Critical Thinking Suppose the top charge in Figure 21-2c is a test charge measuring the field resulting from the two negative charges. Is it small enough to produce an accurate measure? Explain.

No. This charge is large enough to distort the field produced by the other charges with its own field. Compare with Figure 21-4b.

Practice Problems

21.2 Applications of Electric Fields pages 569–579

page 571

16. The electric field intensity between two large, charged, parallel metal plates is 6000 N/C. The plates are 0.05 m apart. What is the electric potential difference between them?

$$\Delta V = Ed = (6000 \text{ N/C})(0.05 \text{ m})$$
$$= 300 \text{ J/C} = 3\times10^{2} \text{ V}$$

17. A voltmeter reads 400 V across two charged, parallel plates that are 0.020 m apart. What is the electric field between them?

$$\Delta V = Ed$$
$$E = \frac{\Delta V}{d} = \frac{400 \text{ V}}{0.020 \text{ m}} = 2\times10^{4} \text{ N/C}$$

18. What electric potential difference is applied to two metal plates that are 0.200 m apart if the electric field between them is 2.50×10^{3} N/C?

$$\Delta V = Ed = (2.50\times10^{3} \text{ N/C})(0.200 \text{ m})$$
$$= 5.00\times10^{2} \text{ V}$$

19. When a potential difference of 125 V is applied to two parallel plates, the field between them is 4.25×10^{3} N/C. How far apart are the plates?

$$\Delta V = Ed$$
$$d = \frac{\Delta V}{E} = \frac{125 \text{ V}}{4.25\times10^{3} \text{ N/C}} = 2.94\times10^{-2} \text{ m}$$

20. A potential difference of 275 V is applied to two parallel plates that are 0.35 cm apart. What is the electric field between the plates?

$$E = \frac{\Delta V}{d} = \frac{275 \text{ V}}{3.5\times10^{-3} \text{ m}} = 7.9\times10^{4} \text{ N/C}$$

page 572

21. What work is done when 3.0 C is moved through an electric potential difference of 1.5 V?

$$W = q\Delta V = (3.0 \text{ C})(1.5 \text{ V}) = 4.5 \text{ J}$$

22. A 12-V car battery can store 1.44×10^{6} C when it is fully charged. How much work can be done by this battery before it needs recharging?

$$W = q\Delta V = (1.44\times10^{6} \text{ C})(12 \text{ V})$$
$$= 1.7\times10^{7} \text{ J}$$

23. An electron in a television picture tube passes through a potential difference of 18,000 V. How much work is done on the electron as it passes through that potential difference?

$$W = q\Delta V = (1.60\times10^{-19} \text{ C})(1.8\times10^{4} \text{ V})$$
$$= 2.9\times10^{-15} \text{ J}$$

24. If the potential difference in problem 18 is between two parallel plates that are 2.4 cm apart, what is the magnitude of the electric field between them?

$$E = \frac{\Delta V}{d} = \frac{5.00\times10^{2} \text{ V}}{0.024 \text{ m}} = 2.1\times10^{4} \text{ N/C}$$

25. The electric field in a particle-accelerator machine is 4.5×10^{5} N/C. How much work is done to move a proton 25 cm through that field?

$$W = q\Delta V = qEd$$
$$= (1.60\times10^{-19} \text{ C})(4.5\times10^{5} \text{ N/C})(0.25 \text{ m})$$
$$= 1.8\times10^{-14} \text{ J}$$

page 574

26. A drop is falling in a Millikan oil-drop apparatus with no electric field. What forces are acting on the oil drop, regardless of its acceleration? If the drop is falling at a constant velocity, describe the forces acting on it.

Gravitational force (weight) downward, friction force of air upward. The two forces are equal in magnitude if the drop falls at constant velocity.

27. An oil drop weighs 1.9×10^{-15} N. It is suspended in an electric field of 6.0×10^{3} N/C. What is the charge on the drop? How many excess electrons does it carry?

$$F_g = Eq$$

$$q = \frac{F_g}{E} = \frac{1.9\times10^{-15}\ \text{N}}{6.0\times10^{3}\ \text{N/C}}$$

$$= 3.2\times10^{-19}\ \text{C}$$

$$\#\ \text{electrons} = \frac{q}{q_e} = \frac{3.2\times10^{-19}\ \text{C}}{1.60\times10^{-19}\ \text{C}} = 2$$

28. An oil drop carries one excess electron and weighs 6.4×10^{-15} N. What electric field strength is required to suspend the drop so it is motionless?

$$E = \frac{F}{q} = \frac{6.4\times10^{-15}\ \text{N}}{1.60\times10^{-19}\ \text{C}} = 4.0\times10^{4}\ \text{N/C}$$

29. A positively charged oil drop weighing 1.2×10^{-14} N is suspended between parallel plates separated by 0.64 cm. The potential difference between the plates is 240 V. What is the charge on the drop? How many electrons is the drop missing?

$$E = \frac{\Delta V}{d} = \frac{240\ \text{V}}{6.4\times10^{-3}\ \text{m}} = 3.8\times10^{4}\ \text{N/C}$$

$$E = \frac{F}{q}$$

$$q = \frac{F}{E} = \frac{1.2\times10^{-14}\ \text{N}}{3.8\times10^{4}\ \text{N/C}} = 3.2\times10^{-19}\ \text{C}$$

$$\#\ \text{electrons} = \frac{q}{q_e} = \frac{3.4\times10^{-19}\ \text{C}}{1.60\times10^{-19}\ \text{C}} = 2$$

page 578

30. A 27-μF capacitor has an electric potential difference of 45 V across it. What is the charge on the capacitor?

$$q = C\Delta V = (27\times10^{-6}\ \text{F})(45\ \text{V})$$

$$= 1.2\times10^{-3}\ \text{C}$$

31. Both a 3.3-μF and a 6.8-μF capacitor are connected across a 24-V electric potential difference. Which capacitor has a greater charge? What is it?

$q = C\Delta V$, so the larger capacitor has a greater charge.

$$q = (6.8\times10^{-6}\ \text{F})(24\ \text{V}) = 1.6\times10^{-4}\ \text{C}$$

32. The same two capacitors as in problem 31 are each charged to 3.5×10^{-4} C. Which has the larger electric potential difference across it? What is it?

$\Delta V = \frac{q}{C}$, so the smaller capacitor has the larger potential difference.

$$\Delta V = \frac{3.5\times10^{-4}\ \text{C}}{3.5\times10^{-6}\ \text{F}} = 1.1\times10^{2}\ \text{V}$$

33. A 2.2-μF capacitor first is charged so that the electric potential difference is 6.0 V. How much additional charge is needed to increase the electric potential difference to 15.0 V?

$$q = C\Delta V$$

$$\Delta q = C(\Delta V_2 - \Delta V_1)$$

$$= (2.2\times10^{-6}\ \text{F})(15.0\ \text{V} - 6.0\ \text{V})$$

$$= 2.0\times10^{-5}\ \text{C}$$

34. When a charge of 2.5×10^{-5} C is added to a capacitor, the potential difference increases from 12.0 V to 14.5 V. What is the capacitance of the capacitor?

$$C = \frac{q}{\Delta V_2 - \Delta V_1} = \frac{2.5\times10^{-5}\ \text{C}}{14.5\ \text{V} - 12.0\ \text{V}}$$

$$= 1.0\times10^{-5}\ \text{F}$$

Section Review

21.2 Applications of Electric Fields pages 569–579

page 579

35. Potential Difference What is the difference between electric potential energy and electric potential difference?

Electric potential energy changes when work is done to move a charge in an electric field. It depends on the amount of charge involved. Electric potential difference is the work done per unit charge to move a charge in an electric field. It is independent of the amount of charge that is moved.

36. Electric Field and Potential Difference Show that a volt per meter is the same as a newton per coulomb.

V/m = J/C·m = N·m/C·m = N/C

37. Millikan Experiment When the charge on an oil drop suspended in a Millikan apparatus is changed, the drop begins to fall. How should the potential difference on the plates be changed to bring the drop back into balance?

The potential difference should be increased.

38. Charge and Potential Difference In problem 37, if changing the potential difference has no effect on the falling drop, what does this tell you about the new charge on the drop?

The drop is electrically neutral (no electron excess or deficiency).

39. Capacitance How much charge is stored on a 0.47-μF capacitor when a potential difference of 12 V is applied to it?

$$q = C\Delta V = (4.7\times10^{-7}\ \text{F})(12\ \text{V})$$
$$= 5.6\times10^{-6}\ \text{C}$$

40. Charge Sharing If a large, positively charged, conducting sphere is touched by a small, negatively charged, conducting sphere, what can be said about the following?

a. the potentials of the two spheres

The spheres will have equal potentials.

b. the charges on the two spheres

The large sphere will have more charge than the small sphere, but they will be the same sign. The sign of the charge will depend on which sphere began with more charge.

41. Critical Thinking Referring back to Figure 21-3a, explain how charge continues to build up on the metal dome of a Van de Graaff generator. In particular, why isn't charge repelled back onto the belt at point B?

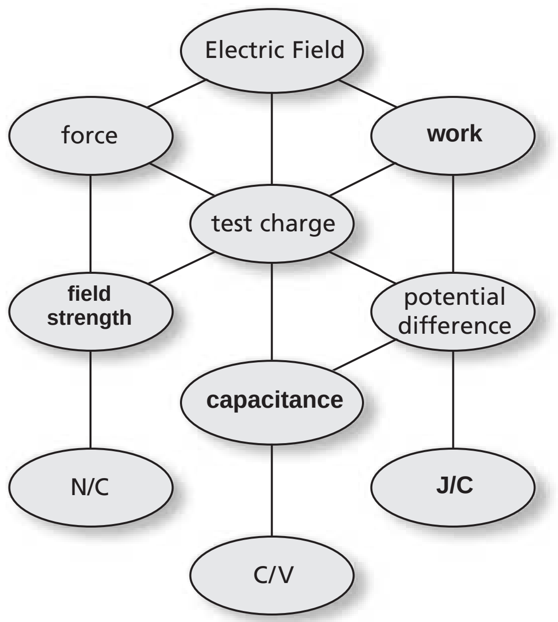
The charges on the metal dome produce no field inside the dome. The charges from the belt are transferred immediately to the outside of the dome, where they have no effect on new charges arriving at point B.

Chapter Assessment

Concept Mapping

page 584

42. Complete the concept map below using the following terms: *capacitance, field strength, J/C, work.*



Mastering Concepts

page 584

43. What are the two properties that a test charge must have? (21.1)

The test charge must be small in magnitude relative to the magnitudes of the charges producing the field and be positive.

44. How is the direction of an electric field defined? (21.1)

The direction of an electric field is the direction of the force on a positive charge placed in the field. This would be away from a positive object and toward a negative object.

45. What are electric field lines? (21.1)

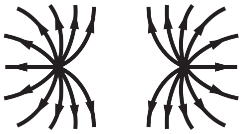
lines of force

46. How is the strength of an electric field indicated with electric field lines? (21.1)

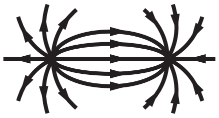
The closer together the electric field lines are, the stronger the electric field.

47. Draw some of the electric field lines between each of the following. (21.1)

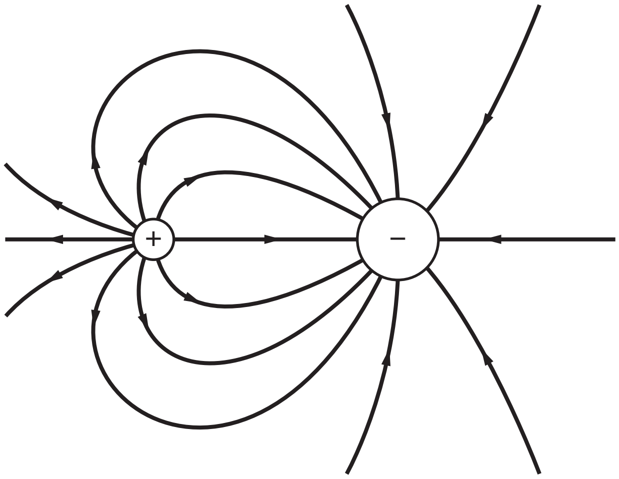
a. two like charges of equal magnitude



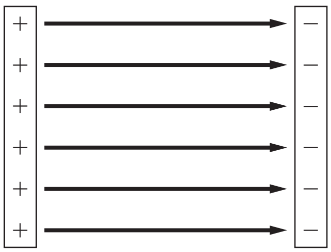
b. two unlike charges of equal magnitude



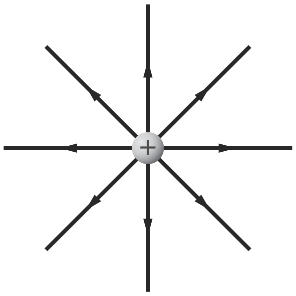
c. a positive charge and a negative charge having twice the magnitude of the positive charge



d. two oppositely charged parallel plates



48. In **Figure 21-15,** where do the electric field lines leave the positive charge end? (21.1)



■ **Figure 21-15**

They end on distant negative charges somewhere beyond the edges of the diagram.

49. What SI unit is used to measure electric potential energy? What SI unit is used to measure electric potential difference? (21.2)

electric potential energy: joule; electric potential: volt

50. Define *volt* in terms of the change in potential energy of a charge moving in an electric field. (21.2)

A *volt* is the change in electric potential energy, Δ*PE*, resulting from moving a unit test charge, *q*, a distance, *d*, of 1 m in an electric field, *E*, of 1 N/C.

$$\Delta V = \Delta PE/q = Ed$$

51. Why does a charged object lose its charge when it is touched to the ground? (21.2)

The charge is shared with the surface of Earth, which is an extremely large object.

52. A charged rubber rod that is placed on a table maintains its charge for some time. Why is the charged rod not discharged immediately? (21.2)

The table is an insulator, or at least a very poor conductor.

53. A metal box is charged. Compare the concentration of charge at the corners of the box to the charge concentration on the sides of the box. (21.2)

The concentration of charge is greater at the corners.

54. Computers Delicate parts in electronic equipment, such as those pictured in **Figure 21-16,** are contained within a metal box inside a plastic case. Why? (21.2)

■ **Figure 21-16**

The metal box shields the parts from external electric fields, which do not exist inside a hollow conductor.

Applying Concepts

pages 584–585

55. What happens to the strength of an electric field when the charge on the test charge is halved?

Nothing. Because the force on the test charge also would be halved, the ratio *F′/q′* and the electric field would remain the same.

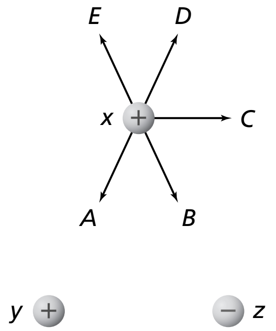
56. Does it require more energy or less energy to move a constant positive charge through an increasing electric field?

Energy is proportional to the force, and the force is proportional to the electric field. Therefore, it requires more energy.

57. What will happen to the electric potential energy of a charged particle in an electric field when the particle is released and free to move?

The electric potential energy of the particle will be converted into kinetic energy of the particle.

58. **Figure 21-17** shows three spheres with charges of equal magnitude, with their signs as shown. Spheres *y* and *z* are held in place, but sphere *x* is free to move. Initially, sphere *x* is equidistant from spheres *y* and *z*. Choose the path that sphere *x* will begin to follow. Assume that no other forces are acting on the spheres.



■ **Figure 21-17**

Sphere *x* will follow path C. It will experience forces shown by D and B. The vector sum is C.

59. What is the unit of electric potential difference in terms of m, kg, s, and C?

$$V = \text{J/C} = \text{N·m/C} = (\text{kg·m/s}^2)(\text{m/C})$$

$$= \text{kg·m}^2/\text{s}^2\text{·C}$$

60. What do the electric field lines look like when the electric field has the same strength at all points in a region?

They are parallel, equally spaced lines.

61. **Millikan Oil-Drop Experiment** When doing a Millikan oil-drop experiment, it is best to work with drops that have small charges. Therefore, when the electric field is turned on, should you try to find drops that are moving rapidly or slowly? Explain.

Slowly. The larger the charge, the stronger the force, and thus, the larger the (terminal) velocity.

62. Two oil drops are held motionless in a Millikan oil-drop experiment.

a. Can you be sure that the charges are the same?

No. Their masses could be different.

b. The ratios of which two properties of the oil drops have to be equal?

charge to mass ratio, *q/m* (or *m/q*)

63. José and Sue are standing on an insulating platform and holding hands when they are given a charge, as in **Figure 21-18.** José is larger than Sue. Who has the larger amount of charge, or do they both have the same amount?

■ **Figure 21-18**

José has a larger surface area, so he will have a larger amount of charge.

64. Which has a larger capacitance, an aluminum sphere with a 1-cm diameter or one with a 10-cm diameter?

The 10-cm diameter sphere has a larger capacitance because the charges can be farther apart, reducing potential rise as it is charged.

65. How can you store different amounts of charge in a capacitor?

Change the voltage across the capacitor.

Mastering Problems

21.1 Creating and Measuring Electric Fields pages 585–586

The charge of an electron is -1.60×10^{-19} C.

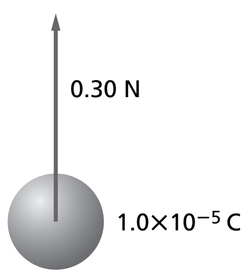
Level 1

66. What charge exists on a test charge that experiences a force of 1.4×10^{-8} N at a point where the electric field intensity is 5.0×10^{-4} N/C?

$$E = \frac{F}{q}$$

$$q = \frac{F}{E} = \frac{1.4\times10^{-8}\ \text{N}}{5.0\times10^{-4}\ \text{N/C}} = 2.8\times10^{-5}\ \text{C}$$

67. A positive charge of 1.0×10^{-5} C, shown in **Figure 21-19,** experiences a force of 0.30 N when it is located at a certain point. What is the electric field intensity at that point?



■ **Figure 21-19**

$$E = \frac{F}{q} = \frac{0.30\ \text{N}}{1.0\times10^{-5}\ \text{C}} = 3.0\times10^{4}\ \text{N/C}$$

in the same direction as the force

68. A test charge experiences a force of 0.30 N on it when it is placed in an electric field intensity of 4.5×10^{5} N/C. What is the magnitude of the charge?

$$E = \frac{F}{q}$$

$$q = \frac{F}{E} = \frac{0.30\ \text{N}}{4.5\times10^{5}\ \text{N/C}} = 6.7\times10^{-7}\ \text{C}$$

69. The electric field in the atmosphere is about 150 N/C downward.

a. What is the direction of the force on a negatively charged particle?

upward

b. Find the electric force on an electron with charge -1.6×10^{-19} C.

$$E = \frac{F}{q}$$

$$F = qE = (1.6\times10^{-19}\ \text{C})(150\ \text{N/C})$$

$$= 2.4\times10^{-17}\ \text{N}$$

$F = 2.4\times10^{-17}$ **N directed upward**

c. Compare the force in part **b** with the force of gravity on the same electron (mass = 9.1×10^{-31} kg).

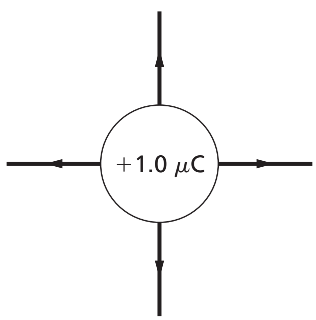
$$F = mg = (9.1\times10^{-31}\ \text{kg})(9.80\ \text{m/s}^2)$$

$$= 8.9\times10^{-30}\ \text{N}$$

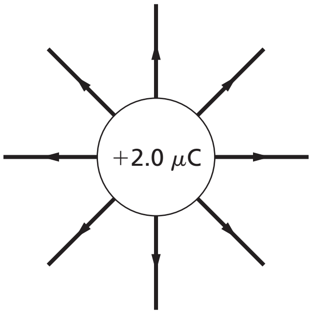
$F = 8.9\times10^{-30}$ **N (downward), more than one trillion times smaller**

70. Carefully sketch each of the following.

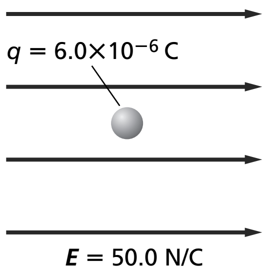
a. the electric field produced by a $+1.0$-μC charge



b. the electric field resulting from a $+2.0\text{-}\mu C$ charge (Make the number of field lines proportional to the change in charge.)



71. A positive test charge of 6.0×10^{-6} C is placed in an electric field of 50.0-N/C intensity, as in **Figure 21-20.** What is the strength of the force exerted on the test charge?



■ **Figure 21-20**

$\boldsymbol{E = \frac{F}{q}}$

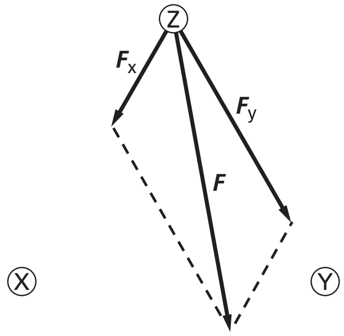
$\boldsymbol{F = qE = (6.0\times10^{-6}\ \text{C})(50.0\ \text{N/C})}$

$\boldsymbol{= 3.0\times10^{-4}\ \text{N}}$

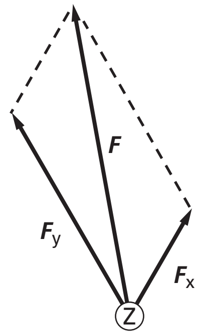
Level 2

72. Charges X, Y, and Z all are equidistant from each other. X has a $+1.0\text{-}\mu C$ charge, Y has a $+2.0\text{-}\mu C$ charge, and Z has a small negative charge.

a. Draw an arrow representing the force on charge Z.



b. Charge Z now has a small positive charge on it. Draw an arrow representing the force on it.



73. In a television picture tube, electrons are accelerated by an electric field having a value of 1.00×10^{5} N/C.

a. Find the force on an electron.

$\boldsymbol{E = \frac{F}{q}}$

$\boldsymbol{F = Eq}$

$\boldsymbol{= (-1.60\times10^{-19}\ \text{C})(1.00\times10^{5}\ \text{N/C})}$

$\boldsymbol{= -1.60\times10^{-14}\ \text{N}}$

b. If the field is constant, find the acceleration of the electron (mass $= 9.11\times10^{-31}$ kg).

$\boldsymbol{F = ma}$

$\boldsymbol{a = \frac{F}{m} = \frac{-1.60\times10^{-14}\ \text{N}}{9.11\times10^{-31}\ \text{kg}}}$

$\boldsymbol{= -1.76\times10^{16}\ \text{m/s}^2}$

74. What is the electric field strength 20.0 cm from a point charge of 8.0×10^{-7} C?

$\boldsymbol{E = \frac{F}{q'}}$**, and** $\boldsymbol{F = \frac{Kqq'}{d^2}}$

so $\boldsymbol{E = \frac{Kq}{d^2}}$

$\boldsymbol{= \frac{(9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)(8.0\times10^{-7}\ \text{C})}{(0.200\ \text{m})^2}}$

$\boldsymbol{= 1.8\times10^{5}\ \text{N/C}}$

75. The nucleus of a lead atom has a charge of 82 protons.

a. What are the direction and magnitude of the electric field at 1.0×10^{-10} m from the nucleus?

$$\mathbf{Q = (82\ protons)(1.60\times10^{-19}\ C/proton)}$$
$$\mathbf{= 1.31\times10^{-17}\ C}$$
$$E = \frac{F}{q} = \frac{1}{q}\left(\frac{KqQ}{d^2}\right) = \frac{KQ}{d^2}$$
$$= \frac{(9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)(1.31\times10^{-17}\ \text{C})}{(1.0\times10^{-10}\ \text{m})^2}$$
$$= 1.2\times10^{13}\ \text{N/C, outward}$$

b. What are the direction and magnitude of the force exerted on an electron located at this distance?

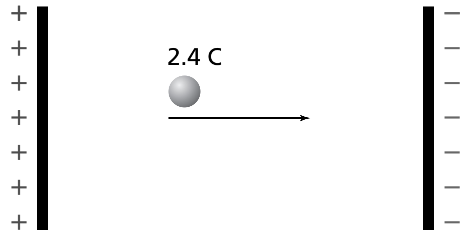
$$F = Eq$$
$$= (1.2\times10^{13}\ \text{N/C})(-1.60\times10^{-19}\ \text{C})$$
$$= -1.9\times10^{-6}\ \text{N, toward the nucleus}$$

21.2 Applications of Electric Fields

pages 586–587

Level 1

76. If 120 J of work is performed to move 2.4 C of charge from the positive plate to the negative plate shown in **Figure 21-21,** what potential difference exists between the plates?



■ **Figure 21-21**

$$\Delta V = \frac{W}{q} = \frac{120\ \text{J}}{2.4\ \text{C}} = 5.0\times10^{1}\ \text{V}$$

77. How much work is done to transfer 0.15 C of charge through an electric potential difference of 9.0 V?

$$\Delta V = \frac{W}{q}$$
$$W = q\Delta V = (0.15\ \text{C})(9.0\ \text{V}) = 1.4\ \text{J}$$

78. An electron is moved through an electric potential difference of 450 V. How much work is done on the electron?

$$\Delta V = \frac{W}{q}$$
$$W = q\Delta V$$
$$= (-1.60\times10^{-19}\ \text{C})(450\ \text{V})$$
$$= -7.2\times10^{-17}\ \text{J}$$

79. A 12-V battery does 1200 J of work transferring charge. How much charge is transferred?

$$\Delta V = \frac{W}{q}$$
$$q = \frac{W}{\Delta V} = \frac{1200\ \text{J}}{12\ \text{V}} = 1.0\times10^{2}\ \text{C}$$

80. The electric field intensity between two charged plates is 1.5×10^{3} N/C. The plates are 0.060 m apart. What is the electric potential difference, in volts, between the plates?

$$\Delta V = Ed$$
$$= (1.5\times10^{3}\ \text{N/C})(0.060\ \text{m})$$
$$= 9.0\times10^{1}\ \text{V}$$

81. A voltmeter indicates that the electric potential difference between two plates is 70.0 V. The plates are 0.020 m apart. What electric field intensity exists between them?

$$\Delta V = Ed$$
$$E = \frac{\Delta V}{d} = \frac{70.0\ \text{V}}{0.020\ \text{m}} = 3500\ \text{V/m}$$
$$= 3500\ \text{N/C}$$

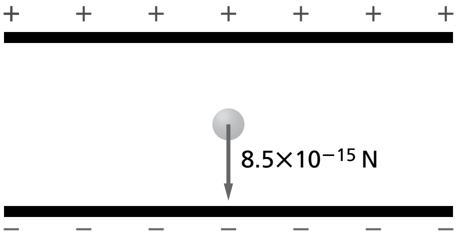
82. A capacitor that is connected to a 45.0-V source contains 90.0 μC of charge. What is the capacitor's capacitance?

$$C = \frac{q}{\Delta V} = \frac{90.0\times10^{-6}\ \text{C}}{45.0\ \text{V}} = 2.00\ \mu\text{F}$$

83. What electric potential difference exists across a 5.4-μF capacitor that has a charge of 8.1×10^{-4} C?

$$C = \frac{q}{\Delta V}$$
$$\Delta V = \frac{q}{C} = \frac{8.1\times10^{-4}\ \text{C}}{5.4\times10^{-6}\ \text{F}}$$
$$= 1.5\times10^{2}\ \text{V}$$

84. The oil drop shown in **Figure 21-22** is negatively charged and weighs 4.5×10^{-15} N. The drop is suspended in an electric field intensity of 5.6×10^{3} N/C.



■ **Figure 21-22**

a. What is the charge on the drop?

$$E = \frac{F}{q}$$

$$q = \frac{F}{E} = \frac{4.5\times10^{-15}\ \text{N}}{5.6\times10^{3}\ \text{N/C}}$$

$$= 8.0\times10^{-19}\ \text{C}$$

b. How many excess electrons does it carry?

$$(8.0\times10^{-19}\ \text{C})\left(\frac{1\ \text{electron}}{1.60\times10^{-19}\ \text{C}}\right)$$

$$= 5\ \text{electrons}$$

85. What is the charge on a 15.0-pF capacitor when it is connected across a 45.0-V source?

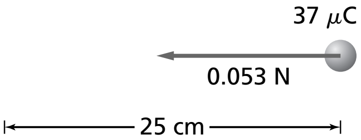
$$C = \frac{q}{\Delta V}$$

$$q = C\Delta V = (15.0\times10^{-12}\ \text{F})(45.0\ \text{V})$$

$$= 6.75\times10^{-10}\ \text{C}$$

Level 2

86. A force of 0.065 N is required to move a charge of 37 μC a distance of 25 cm in a uniform electric field, as in **Figure 21-23.** What is the size of the electric potential difference between the two points?



■ **Figure 21-23**

$$W = Fd$$

and $$\Delta V = \frac{W}{q} = \frac{Fd}{q}$$

$$= \frac{(0.065\ \text{N})(0.25\ \text{m})}{37\times10^{-6}\ \text{C}}$$

$$= 4.4\times10^{2}\ \text{V}$$

87. Photoflash The energy stored in a capacitor with capacitance *C*, and an electric potential difference, ΔV, is represented by $W = \frac{1}{2}C\Delta V^2$. One application of this is in the electronic photoflash of a strobe light, like the one in **Figure 21-24.** In such a unit, a capacitor of 10.0 μF is charged to 3.0×10^{2} V. Find the energy stored.

■ **Figure 21-24**

$$W = \frac{1}{2}C\Delta V^2$$

$$= \left(\frac{1}{2}\right)(10.0\times10^{-6}\ \text{F})(3.0\times10^{2}\ \text{V})^2$$

$$= 0.45\ \text{J}$$

88. Suppose it took 25 s to charge the capacitor in problem 87.

a. Find the average power required to charge the capacitor in this time.

$$P = \frac{W}{t} = \frac{0.45\ \text{J}}{25\ \text{s}} = 1.8\times10^{-2}\ \text{W}$$

b. When this capacitor is discharged through the strobe lamp, it transfers all its energy in 1.0×10^{-4} s. Find the power delivered to the lamp.

$$P = \frac{W}{t} = \frac{0.45\ \text{J}}{1.0\times10^{-4}\ \text{s}} = 4.5\times10^{3}\ \text{W}$$

c. How is such a large amount of power possible?

Power is inversely proportional to the time. The shorter the time for a given amount of energy to be expended, the greater the power.

89. Lasers Lasers are used to try to produce controlled fusion reactions. These lasers require brief pulses of energy that are stored in large rooms filled with capacitors. One such room has a capacitance of 61×10^{-3} F charged to a potential difference of 10.0 kV.

a. Given that $W = \frac{1}{2}C\Delta V^2$, find the energy stored in the capacitors.

$$\boldsymbol{W = \frac{1}{2}C\Delta V^2}$$

$$= \left(\frac{1}{2}\right)(61\times10^{-3}\ \text{F})(1.00\times10^{4}\ \text{V})^2$$

$$= 3.1\times10^{6}\ \text{J}$$

b. The capacitors are discharged in 10 ns (1.0×10^{-8} s). What power is produced?

$$P = \frac{W}{t} = \frac{3.1\times10^{6}\ \text{J}}{1.0\times10^{-8}\ \text{s}} = 3.1\times10^{14}\ \text{W}$$

c. If the capacitors are charged by a generator with a power capacity of 1.0 kW, how many seconds will be required to charge the capacitors?

$$t = \frac{W}{P} = \frac{3.1\times10^{6}\ \text{J}}{1.0\times10^{3}\ \text{W}} = 3.1\times10^{3}\ \text{s}$$

Mixed Review

page 587

Level 1

90. How much work does it take to move 0.25 μC between two parallel plates that are 0.40 cm apart if the field between the plates is 6400 N/C?

$$W = q\Delta V = qEd$$

$$= (2.5\times10^{-7}\ \text{C})(6400\ \text{N/C})(4.0\times10^{-3}\ \text{m})$$

$$= 6.4\times10^{-6}\ \text{J}$$

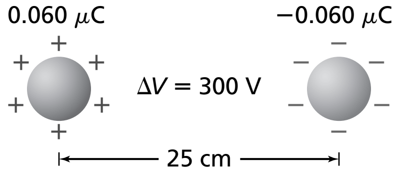
91. How much charge is stored on a 0.22-μF parallel plate capacitor if the plates are 1.2 cm apart and the electric field between them is 2400 N/C?

$$q = C\Delta V = CEd$$

$$= (2.2\times10^{-7}\ \text{F})(2400\ \text{N/C})(1.2\times10^{-2}\ \text{m})$$

$$= 6.3\ \mu\text{C}$$

92. Two identical small spheres, 25 cm apart, carry equal but opposite charges of 0.060 μC, as in **Figure 21-25.** If the potential difference between them is 300 V, what is the capacitance of the system?



■ **Figure 21-25**

$$C = \frac{q}{\Delta V} = \frac{6.0\times10^{-8}\ \text{C}}{300\ \text{V}} = 2\times10^{-10}\ \text{F}$$

93. The plates of a 0.047 μF capacitor are 0.25 cm apart and are charged to a potential difference of 120 V. How much charge is stored on the capacitor?

$$C = \frac{q}{\Delta V}$$

$$q = C\Delta V$$

$$= (4.7\times10^{-8}\ \text{F})(120\ \text{V})$$

$$= 5.6\times10^{-6}\ \text{C} = 5.6\ \mu\text{C}$$

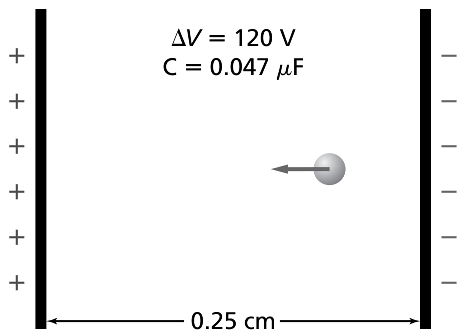
94. What is the strength of the electric field between the plates of the capacitor in Problem 93 above?

$$\Delta V = Ed$$

$$E = \frac{\Delta V}{d}$$

$$= \frac{120\ \text{V}}{2.5\times10^{-3}\ \text{m}} = 4.8\times10^{4}\ \text{V/m}$$

95. An electron is placed between the plates of the capacitor in Problem 93 above, as in **Figure 21-26.** What force is exerted on that electron?



■ **Figure 21-26**

$$E = \frac{F}{q}$$

$$F = Eq$$

$$= (4.8\times10^{4}\ \text{V/m})(1.6\times10^{-19}\ \text{C})$$

$$= 7.7\times10^{-15}\ \text{N}$$

96. How much work would it take to move an additional 0.010 μC between the plates at 120 V in Problem 93?

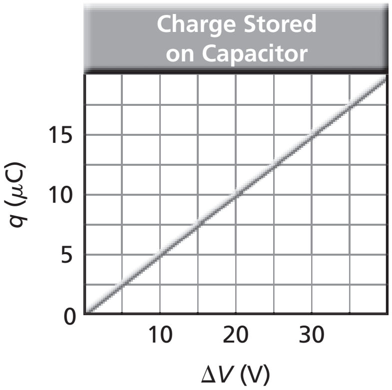
$$\Delta V = \frac{W}{q}$$

$$W = q\Delta V$$

$$= (1.0\times10^{-8}\ \text{C})(120\ \text{V}) = 1.2\times10^{-6}\ \text{J}$$

Level 2

97. The graph in **Figure 21-27** represents the charge stored in a capacitor as the charging potential increases. What does the slope of the line represent?



■ **Figure 21-27**

capacitance of the capacitor

98. What is the capacitance of the capacitor represented by Figure 21-27?

C = slope = 0.50 μF

99. What does the area under the graph line in Figure 21-27 represent?

work done to charge the capacitor

100. How much work is required to charge the capacitor in problem 98 to a potential difference of 25 V?

$$W = \text{area} = \frac{1}{2}bh$$

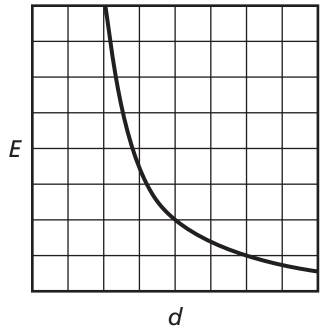
$$= \left(\frac{1}{2}\right)(25\ \text{V})(12.5\ \mu\text{C})$$

$$= 160\ \mu\text{J}$$

101. The work found in Problem 100 above is not equal to $q\Delta V$. Why not?

The potential difference is not constant as the capacitor is charged. Therefore, the area under the graph must be used to find work, not just simple multiplication.

102. Graph the electric field strength near a positive point charge as a function of distance from it.



103. Where is the field of a point charge equal to zero?

Nowhere, or at an infinite distance from the point charge.

104. What is the electric field strength at a distance of zero meters from a point charge? Is there such a thing as a true point charge?

Infinite. No.

Thinking Critically

pages 587–588

105. Apply Concepts Although a lightning rod is designed to carry charge safely to the ground, its primary purpose is to prevent lightning from striking in the first place. How does it do that?

The sharp point on the end of the rod leaks charge into the atmosphere before it has the chance to build up enough potential difference to cause a lightning strike.

106. Analyze and Conclude In an early set of experiments in 1911, Millikan observed that the following measured charges could appear on a single oil drop. What value of elementary charge can be deduced from these data?

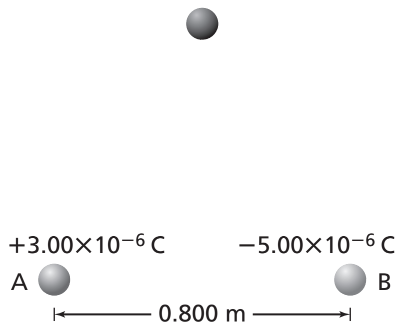
a. 6.563×10^{-19} C
b. 8.204×10^{-19} C
c. 11.50×10^{-19} C
d. 13.13×10^{-19} C
e. 16.48×10^{-19} C
f. 18.08×10^{-19} C
g. 19.71×10^{-19} C
h. 22.89×10^{-19} C
i. 26.13×10^{-19} C

1.63×10^{19} C. Subtracting adjacent values, $b - a$, $c - b$, $d - c$, etc. yields 1.641×10^{-19} C, 3.30×10^{-19} C, 1.63×10^{-19} C, 3.35×10^{-19} C, 1.60×10^{-19} C, 1.63×10^{-19} C, 3.18×10^{-19} C, 3.24×10^{-19} C.

There are two numbers, approximately 1.631×10^{-19} C and 3.2×10^{-19} C, that are common. Averaging each similar group produces one charge of 1.63×10^{-19} C and one charge of 3.27×10^{-19} C (which is two times 1.641×10^{-19} C).

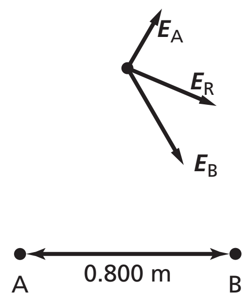
Dividing 1.63×10^{-19} C into each piece of data yields nearly whole-number quotients, indicating it is the value of an elementary charge.

107. Analyze and Conclude Two small spheres, A and B, lie on the x-axis, as in **Figure 21-28.** Sphere A has a charge of $+3.00\times10^{-6}$ C. Sphere B is 0.800 m to the right of sphere A and has a charge of -5.00×10^{-6} C. Find the magnitude and direction of the electric field strength at a point above the x-axis that would form the apex of an equilateral triangle with spheres A and B.



■ **Figure 21-28**

Draw the spheres and vectors representing the fields due to each charge at the given point.



Now do the math:

$$E_A = \frac{F_A}{q'} = \frac{Kq_A}{d^2} = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(3.00\times10^{-6}\ \text{C})}{(0.800\ \text{m})^2} = 4.22\times10^4\ \text{N/C}$$

$$E_B = \frac{F_B}{q'} = \frac{Kq_B}{d^2} = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(5.00\times10^{-6}\ \text{C})}{(0.800\ \text{m})^2} = 7.03\times10^4\ \text{N/C}$$

$$E_{Ax} = E_A \cos 60.0° = (4.22\times10^4\ \text{N/C})(\cos 60.0°) = 2.11\times10^4\ \text{N/C}$$

$$E_{Ay} = E_A \sin 60.0° = (4.22\times10^4\ \text{N/C})(\sin 60.0°) = 3.65\times10^4\ \text{N/C}$$

$E_{Bx} = E_B \cos(-60.0°) = (7.03\times10^4\ \text{N/C})(\cos -60.0°) = 3.52\times10^4\ \text{N/C}$

$E_{By} = E_B \sin(-60.0°) = (7.03\times10^4\ \text{N/C})(\sin -60.0°) = -6.09\times10^4\ \text{N/C}$

$E_x = E_{Ax} + E_{Bx} = (2.11\times10^4\ \text{N/C}) + (3.52\times10^4\ \text{N/C}) = 5.63\times10^4\ \text{N/C}$

$E_y = E_{Ay} + E_{By} = (3.65\times10^4\ \text{N/C}) + (-6.09\times10^4\ \text{N/C}) = -2.44\times10^4\ \text{N/C}$

$E_R = \sqrt{E_x{}^2 + E_y{}^2} = 6.14\times10^4\ \text{N/C}$

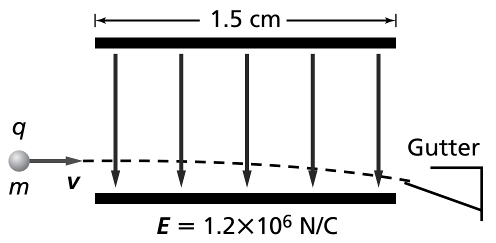
$\tan\theta = \frac{E_y}{E_x}$

$\theta = \tan^{-1}\left(\frac{E_y}{E_x}\right)$

$= \tan^{-1}\left(\frac{-2.44\times10^4\ \text{N/C}}{5.63\times10^4\ \text{N/C}}\right)$

$= -23.4°$

108. Analyze and Conclude In an ink-jet printer, drops of ink are given a certain amount of charge before they move between two large, parallel plates. The purpose of the plates is to deflect the charges so that they are stopped by a gutter and do not reach the paper. This is shown in **Figure 21-29.** The plates are 1.5-cm long and have an electric field of $E = 1.2\times10^6$ N/C between them. Drops with a mass $m = 0.10$ ng, and a charge $q = 1.0\times10^{-16}$ C, are moving horizontally at a speed, $v = 15$ m/s, parallel to the plates. What is the vertical displacement of the drops when they leave the plates? To answer this question, complete the following steps.



■ **Figure 21-29**

a. What is the vertical force on the drops?

$F = Eq$

$= (1.0\times10^{-16}\ \text{C})(1.2\times10^6\ \text{N/C})$

$= 1.2\times10^{-10}\ \text{N}$

b. What is their vertical acceleration?

$a = \frac{F}{m} = \frac{1.2\times10^{-10}\ \text{N}}{1.0\times10^{-13}\ \text{kg}} = 1.2\times10^3\ \text{m/s}^2$

c. How long are they between the plates?

$t = \frac{L}{v} = \frac{1.5\times10^{-2}\ \text{m}}{15\ \text{m/s}} = 1.0\times10^{-3}\ \text{s}$

d. How far are they displaced?

$y = \frac{1}{2}at^2$

$= \left(\frac{1}{2}\right)(1.2\times10^3\ \text{m/s}^2)(1.0\times10^{-3}\ \text{s})^2$

$= 6.0\times10^{-4}\ \text{m} = 0.60\ \text{mm}$

109. Apply Concepts Suppose the Moon had a net negative charge equal to $-q$, and Earth had a net positive charge equal to $+10q$. What value of q would yield the same magnitude of force that you now attribute to gravity?

Equate the expressions for gravitational force and Coulombic force between Earth and the Moon:

$$F = \frac{Gm_Em_M}{d^2} = \frac{Kq_Eq_M}{d^2} = \frac{10Kq^2}{d^2}$$

where $-q$ is the net negative charge of the Moon and q_E, the net positive charge of Earth, is $+10q$.
Solve symbolically before substituting numbers.

$$q = \sqrt{\frac{Gm_Em_M}{10K}}$$

$$= \sqrt{\frac{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(6.00\times10^{24}\ \text{kg})(7.31\times10^{22}\ \text{kg})}{(10)(9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)}}$$

$$= 1.8\times10^{13}\text{C}$$

Writing in Physics

page 588

110. Choose the name of an electric unit, such as coulomb, volt, or farad, and research the life and work of the scientist for whom it was named. Write a brief essay on this person and include a discussion of the work that justified the honor of having a unit named for him.

Student answers will vary. Some examples of scientists they could choose are Volta, Coulomb, Ohm, and Ampère.

Cumulative Review

page 588

111. Michelson measured the speed of light by sending a beam of light to a mirror on a mountain 35 km away. (Chapter 16)

a. How long does it take light to travel the distance to the mountain and back?

(35 km/trip)(2 trips)(1000 m/1 km)/ 3.00×10^8 m/s = 2.3×10^{-4} s

b. Assume that Michelson used a rotating octagon with a mirror on each face of the octagon. Also assume that the light reflects from one mirror, travels to the other mountain, reflects off of a fixed mirror on that mountain, and returns to the rotating mirrors. If the rotating mirror has advanced so that when the light returns, it reflects off of the next mirror in the rotation, how fast is the mirror rotating?

$$\left(\frac{2.3\times10^{-4}\ \text{s}}{1\ \text{mirror}}\right)(8\ \text{mirrors/rev}) = 1.8\times10^{-3}\ \text{s/rev} = T$$

$$f = \frac{1}{T} = \frac{1}{1.8\times10^{-3}\ \text{s/rev}} = 5.6\times10^{2}\ \text{rev/s}$$

Note that if students carry extra digits from part a to prevent rounding errors, they will get an answer of 5.4×10^2 rev/s.

c. If each mirror has a mass of 1.0×10^1 g and rotates in a circle with an average radius of 1.0×10^1 cm, what is the approximate centripetal force needed to hold the mirror while is it rotating?

$$F_c = 4\pi^2 m f^2 r$$

$$= 4\pi^2(0.010\text{ kg})(5.6\times10^2\text{ rev/s})^2(0.10\text{ m})$$

$$= 1.2\times10^4\text{ N}$$

Note that the answer should be 1.2×10^4 N regardless of whether the students use 5.4×10^2 rev/s or 5.6×10^4 rev/s for f.

112. Mountain Scene You can see an image of a distant mountain in a smooth lake just as you can see a mountain biker next to the lake because light from each strikes the surface of the lake at about the same angle of incidence and is reflected to your eyes. If the lake is about 100 m in diameter, the reflection of the top of the mountain is about in the middle of the lake, the mountain is about 50 km away from the lake, and you are about 2 m tall, then approximately how high above the lake does the top of the mountain reach? (Chapter 17)

Since the angle of incidence of the light from the top of the mountain is equal to its angle of reflection from the lake, you and the reflection of the top of the mountain form a triangle that is similar to a triangle formed by the mountain and the top of its reflection in the lake. Your height makes up one side, h_{you} = 2 m and the top of the mountain is halfway across the lake, d_{you} = 50 m. The mountain is a distance $d_{mountain}$ = 50,000 m from its reflection. Find $h_{mountain}$ by equating the ratios of the sides of the two similar triangles.

$$\frac{h_{you}}{d_{you}} = \frac{h_{mountain}}{d_{mountain}}$$

$$h_{mountain} = \frac{h_{you}d_{mountain}}{d_{you}}$$

$$= \frac{(2\text{ m})(50{,}000\text{ m})}{50\text{ m}}$$

$$= 2000\text{ m}$$

113. A converging lens has a focal length of 38.0 cm. If it is placed 60.0 cm from an object, at what distance from the lens will the image be? (Chapter 18)

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(60.0\text{ cm})(38.0\text{ cm})}{60.0\text{ cm} - 38.0\text{ cm}}$$

$$= 104\text{ cm}$$

The image is 104 cm from the lens.

114. A force, F, is measured between two charges, Q and q, separated by a distance, r. What would the new force be for each of the following? (Chapter 20)

a. r is tripled

***F*/9**

b. Q is tripled

3*F*

c. both r and Q are tripled

***F*/3**

d. both r and Q are doubled

***F*/2**

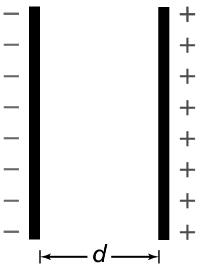
e. all three, r, Q, and q, are tripled

F

Challenge Problem

page 579

The plates of a capacitor attract each other because they carry opposite charges. A capacitor consisting of two parallel plates that are separated by a distance, *d,* has capacitance, *C.*



1. Derive an expression for the force between the two plates when the capacitor has charge, *q*.

Combine the following equations:

$$F = Eq,\ E = \frac{\Delta V}{d},\ \text{and}\ \Delta V = \frac{q}{C}$$

$$F = Eq = \left(\frac{\Delta V}{d}\right)q = \left(\frac{\left(\frac{q}{C}\right)}{d}\right)q = \frac{q^2}{Cd}$$

2. What charge must be stored on a 22-μF capacitor to have a force of 2.0 N between the plates if they are separated by 1.5 mm?

$$F = \frac{q^2}{Cd}$$

$$\text{so } q = \sqrt{FCd}$$

$$= \sqrt{(2.0\ \text{N})(2.2\times10^{-5}\ \text{F})(1.5\times10^{-3}\ \text{m})}$$

$$= 2.6\times10^{-4}\ \text{C}$$

CHAPTER

22 Current Electricity

Practice Problems

22.1 Current and Circuits pages 591–600

page 594

1. The current through a lightbulb connected across the terminals of a 125-V outlet is 0.50 A. At what rate does the bulb convert electric energy to light? (Assume 100 percent efficiency.)

   $P = IV = (0.50\ \text{A})(125\ \text{V}) = 63\ \text{J/s} = 63\ \text{W}$

2. A car battery causes a current of 2.0 A through a lamp and produces 12 V across it. What is the power used by the lamp?

   $P = IV = (2.0\ \text{A})(12\ \text{V}) = 24\ \text{W}$

3. What is the current through a 75-W lightbulb that is connected to a 125-V outlet?

   $P = IV$

   $I = \frac{P}{V} = \frac{75\ \text{W}}{125\ \text{V}} = 0.60\ \text{A}$

4. The current through the starter motor of a car is 210 A. If the battery maintains 12 V across the motor, how much electric energy is delivered to the starter in 10.0 s?

   $P = IV$ and $E = Pt$

   Thus, $E = IVt = (210\ \text{A})(12\ \text{V})(10.0\ \text{s})$

   $= 2.5\times10^4\ \text{J}$

5. A flashlight bulb is rated at 0.90 W. If the lightbulb drops 3.0 V, how much current goes through it?

   $P = IV$

   $I = \frac{P}{V} = \frac{0.90\ \text{W}}{3.0\ \text{V}} = 0.30\ \text{A}$

page 598

For all problems, assume that the battery voltage and lamp resistances are constant, no matter what current is present.

6. An automobile panel lamp with a resistance of 33 Ω is placed across a 12-V battery. What is the current through the circuit?

   $I = \frac{V}{R} = \frac{12\ \text{V}}{33\ \Omega} = 0.36\ \text{A}$

7. A motor with an operating resistance of 32 Ω is connected to a voltage source. The current in the circuit is 3.8 A. What is the voltage of the source?

   $V = IR = (3.8\ \text{A})(32\ \Omega) = 1.2\times10^2\ \text{V}$

8. A sensor uses 2.0×10^{-4} A of current when it is operated by a 3.0-V battery. What is the resistance of the sensor circuit?

   $R = \frac{V}{I} = \frac{3.0\ \text{V}}{2.0\times10^{-4}\ \text{A}} = 1.5\times10^4\ \Omega$

9. A lamp draws a current of 0.50 A when it is connected to a 120-V source.

   a. What is the resistance of the lamp?

   $R = \frac{V}{I} = \frac{120\ \text{V}}{0.50\ \text{A}} = 2.4\times10^2\ \Omega$

   b. What is the power consumption of the lamp?

   $P = IV = (0.50\ \text{A})(120\ \text{V}) = 6.0\times10^1\ \text{W}$

10. A 75-W lamp is connected to 125 V.

   a. What is the current through the lamp?

   $I = \frac{P}{V} = \frac{75\ \text{W}}{125\ \text{V}} = 0.60\ \text{A}$

   b. What is the resistance of the lamp?

   $R = \frac{V}{I} = \frac{125\ \text{V}}{0.60\ \text{A}} = 2.1\times10^2\ \Omega$

11. A resistor is added to the lamp in the previous problem to reduce the current to half of its original value.

a. What is the potential difference across the lamp?

The new value of the current is

$$\frac{0.60\ \text{A}}{2} = 0.30\ \text{A}$$

$$V = IR = (0.30\ \text{A})(2.1\times10^{2}\ \Omega)$$
$$= 6.3\times10^{1}\ \text{V}$$

b. How much resistance was added to the circuit?

The total resistance of the circuit is now

$$R_{\text{total}} = \frac{V}{I} = \frac{125\ \text{V}}{0.30\ \text{A}} = 4.2\times10^{2}\ \Omega$$

Therefore,

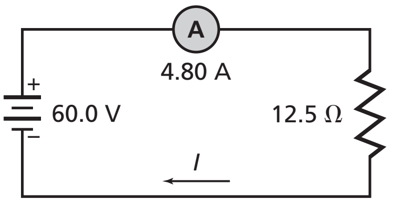
$$R_{\text{res}} = R_{\text{total}} - R_{\text{lamp}}$$
$$= 4.2\times10^{2}\ \Omega - 2.1\times10^{2}\ \Omega$$
$$= 2.1\times10^{2}\ \Omega$$

c. How much power is now dissipated in the lamp?

$$P = IV = (0.30\ \text{A})(6.3\times10^{1}\ \text{V}) = 19\ \text{W}$$

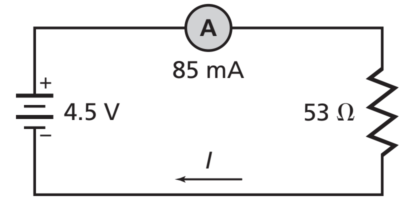
page 600

12. Draw a circuit diagram to include a 60.0-V battery, an ammeter, and a resistance of 12.5 Ω in series. Indicate the ammeter reading and the direction of the current.



$$I = \frac{V}{R} = \frac{60.0\ \text{V}}{12.5\ \Omega} = 4.80\ \text{A}$$

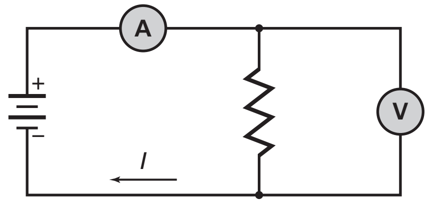
13. Draw a series-circuit diagram showing a 4.5-V battery, a resistor, and an ammeter that reads 85 mA. Determine the resistance and label the resistor. Choose a direction for the conventional current and indicate the positive terminal of the battery.



$$R = \frac{V}{I} = \frac{4.5\ \text{V}}{0.085\ \text{A}} = 53\ \Omega$$

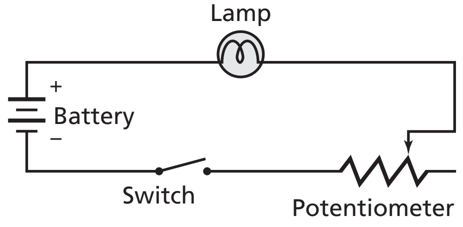
14. Add a voltmeter to measure the potential difference across the resistors in problems 12 and 13 and repeat the problems.

Both circuits will take the following form.

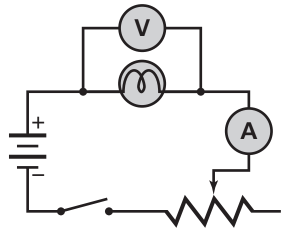


Because the ammeter resistance is assumed zero, the voltmeter readings will be 60.0 V for Practice Problem 12 and 4.5 V for Practice Problem 13.

15. Draw a circuit using a battery, a lamp, a potentiometer to adjust the lamp's brightness, and an on-off switch.



16. Repeat the previous problem, adding an ammeter and a voltmeter across the lamp.

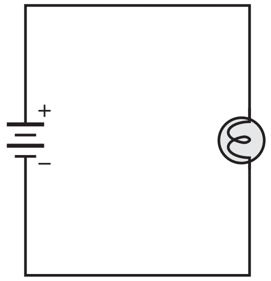


Section Review

22.1 Current and Circuits pages 591–600

page 600

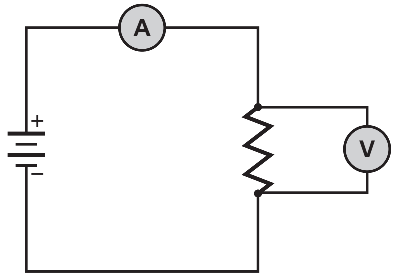
17. Schematic Draw a schematic diagram of a circuit that contains a battery and a lightbulb. Make sure the lightbulb will light in this circuit.



18. Resistance Joe states that because $R = V/I$, if he increases the voltage, the resistance will increase. Is Joe correct? Explain.

No, resistance depends on the device. When V increases, so will I.

19. Resistance You want to measure the resistance of a long piece of wire. Show how you would construct a circuit with a battery, a voltmeter, an ammeter, and the wire to be tested to make the measurement. Specify what you would measure and how you would compute the resistance.



Measure the current through the wire and the potential difference across it. Divide the potential difference by the current to obtain the wire resistance.

20. Power A circuit has 12 Ω of resistance and is connected to a 12-V battery. Determine the change in power if the resistance decreases to 9.0 Ω.

$P_1 = V^2/R_1 = (12\text{ V})^2/12\ \Omega = 12\text{ W}$

$P_2 = V^2/R_2 = (12\text{ V})^2/9.0\ \Omega = 16\text{ W}$

$\Delta P = P_2 - P_1 = 16\text{ W} - 12\text{ W} = 4.0\text{ W}$

4.0 W increase

21. Energy A circuit converts 2.2×10^3 J of energy when it is operated for 3.0 min. Determine the amount of energy it will convert when it is operated for 1 h.

$$E = \left(\frac{2.2\times10^3\text{ J}}{3.0\text{ min}}\right)(60.0\text{ min})$$

$$= 4.4\times10^4\text{ J}$$

22. Critical Thinking We say that power is "dissipated" in a resistor. To dissipate is to use, to waste, or to squander. What is "used" when charge flows through a resistor?

The potential energy of the charges decreases as they flow through the resistor. This decrease in potential energy is used to produce heat in the resistor.

Practice Problems

22.2 Using Electric Energy pages 601–605

page 603

23. A 15-Ω electric heater operates on a 120-V outlet.

a. What is the current through the heater?

$$I = \frac{V}{R} = \frac{120\text{ V}}{15\ \Omega} = 8.0\text{ A}$$

b. How much energy is used by the heater in 30.0 s?

$$E = I^2Rt = (8.0\text{ A})^2(15\ \Omega)(30.0\text{ s})$$

$$= 2.9\times10^4\text{ J}$$

c. How much thermal energy is liberated in this time?

2.9×10^4 J, because all electric energy is converted to thermal energy.

24. A 39-Ω resistor is connected across a 45-V battery.

a. What is the current in the circuit?

$$I = \frac{V}{R} = \frac{45\text{ V}}{39\ \Omega} = 1.2\text{ A}$$

b. How much energy is used by the resistor in 5.0 min?

$$E = \frac{V^2}{R}t$$

$$= \frac{(45\ \text{V})^2}{(39\ \Omega)}(5.0\ \text{min})(60\ \text{s/min})$$

$$= 1.6\times10^4\ \text{J}$$

25. A 100.0-W lightbulb is 22 percent efficient. This means that 22 percent of the electric energy is converted to light energy.

a. How many joules does the lightbulb convert into light each minute it is in operation?

$$E = Pt$$

$$= (0.22)(100.0\ \text{J/s})(1.0\ \text{min})(60\ \text{s/min})$$

$$= 1.3\times10^3\ \text{J}$$

b. How many joules of thermal energy does the lightbulb produce each minute?

$$E = Pt$$

$$= (0.78)(100.0\ \text{J/s})(1.0\ \text{min})(60.0\ \text{s/min})$$

$$= 4.7\times10^3\ \text{J}$$

26. The resistance of an electric stove element at operating temperature is 11 Ω.

a. If 220 V are applied across it, what is the current through the stove element?

$$I = \frac{V}{R} = \frac{220\ \text{V}}{11\ \Omega} = 2.0\times10^1\ \text{A}$$

b. How much energy does the element convert to thermal energy in 30.0 s?

$$E = I^2Rt = (2.0\times10^1\ \text{A})^2(11\ \Omega)(30.0\ \text{s})$$

$$= 1.3\times10^5\ \text{J}$$

c. The element is used to heat a kettle containing 1.20 kg of water. Assume that 65 percent of the heat is absorbed by the water. What is the water's increase in temperature during the 30.0 s?

$Q = mC\Delta T$ **with** $Q = 0.65E$

$$\Delta T = \frac{0.65E}{mC} = \frac{(0.65)(1.3\times10^5\ \text{J})}{(1.20\ \text{kg})(4180\ \text{J/kg}\cdot°\text{C})}$$

$$= 17°\text{C}$$

27. A 120-V water heater takes 2.2 h to heat a given volume of water to a certain temperature. How long would a 240-V unit operating with the same current take to accomplish the same task?

$$E = IVt = I(2V)\left(\frac{t}{2}\right)$$

For a given amount of energy, doubling the voltage will divide the time by 2.

$$t = \frac{2.2\ \text{h}}{2} = 1.1\ \text{h}$$

page 605

28. An electric space heater draws 15.0 A from a 120-V source. It is operated, on the average, for 5.0 h each day.

a. How much power does the heater use?

$$P = IV = (15.0\ \text{A})(120\ \text{V})$$

$$= 1800\ \text{W} = 1.8\ \text{kW}$$

b. How much energy in kWh does it consume in 30 days?

$$E = Pt = (1.8\ \text{kW})(5.0\ \text{h/day})(30\ \text{days})$$

$$= 270\ \text{kWh}$$

c. At $0.12 per kWh, how much does it cost to operate the heater for 30 days?

Cost = ($0.12/kWh)(270 kWh)

= $32.40

29. A digital clock has a resistance of 12,000 Ω and is plugged into a 115-V outlet.

a. How much current does it draw?

$$I = \frac{V}{R} = \frac{115\ \text{V}}{12{,}000\ \Omega} = 9.6\times10^{-3}\ \text{A}$$

b. How much power does it use?

$$P = VI = (115\ \text{V})(9.6\times10^{-3}\ \text{A}) = 1.1\ \text{W}$$

c. If the owner of the clock pays $0.12 per kWh, how much does it cost to operate the clock for 30 days?

Cost = $(1.1\times10^{-3}\ \text{kWh})(\$0.12/\text{kWh})(30\ \text{days})(24\ \text{h/day})$

= $0.10

30. An automotive battery can deliver 55 A at 12 V for 1.0 h and requires 1.3 times as much energy for recharge due to its less-than-perfect efficiency. How long will it take to charge the battery using a current of 7.5 A? Assume that the charging voltage is the same as the discharging voltage.

$$E_{charge} = (1.3)IVt$$
$$= (1.3)(55\ A)(12\ V)(1.0\ h)$$
$$= 858\ Wh$$
$$t = \frac{E}{IV} = \frac{858\ Wh}{(7.5\ A)(12\ V)} = 9.5\ h$$

31. Rework the previous problem by assuming that the battery requires the application of 14 V when it is recharging.

$$E_{charge} = (1.3)IVt$$
$$= (1.3)(55\ A)(12\ V)(1.0\ h)$$
$$= 858\ Wh$$
$$t = \frac{E}{IV} = \frac{858\ Wh}{(7.5\ A)(14\ V)} = 8.2\ h$$

Section Review

22.2 Using Electric Energy pages 601–605

page 605

32. Energy A car engine drives a generator, which produces and stores electric charge in the car's battery. The headlamps use the electric charge stored in the car battery. List the forms of energy in these three operations.

Mechanical energy from the engine converted to electric energy in the generator; electric energy stored as chemical energy in the battery; chemical energy converted to electric energy in the battery and distributed to the headlamps; electric energy converted to light and thermal energy in headlamps.

33. Resistance A hair dryer operating from 120 V has two settings, hot and warm. In which setting is the resistance likely to be smaller? Why?

Hot draws more power, $P = IV$, so the fixed voltage current is larger. Because $I = V/R$ the resistance is smaller.

34. Power Determine the power change in a circuit if the applied voltage is decreased by one-half.

$$\frac{P_1}{P_2} = \frac{V_2^2/R}{V_1^2/R} = \frac{(0.5V_1)^2/R}{V_1^2} = 0.25$$

35. Efficiency Evaluate the impact of research to improve power transmission lines on society and the environment.

Research to improve power transmission lines would benefit society in cost of electricity. Also, if less power was lost during transmission, less coal and other power-producing resources would have to be used, which would improve the quality of our environment.

36. Voltage Why would an electric range and an electric hot-water heater be connected to a 240-V circuit rather than a 120-V circuit?

For the same power, at twice the voltage, the current would be halved. The I^2R loss in the circuit wiring would be dramatically reduced because it is proportional to the square of the current.

37. Critical Thinking When demand for electric power is high, power companies sometimes reduce the voltage, thereby producing a "brown-out." What is being saved?

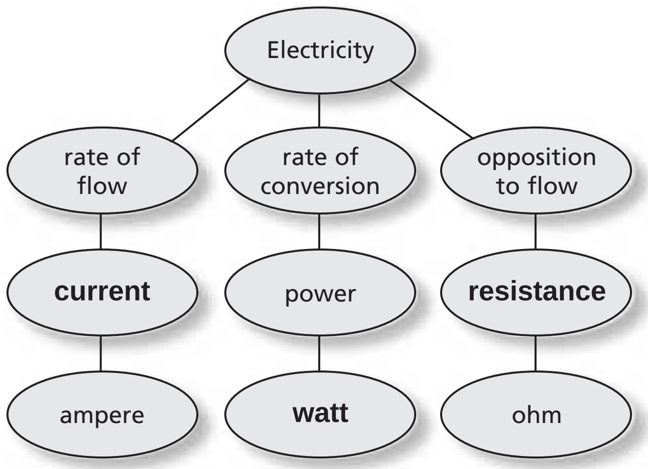
Power, not energy; most devices will have to run longer.

Chapter Assessment

Concept Mapping

page 610

38. Complete the concept map using the following terms: *watt, current, resistance.*



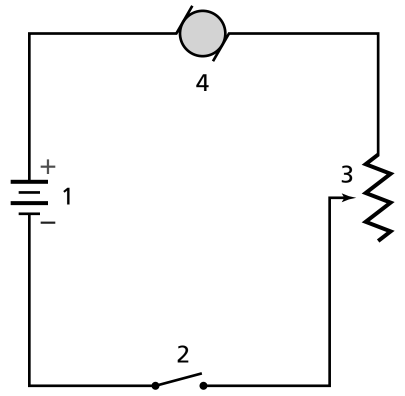
Mastering Concepts

page 610

39. Define the unit of electric current in terms of fundamental MKS units. (22.1)

1 A = 1 C/1 s

40. How should a voltmeter be connected in **Figure 22-12** to measure the motor's voltage? (22.1)



■ **Figure 22-12**

The positive voltmeter lead connects to the left-hand motor lead, and the negative voltmeter lead connects to the right-hand motor lead.

41. How should an ammeter be connected in Figure 22-12 to measure the motor's current? (22.1)

Break the circuit between the battery and the motor. Then connect the positive ammeter lead to the positive side of the break (the side connected to the positive battery terminal) and the negative ammeter lead to the negative side nearest the motor.

42. What is the direction of the conventional motor current in Figure 22-12? (22.1)

from left to right through the motor

43. Refer to Figure 22-12 to answer the following questions. (22.1)

a. Which device converts electric energy to mechanical energy?

4

b. Which device converts chemical energy to electric energy?

1

c. Which device turns the circuit on and off?

2

d. Which device provides a way to adjust speed?

3

44. Describe the energy conversions that occur in each of the following devices. (22.1)

a. an incandescent lightbulb

electric energy to heat and light

b. a clothes dryer

electric energy to heat and kinetic energy

c. a digital clock radio

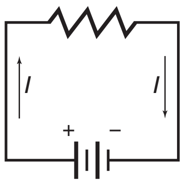
electric energy to light and sound

45. Which wire conducts electricity with the least resistance: one with a large cross-sectional diameter or one with a small cross-sectional diameter? (22.1)

A larger-diameter wire has a smaller resistance because there are more electrons to carry the charge.

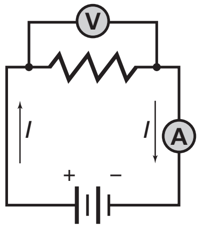
46. A simple circuit consists of a resistor, a battery, and connecting wires. (22.1)

a. Draw a circuit schematic of this simple circuit.



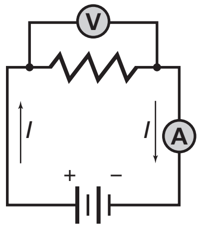
b. How must an ammeter be connected in a circuit for the current to be correctly read?

The ammeter must be connected in series.



c. How must a voltmeter be connected to a resistor for the potential difference across it to be read?

The voltmeter must be connected in parallel.



47. Why do lightbulbs burn out more frequently just as they are switched on rather than while they are operating? (22.2)

The low resistance of the cold filament allows a high current initially and a greater change in temperature, subjecting the filament to greater stress.

48. If a battery is short-circuited by a heavy copper wire being connected from one terminal to the other, the temperature of the copper wire rises. Why does this happen? (22.2)

The short circuit produces a high current, which causes more electrons to collide with the atoms of the wire. This raises the atoms' kinetic energies and the temperature of the wire.

49. What electric quantities must be kept small to transmit electric energy economically over long distances? (22.2)

the resistance of the wire and the current in the wire

50. Define the unit of power in terms of fundamental MKS units. (22.2)

$$\mathbf{W} = \frac{\mathbf{C}}{\mathbf{s}}\cdot\frac{\mathbf{J}}{\mathbf{C}} = \frac{\mathbf{J}}{\mathbf{s}} = \frac{\mathbf{kg}\cdot\frac{\mathbf{m}^2}{\mathbf{s}^2}}{\mathbf{s}} = \frac{\mathbf{kg}\cdot\mathbf{m}^2}{\mathbf{s}^3}$$

Applying Concepts

pages 610–611

51. Batteries When a battery is connected to a complete circuit, charges flow in the circuit almost instantaneously. Explain.

A potential difference is felt over the entire circuit as soon as the battery is connected to the circuit. The potential difference causes the charges to begin to flow. Note: The charges flow slowly compared to the change in potential difference.

52. Explain why a cow experiences a mild shock when it touches an electric fence.

By touching the fence and the ground, the cow encounters a difference in potential and conducts current, thus receiving a shock.

53. Power Lines Why can birds perch on high-voltage lines without being injured?

No potential difference exists along the wires, so there is no current through the birds' bodies.

54. Describe two ways to increase the current in a circuit.

Either increase the voltage or decrease the resistance.

55. Lightbulbs Two lightbulbs work on a 120-V circuit. One is 50 W and the other is 100 W. Which bulb has a higher resistance? Explain.

50-W bulb

$P = \frac{V^2}{R}$, **so** $R = \frac{V^2}{P}$

Therefore, the lower *P* is caused by a higher *R*.

56. If the voltage across a circuit is kept constant and the resistance is doubled, what effect does this have on the circuit's current?

If the resistance is doubled, the current is halved.

57. What is the effect on the current in a circuit if both the voltage and the resistance are doubled? Explain.

No effect. $V = IR$, so $I = V/R$, and if the voltage and the resistance both are doubled, the current will not change.

58. Ohm's Law Sue finds a device that looks like a resistor. When she connects it to a 1.5-V battery, she measures only 45×10^{-6} A, but when she uses a 3.0-V battery, she measures 25×10^{-3} A. Does the device obey Ohm's law?

No. $V = IR$, so $R = V/I$. At 1.5 V,

$$R = \frac{1.5\text{ V}}{45\times10^{-6}} = 3.3\times10^{4}\ \Omega$$

$$\text{At 3.0 V, } R = \frac{3.0\text{ V}}{25\times10^{-3}\text{ A}} = 120\ \Omega$$

A device that obeys Ohm's law has a resistance that is independent of the applied voltage.

59. If the ammeter in Figure 22-4a on page 596 were moved to the bottom of the diagram, would the ammeter have the same reading? Explain.

Yes, because the current is the same everywhere in this circuit.

60. Two wires can be placed across the terminals of a 6.0-V battery. One has a high resistance, and the other has a low resistance. Which wire will produce thermal energy at a faster rate? Why?

the wire with the smaller resistance

$$P = \frac{V^2}{R}$$

Smaller R produces larger power P dissipated in the wire, which produces thermal energy at a faster rate.

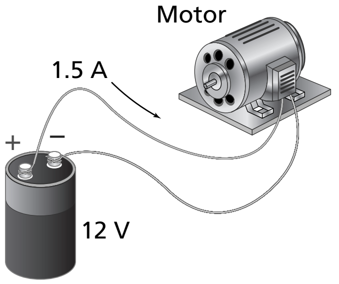
Mastering Problems

22.1 Current and Circuits

pages 611–612

Level 1

61. A motor is connected to a 12-V battery, as shown in **Figure 22-13.**



■ **Figure 22-13**

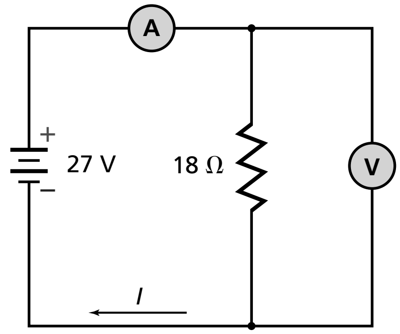
a. How much power is delivered to the motor?

$P = VI = (12\text{ V})(1.5\text{ A}) = 18\text{ W}$

b. How much energy is converted if the motor runs for 15 min?

$$E = Pt = (18\text{ W})(15\text{ min})(60\text{ s/min})$$
$$= 1.6\times10^{4}\text{ J}$$

62. Refer to **Figure 22-14** to answer the following questions.



■ **Figure 22-14**

a. What should the ammeter reading be?

$$I = V/R = \frac{27\text{ V}}{18\ \Omega} = 1.5\text{ A}$$

b. What should the voltmeter reading be?

27 V

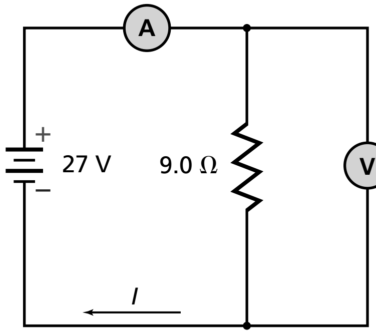
c. How much power is delivered to the resistor?

$P = VI = (27\text{ V})(1.5\text{ A}) = 41\text{ W}$

d. How much energy is delivered to the resistor per hour?

$E = Pt = (41\text{ W})(3600\text{ s}) = 1.5\times10^{5}\text{ J}$

63. Refer to **Figure 22-15** to answer the following questions.



■ **Figure 22-15**

a. What should the ammeter reading be?

$$I = V/R = \frac{27\ V}{9.0\ \Omega} = 3.0\ A$$

b. What should the voltmeter reading be?

27 V

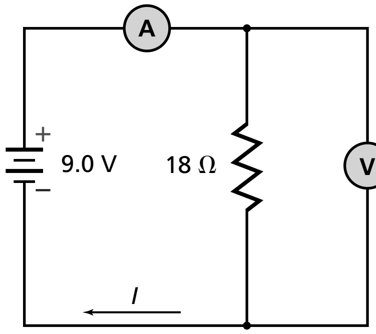
c. How much power is delivered to the resistor?

$$P = VI = (27\ V)(3.0\ A) = 81\ W$$

d. How much energy is delivered to the resistor per hour?

$$E = Pt = (81\ W)(3600\ s) = 2.9\times10^5\ J$$

64. Refer to **Figure 22-16** to answer the following questions.



■ **Figure 22-16**

a. What should the ammeter reading be?

$$I = V/R = \frac{9.0\ V}{18\ \Omega} = 0.50\ A$$

b. What should the voltmeter reading be?

9.0 V

c. How much power is delivered to the resistor?

$$P = VI = (9.0\ V)(0.50\ A) = 4.5\ W$$

d. How much energy is delivered to the resistor per hour?

$$E = Pt = (4.5\ W)(3600\ s) = 1.6\times10^4\ J$$

65. **Toasters** The current through a toaster that is connected to a 120-V source is 8.0 A. What power is dissipated by the toaster?

$$P = IV = (8.0\ A)(120\ V) = 9.6\times10^2\ W$$

66. **Lightbulbs** A current of 1.2 A is measured through a lightbulb when it is connected across a 120-V source. What power is dissipated by the bulb?

$$P = IV = (1.2\ A)(120\ V) = 1.4\times10^2\ W$$

67. A lamp draws 0.50 A from a 120-V generator.

a. How much power is delivered?

$$P = IV = (0.50\ A)(120\ V) = 6.0\times10^1\ W$$

b. How much energy is converted in 5.0 min?

The definition of power is $P = \frac{E}{t}$**, so**

$$E = Pt$$

$$= (6.0\times10^1\ W)\left(\frac{5.0\ min}{1}\right)\left(\frac{60\ s}{min}\right)$$

$$= 18{,}000\ J = 1.8\times10^4\ J$$

68. A 12-V automobile battery is connected to an electric starter motor. The current through the motor is 210 A.

a. How many joules of energy does the battery deliver to the motor each second?

$$P = IV = (210\ A)(12\ V) = 2500\ J/s$$
or $2.5\times10^3\ J/s$

b. What power, in watts, does the motor use?

$$P = 2.5\times10^3\ W$$

69. **Dryers** A 4200-W clothes dryer is connected to a 220-V circuit. How much current does the dryer draw?

$$P = IV$$

$$I = \frac{P}{V} = \frac{4200\ W}{220\ V} = 19\ A$$

70. Flashlights A flashlight bulb is connected across a 3.0-V potential difference. The current through the bulb is 1.5 A.

a. What is the power rating of the bulb?

$P = IV = (1.5\text{ A})(3.0\text{ V}) = 4.5\text{ W}$

b. How much electric energy does the bulb convert in 11 min?

The definition of power is $P = \frac{E}{t}$, **so**

$E = Pt$

$= (4.5\text{ W})(11\text{ min})\left(\frac{60\text{ s}}{\text{min}}\right)$

$= 3.0\times10^{3}\text{ J}$

71. Batteries A resistor of 60.0 Ω has a current of 0.40 A through it when it is connected to the terminals of a battery. What is the voltage of the battery?

$V = IR = (0.40\text{ A})(60.0\ \Omega) = 24\text{ V}$

72. What voltage is applied to a 4.0-Ω resistor if the current is 1.5 A?

$V = IR = (1.5\text{ A})(4.0\ \Omega) = 6.0\text{ V}$

73. What voltage is placed across a motor with a 15-Ω operating resistance if there is 8.0 A of current?

$V = IR = (8.0\text{ A})(15\ \Omega) = 1.2\times10^{2}\text{ V}$

74. A voltage of 75 V is placed across a 15-Ω resistor. What is the current through the resistor?

$V = IR$

$I = \frac{V}{R} = \frac{75\text{ V}}{15\ \Omega} = 5.0\text{ A}$

Level 2

75. Some students connected a length of nichrome wire to a variable power supply to produce between 0.00 V and 10.00 V across the wire. They then measured the current through the wire for several voltages. The students recorded the data for the voltages used and the currents measured, as shown in **Table 22-2.**

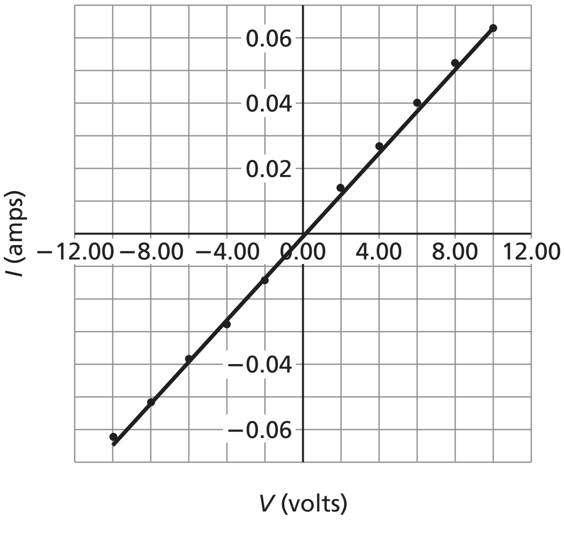
Table 22-2

Voltage, *V* (volts)	Current, *I* (amps)	Resistance, *R* = *V*/*I* (amps)
2.00	0.0140	______
4.00	0.0270	______
6.00	0.0400	______
8.00	0.0520	______
10.00	0.0630	______
−2.00	−0.0140	______
−4.00	−0.0280	______
−6.00	−0.0390	______
−8.00	−0.0510	______
−10.00	−0.0620	______

a. For each measurement, calculate the resistance.

R = 143 Ω, R = 148 Ω, R = 150 Ω, R = 154 Ω, R = 159 Ω, R = 143 Ω, R = 143 Ω, R = 154 Ω, R = 157 Ω, R = 161 Ω

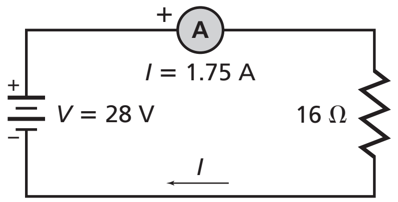
b. Graph *I* versus *V*.



c. Does the nichrome wire obey Ohm's law? If not, for all the voltages, specify the voltage range for which Ohm's law holds.

Ohm's law is obeyed when the resistance of a device is constant and independent of the potential difference. The resistance of the nichrome wire increases somewhat as the magnitude of the voltage increases, so the wire does not quite obey Ohm's law.

76. Draw a series circuit diagram to include a 16-Ω resistor, a battery, and an ammeter that reads 1.75 A. Indicate the positive terminal and the voltage of the battery, the positive terminal of the ammeter, and the direction of conventional current.



$$V = IR = (1.75 \text{ A})(16\ \Omega) = 28 \text{ V}$$

77. A lamp draws a 66-mA current when connected to a 6.0-V battery. When a 9.0-V battery is used, the lamp draws 75 mA.

a. Does the lamp obey Ohm's law?

No. The voltage is increased by a factor of $\frac{9.0}{6.0} = 1.5$, but the current is increased by a factor of $\frac{75}{66} = 1.1$

b. How much power does the lamp dissipate when it is connected to the 6.0-V battery?

$$P = IV = (66\times10^{-3} \text{ A})(6.0 \text{ V}) = 0.40 \text{ W}$$

c. How much power does it dissipate at 9.0 V?

$$P = IV = (75\times10^{-3} \text{ A})(9.0 \text{ V}) = 0.68 \text{ W}$$

78. Lightbulbs How much energy does a 60.0-W lightbulb use in half an hour? If the lightbulb converts 12 percent of electric energy to light energy, how much thermal energy does it generate during the half hour?

$$P = \frac{E}{t}$$

$$E = Pt = (60.0 \text{ W})(1800 \text{ s}) = 1.08\times10^5 \text{ J}$$

If the bulb is 12 percent efficient, 88 percent of the energy is lost to heat, so

$$Q = (0.88)(1.08\times10^5 \text{ J}) = 9.5\times10^4 \text{ J}$$

79. The current through a lamp connected across 120 V is 0.40 A when the lamp is on.

a. What is the lamp's resistance when it is on?

$$V = IR$$

$$R = \frac{V}{I} = \frac{120 \text{ V}}{0.40 \text{ A}} = 3.0\times10^2\ \Omega$$

b. When the lamp is cold, its resistance is $\frac{1}{5}$ as great as it is when the lamp is hot. What is the lamp's cold resistance?

$$\left(\frac{1}{5}\right)(3.0\times10^2\ \Omega) = 6.0\times10^1\ \Omega$$

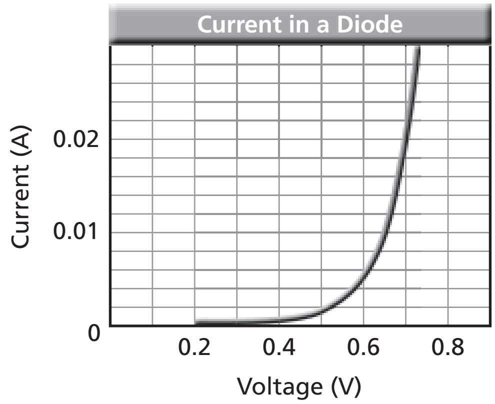
c. What is the current through the lamp as it is turned on if it is connected to a potential difference of 120 V?

$$V = IR$$

$$I = \frac{V}{R} = \frac{120 \text{ V}}{6.0\times10^1\ \Omega} = 2.0 \text{ A}$$

Level 3

80. The graph in **Figure 22-17** shows the current through a device called a silicon diode.



■ **Figure 22-17**

a. A potential difference of +0.70 V is placed across the diode. What is the resistance of the diode?

From the graph, I = 22 m/A, and $V = IR$, so

$$R = \frac{V}{I} = \frac{0.70 \text{ V}}{2.2\times10^{-2} \text{ A}} = 32\ \Omega$$

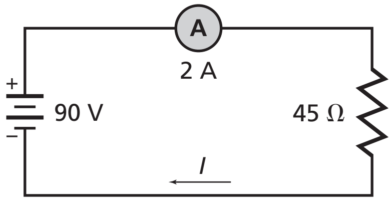
b. What is the diode's resistance when a +0.60-V potential difference is used?

$$R = \frac{V}{I} = \frac{0.60 \text{ V}}{5.2\times10^{-3} \text{ A}} = 1.2\times10^2\ \Omega$$

c. Does the diode obey Ohm's law?

No. Resistance depends on voltage.

81. Draw a schematic diagram to show a circuit including a 90-V battery, an ammeter, and a resistance of 45 Ω connected in series. What is the ammeter reading? Draw arrows showing the direction of conventional current.



$V = IR$

$I = \frac{V}{R} = \frac{90\text{ V}}{45\ \Omega} = 2\text{ A}$

22.2 Using Electric Energy

pages 612–613

Level 1

82. Batteries A 9.0-V battery costs \$3.00 and will deliver 0.0250 A for 26.0 h before it must be replaced. Calculate the cost per kWh.

$E = IVt = (0.0250\text{ A})(9.0\text{ V})(26.0\text{ h})$
$= 5.9\text{ Wh} = 5.9\times10^{-3}\text{ kWh}$

$\text{Rate} = \frac{\text{cost}}{E} = \frac{\$3.00}{5.9\times10^{-3}\text{ kWh}}$
$= \$510/\text{kWh}$

83. What is the maximum current allowed in a 5.0-W, 220-Ω resistor?

$P = I^2R$

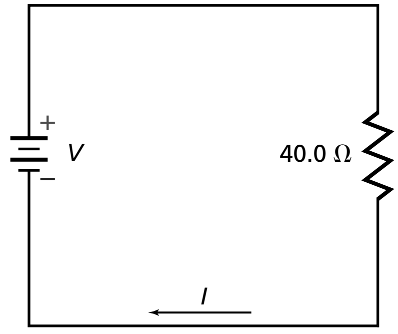
$I = \sqrt{\frac{P}{R}} = \sqrt{\frac{5.0\text{ W}}{220\ \Omega}} = 0.15\text{ A}$

84. A 110-V electric iron draws 3.0 A of current. How much thermal energy is developed in an hour?

$Q = E = VIt = (110\text{ V})(3.0\text{ A})(1.0\text{ h})(3600\text{ s/h})$
$= 1.2\times10^{6}\text{ J}$

Level 2

85. For the circuit shown in **Figure 22-18,** the maximum safe power is 5.0×10^{1} W. Use the figure to find the following:



■ **Figure 22-18**

a. the maximum safe current

$P = I^2R$

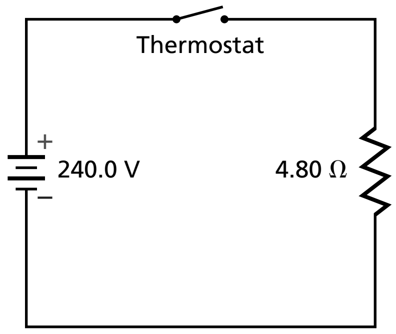
$I = \sqrt{\frac{P}{R}} = \sqrt{\frac{5.0\times10^{1}\text{ W}}{40.0\ \Omega}} = 1\text{ A}$

b. the maximum safe voltage

$P = V^2/R$

$V = \sqrt{PR} = \sqrt{(5.0\times10^{1}\text{ W})(40.0\ \Omega)}$
$= 45\text{ V}$

86. Utilities Figure 22-19 represents an electric furnace. Calculate the monthly (30-day) heating bill if electricity costs \$0.10 per kWh and the thermostat is on one-fourth of the time.



■ **Figure 22-19**

$E = \left(\frac{V^2}{R}\right)(t)$

$= \left(\frac{(240.0\text{ V})^2}{4.80\ \Omega}\right)(30\text{ d})(24\text{ h/d})(0.25)$

$= 2160\text{ kWh}$

$\text{Cost} = (2160\text{ kWh})(\$0.100/\text{kWh}) = \$216$

87. Appliances A window air conditioner is estimated to have a cost of operation of \$50 per 30 days. This is based on the assumption that the air conditioner will run half of the time and that electricity costs \$0.090 per kWh. Determine how much current the air conditioner will take from a 120-V outlet.

Cost = (*E*)(rate)

$$E = \frac{\text{Cost}}{\text{rate}} = \frac{\$50}{\$0.090/\text{kWh}}$$

$$= 556 \text{ kWh}$$

$$E = IVt$$

$$I = \frac{E}{Vt} = \frac{(556 \text{ kWh})(1000 \text{ W/kW})}{(120 \text{ V})(30 \text{ d})(24 \text{ h/d})(0.5)}$$

$$= 12.9 \text{ A}$$

88. **Radios** A transistor radio operates by means of a 9.0-V battery that supplies it with a 50.0-mA current.

a. If the cost of the battery is \$2.49 and it lasts for 300.0 h, what is the cost per kWh to operate the radio in this manner?

$$P = IV = (0.050 \text{ A})(9.0 \text{ V}) = 0.45 \text{ W}$$
$$= 4.5\times10^{-4} \text{ kW}$$

$$\text{Cost} = \frac{\$2.49}{(4.5\times10^{-4} \text{ kW})(300.0 \text{ h})}$$

$$= \$18.00/\text{kWh}$$

b. The same radio, by means of a converter, is plugged into a household circuit by a homeowner who pays \$0.12 per kWh. What does it now cost to operate the radio for 300.0 h?

$$\text{Cost} = (\$0.12/\text{kWh})(4.5\times10^{-4} \text{ kW})(300 \text{ h})$$

$$= \$0.02$$

Mixed Review

page 613

Level 1

89. If a person has \$5, how long could he or she play a 200 W stereo if electricity costs \$0.15 per kWh?

$$E = Pt = \frac{\text{Cost}}{\text{Rate}}$$

$$t = \frac{\text{Cost}}{(\text{Rate})(P)}$$

$$= \frac{\$5}{(\$0.15/\text{kWh})(200 \text{ W})\left(\frac{1 \text{ kW}}{1000 \text{ W}}\right)}$$

$$= 200 \text{ h}$$

90. A current of 1.2 A is measured through a 50.0-Ω resistor for 5.0 min. How much heat is generated by the resistor?

$$Q = E = I^2Rt$$

$$= (1.2 \text{ A})^2(50.0\ \Omega)(5.0 \text{ min})\left(\frac{60 \text{ s}}{\text{min}}\right)$$

$$= 2.2\times10^4 \text{ J}$$

91. A 6.0-Ω resistor is connected to a 15-V battery.

a. What is the current in the circuit?

$$V = IR$$

$$I = \frac{V}{R} = \frac{15 \text{ V}}{6.0\ \Omega} = 2.5 \text{ A}$$

b. How much thermal energy is produced in 10.0 min?

$$Q = E = I^2Rt$$

$$= (2.5 \text{ A})^2(6.0\ \Omega)(10.0 \text{ min})\left(\frac{60 \text{ s}}{\text{min}}\right)$$

$$= 2.3\times10^4 \text{ J}$$

Level 2

92. **Lightbulbs** An incandescent lightbulb with a resistance of 10.0 Ω when it is not lit and a resistance of 40.0 Ω when it is lit has 120 V placed across it.

a. What is the current draw when the bulb is lit?

$$I = \frac{V}{R} = \frac{120 \text{ V}}{40.0\ \Omega} = 3.0 \text{ A}$$

b. What is the current draw at the instant the bulb is turned on?

$$I = \frac{V}{R} = \frac{120 \text{ V}}{10.0\ \Omega} = 12 \text{ A}$$

c. When does the lightbulb use the most power?

the instant it is turned on

93. A 12-V electric motor's speed is controlled by a potentiometer. At the motor's slowest setting, it uses 0.02 A. At its highest setting, the motor uses 1.2 A. What is the range of the potentiometer?

The slowest speed's resistance is $R = V/I = 12 \text{ V}/0.02 \text{ A} = 600\ \Omega$. The fastest speed's resistance is $R = V/I = 12 \text{ V}/1.2 \text{ A} = 1.0\times10^1\ \Omega$. The range is $1.0\times10^1\ \Omega$ to $600\ \Omega$.

Level 3

94. An electric motor operates a pump that irrigates a farmer's crop by pumping 1.0×10^4 L of water a vertical distance of 8.0 m into a field each hour. The motor has an operating resistance of 22.0 Ω and is connected across a 110-V source.

a. What current does the motor draw?

$$V = IR$$

$$I = \frac{V}{R} = \frac{110\ \text{V}}{22.0\ \Omega} = 5.0\ \text{A}$$

b. How efficient is the motor?

$$E_W = mgd$$

$$= (1\times10^4\ \text{kg})(9.80\ \text{m/s}^2)(8.0\ \text{m})$$

$$= 8\times10^5\ \text{J}$$

$$E_m = IVt = (5.0\ \text{A})(110\ \text{V})(3600\ \text{s})$$

$$= 2.0\times10^6\ \text{J}$$

$$\text{Efficiency} = \frac{E_w}{E_m}\times 100$$

$$= \frac{8\times10^5\ \text{J}}{2.0\times10^6\ \text{J}}\times 100$$

$$= 40\%$$

95. A heating coil has a resistance of 4.0 Ω and operates on 120 V.

a. What is the current in the coil while it is operating?

$$V = IR$$

$$I = \frac{V}{R} = \frac{120\ \text{V}}{4.0\ \Omega} = 3.0\times10^1\ \text{A}$$

b. What energy is supplied to the coil in 5.0 min?

$$E = I^2Rt$$

$$= (3.0\times10^1\ \text{A})^2(4.0\ \Omega)(5.0\ \text{min})\left(\frac{60\ \text{s}}{\text{min}}\right)$$

$$= 1.1\times10^6\ \text{J}$$

c. If the coil is immersed in an insulated container holding 20.0 kg of water, what will be the increase in the temperature of the water? Assume 100 percent of the heat is absorbed by the water.

$$Q = mC\Delta T$$

$$\Delta T = \frac{Q}{mC}$$

$$= \frac{1.1\times10^6\ \text{J}}{(20.0\ \text{kg})(4180\ \text{J/kg·C°})}$$

$$= 13°\text{C}$$

d. At $0.08 per kWh, how much does it cost to operate the heating coil 30 min per day for 30 days?

$$\text{Cost} = \left(\frac{1.1\times10^6\ \text{J}}{5\ \text{min}}\right)\left(\frac{30\ \text{min}}{\text{day}}\right)(30\ \text{days})\left(\frac{1\ \text{kWh}}{3.6\times10^6\ \text{J}}\right)\left(\frac{\$0.08}{\text{kWh}}\right)$$

$$= \$4.40$$

96. Appliances An electric heater is rated at 500 W.

a. How much energy is delivered to the heater in half an hour?

$$E = Pt = (5\times10^2\ \text{W})(1800\ \text{s})$$

$$= 9\times10^5\ \text{J}$$

b. The heater is being used to heat a room containing 50 kg of air. If the specific heat of air is 1.10 kJ/kg·°C, and 50 percent of the thermal energy heats the air in the room, what is the change in air temperature in half an hour?

$$Q = mC\Delta T$$

$$\Delta T = \frac{Q}{mC}$$

$$= \frac{(0.5)(9\times10^5\ \text{J})}{(50.0\ \text{kg})(1100\ \text{J/kg·C°})}$$

$$= 8°\text{C}$$

c. At $0.08 per kWh, how much does it cost to run the heater 6.0 h per day for 30 days?

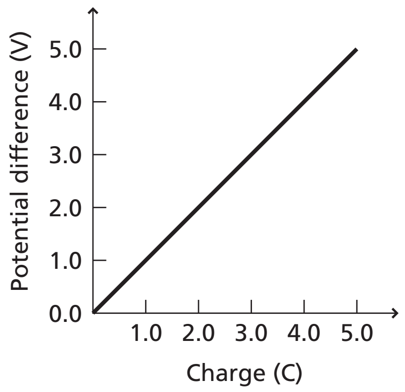
$$\text{Cost} = \left(\frac{500\ \text{J}}{\text{s}}\right)\left(\frac{6.0\ \text{h}}{\text{day}}\right)\left(\frac{3600\ \text{s}}{\text{h}}\right)(30\ \text{days})\left(\frac{1\text{kWH}}{3.6\times10^6\ \text{J}}\right)\left(\frac{\$0.08}{\text{kWh}}\right)$$

$$= \$7$$

Thinking Critically

page 614

97. Formulate Models How much energy is stored in a capacitor? The energy needed to increase the potential difference of a charge, *q*, is represented by $E = qV$. But in a capacitor, $V = q/C$. Thus, as charge is added, the potential difference increases. As more charge is added, however, it takes more energy to add the additional charge. Consider a 1.0-F "supercap" used as an energy storage device in a personal computer. Plot a graph of V as the capacitor is charged by adding 5.0 C to it. What is the voltage across the capacitor? The area under the curve is the energy stored in the capacitor. Find the energy in joules. Is it equal to the total charge times the final potential difference? Explain.



Voltage $V = \frac{q}{C} = \frac{5.0\text{ C}}{1.0\text{ F}} = 5.0\text{ V}$

Energy E **= area under curve**

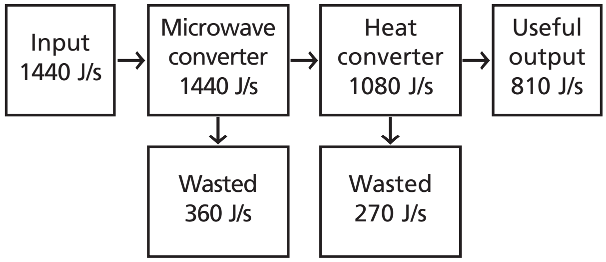
$= \frac{1}{2}(5.0\text{ V})(5.0\text{ C})$

$= 13\text{ J}$

No. Graphically, total change times final potential difference is exactly twice the area under the curve. Physically, it means that each coulomb would require the same maximum amount of energy to place it on the capacitor. Actually, the amount of energy needed to add each charge increases as charge accumulates on the capacitor.

98. Apply Concepts A microwave oven operates at 120 V and requires 12 A of current. Its electric efficiency (converting AC to microwave radiation) is 75 percent, and its conversion efficiency from microwave radiation to heating water is also 75 percent.

a. Draw a block power diagram similar to the energy diagram shown in Figure 22-2b on page 593. Label the function of each block according to total joules per second.



b. Derive an equation for the rate of temperature increase ($\Delta T/s$) from the information presented in Chapter 12. Solve for the rate of temperature rise given the rate of energy input, the mass, and the specific heat of a substance.

$$\frac{\Delta T}{\Delta t} = \frac{1}{mC}\left(\frac{\Delta Q}{\Delta t}\right)$$

c. Use your equation to solve for the rate of temperature rise in degrees Celsius per second when using this oven to heat 250 g of water above room temperature.

$$\frac{\Delta T}{\Delta t} = \frac{1}{mC}\left(\frac{\Delta Q}{\Delta t}\right)$$

$$= \frac{810\text{ J/s}}{(0.25\text{ kg})(4180\text{ J/kg·°C})}$$

$$= 0.78\text{°C/s}$$

d. Review your calculations carefully for the units used and discuss why your answer is in the correct form.

The kg unit cancels and the J unit cancels, leaving °C/s.

e. Discuss, in general terms, different ways in which you could increase the efficiency of microwave heating.

The efficiency of conversion from electric energy to microwave energy is 75 percent. It might be possible to find a way to convert electric energy to radiation using a different approach that would be more efficient. The efficiency of conversion from microwave radiation to thermal energy in water is 75 percent. It might be possible to use a different frequency of electromagnetic radiation to improve this rating. Or, it might be possible to find a new

geometry of radiating objects to be heated to improve the efficiency.

f. Discuss, in efficiency terms, why microwave ovens are not useful for heating everything.

The conversion efficiency from microwave energy to thermal energy is good for water. It's not as good for other materials. The containers and dishes designed for use with microwave ovens convert little of the energy.

g. Discuss, in general terms, why it is not a good idea to run microwave ovens when they are empty.

The empty oven means that the microwave energy has to be dissipated in the oven. This can lead to overheating of the oven components and to their failure.

99. Analyze and Conclude A salesclerk in an appliance store states that microwave ovens are the most electrically efficient means of heating objects.

a. Formulate an argument to refute the clerk's claim. *Hint: Think about heating a specific object.*

In the case of heating a cup of water, an immersion heater uses only resistance for energy conversion and is nearly 100 percent efficient. A microwave oven uses two energy conversions (electricity to microwave radiation to heat) and is typically around 50 percent efficient.

b. Formulate an argument to support the clerk's claim. *Hint: Think about heating a specific object.*

In the case of heating a potato, a microwave oven heats mostly the potato and is more efficient than an electric oven or skillet, which also heats the air, cabinets, racks, etc.

c. Formulate a diplomatic reply to the clerk.

"It can be true, but it depends on the specific application."

100. Apply Concepts The sizes of 10-Ω resistors range from a pinhead to a soup can. Explain.

The physical size of a resistor is determined by its power rating. Resistors rated at 100 W are much larger than those rated at 1 W.

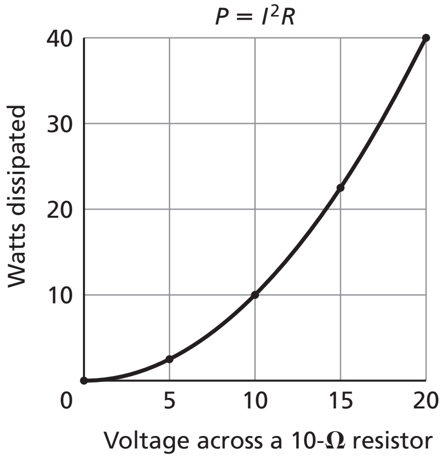
101. Make and Use Graphs The diode graph shown in Figure 22-17 on page 612 is more useful than a similar graph for a resistor that obeys Ohm's law. Explain.

The volt–ampere graph for a resistor obeying Ohm's law is a straight line and is seldom necessary.

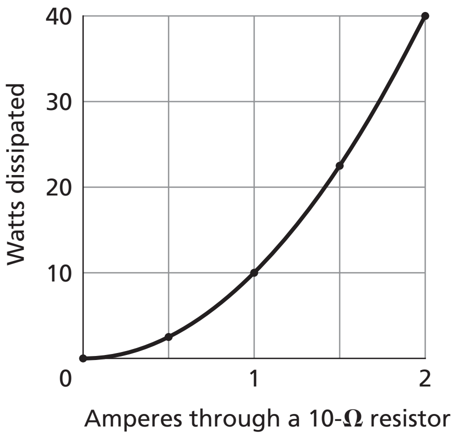
102. Make and Use Graphs Based on what you have learned in this chapter, identify and prepare two parabolic graphs.

voltage–power and current–power

$P = I^2R$



$P = \frac{V^2}{R}$



Writing in Physics

page 614

103. There are three kinds of equations encountered in science: (1) definitions, (2) laws, and (3) derivations. Examples of these are: (1) an ampere is equal to one coulomb per second, (2) force is equal to mass times acceleration, (3) power is equal to voltage squared divided by resistance. Write a one-page explanation of where "resistance is equal to voltage divided by current" fits. Before you begin to write, first research the three categories given above.

The student's answer should include the idea (1) that, for devices obeying Ohm's law, the voltage drop is proportional to current through the device and (2) that the formula $R = V/I$, the definition of resistance, is a derivation from Ohm's law.

104. In Chapter 13, you learned that matter expands when it is heated. Research the relationship between thermal expansion and high-voltage transmission lines.

Answers will vary, but students should determine that transmission lines can become hot enough to expand and sag when they have high currents. Sagging lines can be dangerous if they touch objects beneath them, such as trees or other power lines.

Cumulative Review

page 614

105. A person burns energy at the rate of about 8.4×10^6 J per day. How much does she increase the entropy of the universe in that day? How does this compare to the entropy increase caused by melting 20 kg of ice? (Chapter 12)

$\Delta S = Q/T$ **where** T **is the body temperature of 310 K.**

$$\Delta S = (8.4\times10^6\ \text{J})/(310\ \text{K}) = 2.7\times10^4\ \text{J/K}$$

For melting ice

$$\Delta S = (20\ \text{kg})(3.34\times10^5\ \text{J/kg})/(273\ \text{K}) = 2.4\times10^4\ \text{J/K}$$

106. When you go up the elevator of a tall building, your ears might pop because of the rapid change in pressure. What is the pressure change caused by riding in an elevator up a 30-story building (150 m)? The density of air is about 1.3 kg/m^3 at sea level. (Chapter 13)

$$\Delta P = \rho g h = (1.3\ \text{kg/m}^3)(9.80\ \text{m/s}^2)(150\ \text{m})$$

= 1.9 kPa or about 2/100 of the total air pressure

107. What is the wavelength in air of a 17-kHz sound wave, which is at the upper end of the frequency range of human hearing? (Chapter 15)

$$v = \lambda f$$

$$\lambda = \frac{v}{f} = \frac{343\ \text{m/s}}{17{,}000\ \text{Hz}} = 0.020\ \text{m} = 2.0\ \text{cm}$$

108. Light of wavelength 478 nm falls on a double slit. First-order bright bands appear 3.00 mm from the central bright band. The screen is 0.91 m from the slits. How far apart are the slits? (Chapter 19)

$$\lambda = \frac{xd}{L}$$

$$d = \frac{\lambda L}{x} = \frac{(478\times10^{-9}\ \text{m})(0.91\ \text{m})}{(3.00\times10^{-3}\ \text{m})} = 1.4\times10^{-4}\ \text{m}$$

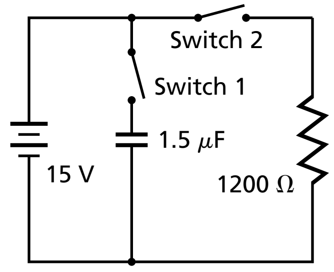
109. A charge of $+3.0\times10^{-6}$ C is 2.0 m from a second charge of $+6.0\times10^{-5}$ C. What is the magnitude of the force between them? (Chapter 20)

$$F = K\frac{q_A q_B}{d^2} = (9.0\times10^9\ \text{N·m}^2/\text{C}^2)\frac{(3.0\times10^{-6}\ \text{C})(6.0\times10^{-5}\ \text{C})}{(2.0\ \text{m})^2} = 0.41\ \text{N}$$

Challenge Problem

page 604

Use the figure to the right to help you answer the questions below.



1. Initially, the capacitor is uncharged. Switch 1 is closed, and Switch 2 remains open. What is the voltage across the capacitor?

15 V

2. Switch 1 is now opened, and Switch 2 remains open. What is the voltage across the capacitor? Why?

It remains 15 V because there is no path for the charge to be removed.

3. Next, Switch 2 is closed, while Switch 1 remains open. What is the voltage across the capacitor and the current through the resistor immediately after Switch 2 is closed?

15 V and 13 mA

4. As time goes on, what happens to the voltage across the capacitor and the current through the resistor?

The capacitor voltage remains at 15 V because there is no path to discharge the capacitor; the current remains at 13 mA because the battery voltage is constant at 15 V. However, if the battery and capacitor were real components instead of ideal circuit components, the capacitor voltage eventually would become zero due to leakage, and the current eventually would become zero due to battery depletion.

CHAPTER

23 Series and Parallel Circuits

Practice Problems

23.1 Simple Circuits pages 617–626

page 619

1. Three 20-Ω resistors are connected in series across a 120-V generator. What is the equivalent resistance of the circuit? What is the current in the circuit?

$$R = R_1 + R_2 + R_3$$
$$= 20\ \Omega + 20\ \Omega + 20\ \Omega$$
$$= 60\ \Omega$$
$$I = \frac{V}{R} = \frac{120\ \text{V}}{60\ \Omega} = 2\ \text{A}$$

2. A 10-Ω, 15-Ω, and 5-Ω resistor are connected in a series circuit with a 90-V battery. What is the equivalent resistance of the circuit? What is the current in the circuit?

$$R = R_1 + R_2 + R_3$$
$$= 10\ \Omega + 15\ \Omega + 5\ \Omega = 30\ \Omega$$
$$I = \frac{V}{R} = \frac{90\ \text{V}}{30\ \Omega} = 3\ \text{A}$$

3. A 9-V battery is in a circuit with three resistors connected in series.

a. If the resistance of one of the resistors increases, how will the equivalent resistance change?

It will increase.

b. What will happen to the current?

$I = \frac{V}{R}$, **so it will decrease.**

c. Will there be any change in the battery voltage?

No. It does not depend on the resistance.

4. A string of holiday lights has ten bulbs with equal resistances connected in series. When the string of lights is connected to a 120-V outlet, the current through the bulbs is 0.06 A.

a. What is the equivalent resistance of the circuit?

$$R = \frac{V}{I} = \frac{120\ \text{V}}{0.06\ \text{A}} = 2\times10^3\ \Omega$$

b. What is the resistance of each bulb?

$$R_{bulb} = \frac{R}{10} = \frac{2\times10^3\ \Omega}{10} = 2\times10^2\ \Omega$$

5. Calculate the voltage drops across the three resistors in problem 2, and verify that their sum equals the voltage of the battery.

$$V_1 = IR_1 = (3\ \text{A})(10\ \Omega) = 30\ \text{V}$$
$$V_2 = IR_2 = (3\ \text{A})(15\ \Omega) = 45\ \text{V}$$
$$V_3 = IR_3 = (3\ \text{A})(5\ \Omega) = 15\ \text{V}$$
$$V_1 + V_2 + V_3 = 30\ \text{V} + 45\ \text{V} + 15\ \text{V}$$
$$= 90\ \text{V}$$
$$= \text{voltage of battery}$$

page 622

6. The circuit shown in Example Problem 1 is producing these symptoms: the ammeter reads 0 A, V_A reads 0 V, and V_B reads 45 V. What has happened?

R_B has failed. It has infinite resistance, and the battery voltage appears across it.

7. Suppose the circuit shown in Example Problem 1 has these values: R_A = 255 Ω, R_B = 292 Ω, and V_A = 17.0 V. No other information is available.

a. What is the current in the circuit?

$$I = \frac{V}{R} = \frac{17.0\ \text{V}}{255.0\ \Omega} = 66.7\ \text{mA}$$

b. What is the battery voltage?

First, find the total resistance, then solve for voltage.

$$R = R_A + R_B$$
$$= 255\ \Omega + 292\ \Omega$$
$$= 547\ \Omega$$
$$V = IR = (66.7\ \text{mA})(547\ \Omega) = 36.5\ \text{V}$$

c. What are the total power dissipation and the individual power dissipations?

$P = IV = (66.7\ \text{mA})(36.5\ \text{V}) = 2.43\ \text{W}$

$P_A = I^2R_A$

$= (66.7\ \text{mA})^2(255\ \Omega)$

$= 1.13\ \text{W}$

$P_B = I^2R_B$

$= (66.7\ \text{mA})^2(292\ \Omega)$

$= 1.30\ \text{W}$

d. Does the sum of the individual power dissipations in the circuit equal the total power dissipation in the circuit? Explain.

Yes. The law of conservation of energy states that energy cannot be created or destroyed; therefore, the rate at which energy is converted, or power dissipated, will equal the sum of all parts.

8. Holiday lights often are connected in series and use special lamps that short out when the voltage across a lamp increases to the line voltage. Explain why. Also explain why these light sets might blow their fuses after many bulbs have failed.

If not for the shorting mechanism, the entire set would go out when one lamp burns out. After several lamps fail and then short, the total resistance of the remaining working lamps results in an increased current that is sufficient to blow the fuse.

9. The circuit in Example Problem 1 has unequal resistors. Explain why the resistor with the lower resistance will operate at a lower temperature.

The resistor with the lower resistance will dissipate less power, and thus will be cooler.

10. A series circuit is made up of a 12.0-V battery and three resistors. The voltage across one resistor is 1.21 V, and the voltage across another resistor is 3.33 V. What is the voltage across the third resistor?

$V_{source} = V_A + V_B + V_C$

$V_C = V_{source} - (V_A + V_B)$

$= 12.0\ \text{V} - (1.21\ \text{V} + 3.33\ \text{V}) = 7.46\ \text{V}$

page 623

11. A 22-Ω resistor and a 33-Ω resistor are connected in series and placed across a 120-V potential difference.

a. What is the equivalent resistance of the circuit?

$R = R_1 + R_2 = 22\ \Omega + 33\ \Omega = 55\ \Omega$

b. What is the current in the circuit?

$I = \frac{V}{R} = \frac{120\ \text{V}}{55\ \Omega} = 2.2\ \text{A}$

c. What is the voltage drop across each resistor?

$V_1 = IR_1$

$= \left(\frac{V}{R}\right)R_1$

$= \left(\frac{120\ \text{V}}{55\ \Omega}\right)(22\ \Omega)$

$= 48\ \text{V}$

$V_2 = IR_2 = \left(\frac{120\ \text{V}}{55\ \Omega}\right)(33\ \Omega) = 72\ \text{V}$

d. What is the voltage drop across the two resistors together?

$V = 48\ \text{V} + 72\ \text{V} = 1.20\times10^2\ \text{V}$

12. Three resistors of 3.3 kΩ, 4.7 kΩ, and 3.9 kΩ are connected in series across a 12-V battery.

a. What is the equivalent resistance?

$R = 3.3\ \text{k}\Omega + 4.7\ \text{k}\Omega + 3.9\ \text{k}\Omega$

$= 1.2\times10^1\ \text{k}\Omega$

b. What is the current through the resistors?

$I = \frac{V}{R} = \frac{12\ \text{V}}{12\times10^4\ \Omega}$

$= 1.0\ \text{mA} = 1.0\times10^{-3}\ \text{A}$

c. What is the voltage drop across each resistor?

$V = IR$

$V_1 = (3.3\ \text{k}\Omega)(1.0\times10^{-3}\ \text{A}) = 3.3\ \text{V}$

$V_2 = (4.7\ \text{k}\Omega)(1.0\times10^{-3}\ \text{A}) = 4.7\ \text{V}$

$V_3 = (3.9\ \text{k}\Omega)(1.0\times10^{-3}\ \text{A}) = 3.9\ \text{V}$

so $V = 3.3$ V, 4.7 V, and 3.9 V

d. Find the total voltage drop across the three resistors.

$V = 3.3\ \text{V} + 4.7\ \text{V} + 3.9\ \text{V} = 11.9\ \text{V}$

13. A student makes a voltage divider from a 45-V battery, a 475-kΩ resistor, and a 235-kΩ resistor. The output is measured across the smaller resistor. What is the voltage?

$$V_B = \frac{VR_B}{R_A + R_B} = \frac{(45\ \text{V})(235\ \text{k}\Omega)}{475\ \text{k}\Omega + 235\ \text{k}\Omega} = 15\ \text{V}$$

14. Select a resistor to be used as part of a voltage divider along with a 1.2-kΩ resistor. The drop across the 1.2-kΩ resistor is to be 2.2 V when the supply is 12 V.

$$V_B = \frac{VR_B}{R_A + R_B}$$

$$R_A = \frac{VR_B}{V_B} - R_B$$

$$= \frac{(12.0\ \text{V})(1.2\ \text{k}\Omega)}{2.2\ \text{V}} - 1.2\ \text{k}\Omega$$

$$= 5.3\ \text{k}\Omega$$

page 626

15. Three 15.0-Ω resistors are connected in parallel and placed across a 30.0-V battery.

a. What is the equivalent resistance of the parallel circuit?

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$= \frac{1}{15.0\ \Omega} + \frac{1}{15.0\ \Omega} + \frac{1}{15.0\ \Omega}$$

$$= \frac{3}{15.0\ \Omega}$$

$R = 5.00\ \Omega$

b. What is the current through the entire circuit?

$$I = \frac{V}{R} = \frac{30.0\ \text{V}}{5.00\ \Omega} = 6.00\ \text{A}$$

c. What is the current through each branch of the circuit?

$$I = \frac{V}{R_1} = \frac{30.0\ \text{V}}{15.0\ \Omega} = 2.00\ \text{A}$$

16. A 120.0-Ω resistor, a 60.0-Ω resistor, and a 40.0-Ω resistor are connected in parallel and placed across a 12.0-V battery.

a. What is the equivalent resistance of the parallel circuit?

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$= \frac{1}{120.0\ \Omega} + \frac{1}{60.0\ \Omega} + \frac{1}{40.0\ \Omega}$$

$R = 20.0\ \Omega$

b. What is the current through the entire circuit?

$$I = \frac{V}{R} = \frac{12.0\ \text{V}}{20.0\ \Omega} = 0.600\ \text{A}$$

c. What is the current through each branch of the circuit?

$$I_1 = \frac{V}{R_1} = \frac{12.0\ \text{V}}{120.0\ \Omega} = 0.100\ \text{A}$$

$$I_2 = \frac{V}{R_2} = \frac{12.0\ \text{V}}{60.0\ \Omega} = 0.200\ \text{A}$$

$$I_3 = \frac{V}{R_3} = \frac{12.0\ \text{V}}{40.0\ \Omega} = 0.300\ \text{A}$$

17. Suppose that one of the 15.0-Ω resistors in problem 15 is replaced by a 10.0-Ω resistor.

a. Does the equivalent resistance change? If so, how?

Yes, it gets smaller.

b. Does the amount of current through the entire circuit change? If so, in what way?

Yes, it gets larger.

c. Does the amount of current through the other 15.0-Ω resistors change? If so, how?

No, it remains the same. Currents are independent.

18. A 150-Ω branch in a circuit must be reduced to 93 Ω. A resistor will be added to this branch of the circuit to make this change. What value of resistance should be used and how must the resistor be connected?

A parallel resistor will be required to reduce the resistance.

$$\frac{1}{R} = \frac{1}{R_A} + \frac{1}{R_B}$$

$$\frac{1}{R_A} = \frac{1}{R} - \frac{1}{R_B} = \frac{1}{93\ \Omega} - \frac{1}{150\ \Omega}$$

$R_A = 2.4\times10^2\ \Omega$

$2.4\times10^2\ \Omega$ in parallel with the 150-Ω resistance

19. A 12-Ω, 2-W resistor is connected in parallel with a 6.0-Ω, 4-W resistor. Which will become hotter if the voltage across them keeps increasing?

Neither. They both reach maximum dissipation at the same voltage.

$P = \frac{V^2}{R}$

$V = \sqrt{PR}$

The voltage is equal across parallel resistors, so:

$V = \sqrt{P_1R_1} = \sqrt{P_2R_2}$

$= \sqrt{(2\ \text{W})(12\ \Omega)}$

$= \sqrt{(4\ \text{W})(6.0\ \Omega)}$

$= 5\ \text{V maximum}$

Section Review

23.1 Simple Circuits pages 617–626

page 626

20. Circuit Types Compare and contrast the voltages and the currents in series and parallel circuits.

The student's answer should include the following ideas:

(1) In a series circuit, the current in each of the devices is the same, and the sum of the device voltage drops equals the source voltage.

(2) In a parallel circuit, the voltage drop across each device is the same and the sum of the currents through each loop equals the source current.

21. Total Current A parallel circuit has four branch currents: 120 mA, 250 mA, 380 mA, and 2.1 A. How much current is supplied by the source?

$I_T = I_1 + I_2 + I_3 + I_4$

$= 120\ \text{mA} + 250\ \text{mA} + 380\ \text{mA} + 2.1\ \text{A}$

$= 0.12\ \text{A} + 0.25\ \text{A} + 0.38\ \text{A} + 2.1\ \text{A}$

$= 2.9\ \text{A}$

22. Total Current A series circuit has four resistors. The current through one resistor is 810 mA. How much current is supplied by the source?

810 mA. Current is the same everywhere in a series circuit.

23. Circuits A switch is connected in series with a 75-W bulb to a source of 120 V.

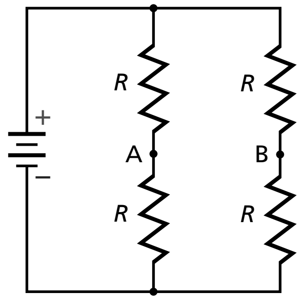
a. What is the potential difference across the switch when it is closed (turned on)?

0 V; $V = IR$ with $R = 0$

b. What is the potential difference across the switch if another 75-W bulb is added in series?

0 V; $V = IR$ with $R = 0$

24. Critical Thinking The circuit in **Figure 23-8** has four identical resistors. Suppose that a wire is added to connect points A and B. Answer the following questions, and explain your reasoning.



■ **Figure 23-8**

a. What is the current through the wire?

0 A; the potentials of points A and B are the same.

b. What happens to the current through each resistor?

nothing

c. What happens to the current drawn from the battery?

nothing

d. What happens to the potential difference across each resistor?

nothing

Practice Problems

23.2 Applications of Circuits pages 627–631

page 630

25. A series-parallel circuit has three resistors: one dissipates 2.0 W, the second 3.0 W, and the third 1.5 W. How much current does the circuit require from a 12-V battery?

By conservation of energy (and power):

$$P_T = P_1 + P_2 + P_3$$

$$= 2.0\text{ W} + 3.0\text{ W} + 1.5\text{ W}$$

$$= 6.5\text{ W}$$

$$P_T = IV$$

$$I = \frac{P_T}{V} = \frac{6.5\text{ W}}{12\text{ V}} = 0.54\text{ A}$$

26. There are 11 lights in series, and they are in series with two lights in parallel. If the 13 lights are identical, which of them will burn brightest?

The 11 lights in series will burn brighter. The parallel lights each will conduct half of the current of the series lights and they will burn at one-fourth the intensity of the series lights since $P = I^2R$.

27. What will happen to the circuit in problem 26 if one of the parallel lights burns out?

Then, all of the working lights are in series. The 12 working lights will burn with equal intensity.

28. What will happen to the circuit in problem 26 if one of the parallel lights shorts out?

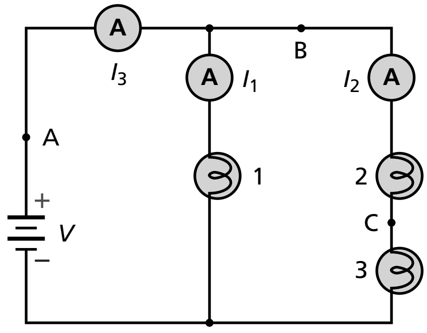
Then, the shorted light will reduce the voltage across itself and its parallel companion to 0. The 11 series lights will burn with equal, but increased, intensity and the two parallel lights will go out.

Section Review

23.2 Applications of Circuits pages 627–631

page 631

Refer to ***Figure 23-13*** *for questions 29–33, and 35. The bulbs in the circuit are identical.*



■ **Figure 23-13**

29. Brightness How do the bulb brightnesses compare?

Bulbs 2 and 3 are equal in brightness but dimmer than bulb 1.

30. Current If I_3 measures 1.7 A and I_1 measures 1.1 A, how much current is flowing in bulb 2?

$$I_3 = I_1 + I_2$$

$$I_2 = I_3 - I_1 = 1.7\text{ A} - 1.1\text{ A} = 0.6\text{ A}$$

31. Circuits in Series The wire at point C is broken and a small resistor is inserted in series with bulbs 2 and 3. What happens to the brightnesses of the two bulbs? Explain.

Both dim equally. The current in each is reduced by the same amount.

32. Battery Voltage A voltmeter connected across bulb 2 measures 3.8 V, and a voltmeter connected across bulb 3 measures 4.2 V. What is the battery voltage?

These bulbs are in series, so:

$$V_T = V_1 + V_2 = 3.8\text{ V} + 4.2\text{ V} = 8.0\text{ V}$$

33. Circuits Using the information from problem 32, determine if bulbs 2 and 3 are identical.

No. Identical bulbs in series would have identical voltage drops since their currents are the same.

34. Circuit Protection Describe three common safety devices associated with household wiring.

fuses, circuit breakers, ground-fault circuit interrupters

35. Critical Thinking Is there a way to make the three bulbs in Figure 23-13 burn with equal intensity without using any additional resistors? Explain.

Yes. Because intensity is proportional to power, it would be necessary to use a bulb at location 1 that has four times the operating resistance of each of those at locations 2 and 3.

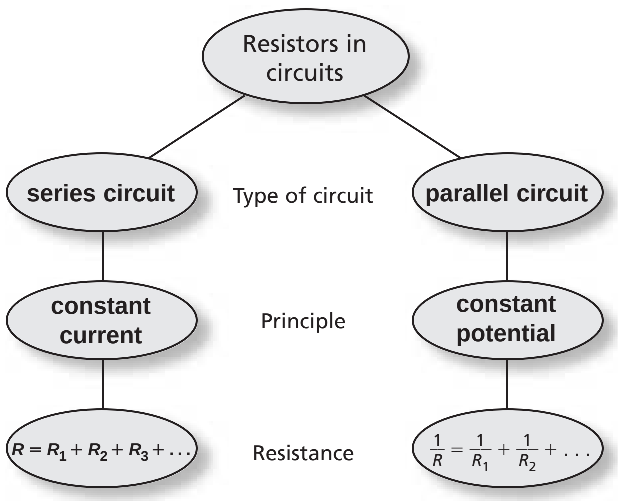
$V^2/4R = (V/2)^2/R$

Chapter Assessment

Concept Mapping

page 636

36. Complete the concept map using the following terms: *series circuit,* $R = R_1 + R_2 + R_3$, *constant current, parallel circuit, constant potential.*



Mastering Concepts

page 636

37. Why is it frustrating when one bulb burns out on a string of holiday tree lights connected in series? (23.1)

When one bulb burns out, the circuit is open and all the bulbs go out.

38. Why does the equivalent resistance decrease as more resistors are added to a parallel circuit? (23.1)

Each new resistor provides an additional path for the current.

39. Several resistors with different values are connected in parallel. How do the values of the individual resistors compare with the equivalent resistance? (23.1)

The equivalent resistance will be less than that of any of the resistors.

40. Why is household wiring constructed in parallel instead of in series? (23.1)

Appliances in parallel can be run independently of one another.

41. Why is there a difference in equivalent resistance between three 60-Ω resistors connected in series and three 60-Ω resistors connected in parallel? (23.1)

In a series circuit, the current is opposed by each resistance in turn. The total resistance is the sum of the resistors. In a parallel circuit, each resistance provides an additional path for current. The result is a decrease in total resistance.

42. Compare the amount of current entering a junction in a parallel circuit with that leaving the junction. (A junction is a point where three or more conductors are joined.) (23.1)

The amount of current entering a junction is equal to the amount of current leaving.

43. Explain how a fuse functions to protect an electric circuit. (23.2)

The purpose of a fuse is to prevent conductors from being overloaded with current, causing fires due to overheating. A fuse is simply a short length of wire that will melt from the heating effect if the current exceeds a certain maximum.

44. What is a short circuit? Why is a short circuit dangerous? (23.2)

A short circuit is a circuit that has extremely low resistance. A short circuit is dangerous because any potential difference will produce a large current. The heating effect of the current can cause a fire.

45. Why is an ammeter designed to have a very low resistance? (23.2)

An ammeter must have low resistance because it is placed in series in the circuit. If its resistance were high, it would significantly change the total resistance of the circuit and thus serve to reduce the current in the circuit, thereby changing the current it is meant to measure.

46. Why is a voltmeter designed to have a very high resistance? (23.2)

A voltmeter is placed in parallel with the portion of the circuit whose difference in potential is to be measured. A voltmeter must have very high resistance for the same reason that an ammeter has low resistance. If the voltmeter had low resistance, it would lower the resistance of the portion of the circuit it is across and increase the current in the circuit. This would produce a higher voltage drop across the part of the circuit where the voltmeter is located, changing the voltage it is measuring.

47. How does the way in which an ammeter is connected in a circuit differ from the way in which a voltmeter is connected? (23.2)

An ammeter is connected in series; a voltmeter is connected in parallel.

Applying Concepts

page 636

48. What happens to the current in the other two lamps if one lamp in a three-lamp series circuit burns out?

If one of the lamp filaments burns out, the current will cease and all the lamps will go out.

49. Suppose the resistor, R_A, in the voltage divider in Figure 23-4 is made to be a variable resistor. What happens to the voltage output, V_B, of the voltage divider if the resistance of the variable resistor is increased?

$V_B = VR_B/(R_A + R_B)$**. As** R_A **increases,** V_B **will decrease.**

50. Circuit A contains three 60-Ω resistors in series. Circuit B contains three 60-Ω resistors in parallel. How does the current in the second 60-Ω resistor of each circuit change if a switch cuts off the current to the first 60-Ω resistor?

Circuit A: There will be no current in the resistor.

Circuit B: The current in the resistor will remain the same

51. What happens to the current in the other two lamps if one lamp in a three-lamp parallel circuit burns out?

If one of the filaments burns out, the resistance and the potential difference across the other lamps will not change; therefore, their currents will remain the same.

52. An engineer needs a 10-Ω resistor and a 15-Ω resistor, but there are only 30-Ω resistors in stock. Must new resistors be purchased? Explain.

No, the 30-Ω resistors can be used in parallel. Three 30-Ω resistors in parallel will give a 10-Ω resistance. Two 30-Ω resistors in parallel will give a 15-Ω resistance.

53. If you have a 6-V battery and many 1.5-V bulbs, how could you connect them so that they light but do not have more than 1.5 V across each bulb?

Connect four of the bulbs in series. The voltage drop across each will be (6.0 V)/4 = 1.5 V.

54. Two lamps have different resistances, one larger than the other.

a. If the lamps are connected in parallel, which is brighter (dissipates more power)?

The lamp with the lower resistance: $P = IV$ and $I = V/R$, so $P = V^2/R$. Because the voltage drop is the same across both lamps, the smaller R means larger P, and thus will be brighter.

b. When the lamps are connected in series, which lamp is brighter?

The lamp with the higher resistance; $P = IV$ and $V = IR$, so $P = I^2R$. Because the current is the same in both lamps, the larger R means larger P, and thus will be brighter.

55. For each of the following, write the form of circuit that applies: series or parallel.

a. The current is the same everywhere throughout the entire circuit.

series

b. The total resistance is equal to the sum of the individual resistances.

series

c. The voltage drop across each resistor in the circuit is the same.

parallel

d. The voltage drop in the circuit is proportional to the resistance.

series

e. Adding a resistor to the circuit decreases the total resistance.

parallel

f. Adding a resistor to the circuit increases the total resistance.

series

g. If the current through one resistor in the circuit goes to zero, there is no current in the entire circuit.

series

h. If the current through one resistor in the circuit goes to zero, the current through all other resistors remains the same.

parallel

i. This form is suitable for house wiring.

parallel

56. **Household Fuses** Why is it dangerous to replace the 15-A fuse used to protect a household circuit with a fuse that is rated at 30 A?

The 30-A fuse allows more current to flow through the circuit, generating more heat in the wires, which can be dangerous.

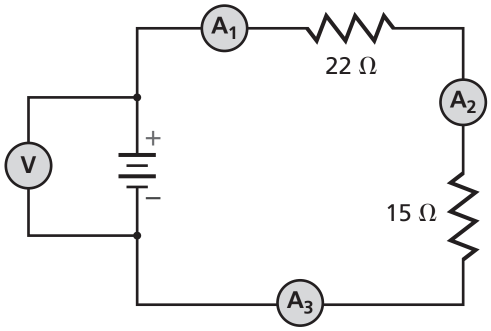
Mastering Problems

23.1 Simple Circuits

pages 637–638

Level 1

57. Ammeter 1 in **Figure 23-14** reads 0.20 A.



■ **Figure 23-14**

a. What should ammeter 2 indicate?

0.20 A, because current is constant in a series circuit.

b. What should ammeter 3 indicate?

0.20 A, because current is constant in a series circuit.

58. Calculate the equivalent resistance of these series-connected resistors: 680 Ω, 1.1 kΩ, and 10 kΩ.

$R = 680\ \Omega + 1100\ \Omega + 10{,}000\ \Omega$

$= 12\ k\Omega$

59. Calculate the equivalent resistance of these parallel-connected resistors: 680 Ω, 1.1 kΩ, and 10.2 kΩ.

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$R = \frac{1}{\left(\frac{1}{0.68\ k\Omega} + \frac{1}{1.1\ k\Omega} + \frac{1}{10.2\ k\Omega}\right)}$$

$= 0.40\ k\Omega$

60. A series circuit has two voltage drops: 5.50 V and 6.90 V. What is the supply voltage?

$V = 5.50\ V + 6.90\ V = 12.4\ V$

61. A parallel circuit has two branch currents: 3.45 A and 1.00 A. What is the current in the energy source?

$I = 3.45\ A + 1.00\ A = 4.45\ A$

Level 2

62. Ammeter 1 in Figure 23-14 reads 0.20 A.

a. What is the total resistance of the circuit?

$R = R_1 + R_2 = 15\ \Omega + 22\ \Omega = 37\ \Omega$

b. What is the battery voltage?

$V = IR = (0.20\ A)(37\ \Omega) = 7.4\ V$

c. How much power is delivered to the 22-Ω resistor?

$P = I^2R = (0.20\ A)^2(22\ \Omega) = 0.88\ W$

d. How much power is supplied by the battery?

$P = IV = (0.20\ A)(7.4\ V) = 1.5\ W$

63. Ammeter 2 in Figure 23-14 reads 0.50 A.

a. Find the voltage across the 22-Ω resistor.

$V = IR = (0.50\ A)(22\ \Omega) = 11\ V$

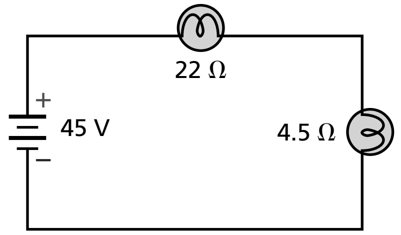
b. Find the voltage across the 15-Ω resistor.

$V = IR = (0.50\ A)(15\ \Omega) = 7.5\ V$

c. What is the battery voltage?

$V = V_1 + V_2 = (11\ V) + (7.5\ V) = 19\ V$

64. A 22-Ω lamp and a 4.5-Ω lamp are connected in series and placed across a potential difference of 45 V as shown in **Figure 23-15.**



■ **Figure 23-15**

a. What is the equivalent resistance of the circuit?

$22\ \Omega + 4.5\ \Omega = 26\ \Omega$

b. What is the current in the circuit?

$I = \frac{V}{R} = \frac{45\ V}{27\ \Omega} = 1.7\ A$

c. What is the voltage drop across each lamp?

$V = IR = (1.7\ A)(22\ \Omega) = 37\ V$

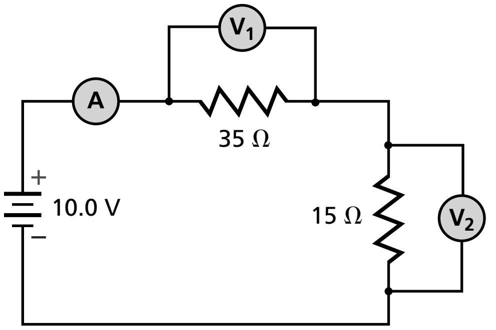
$V = IR = (1.7\ A)(4.5\ \Omega) = 7.7\ V$

d. What is the power dissipated in each lamp?

$P = IV = (1.7\ A)(37\ V) = 63\ W$

$P = IV = (1.7\ A)(7.7\ V) = 13\ W$

65. Refer to **Figure 23-16** to answer the following questions.



■ **Figure 23-16**

a. What should the ammeter read?

$R = R_1 + R_2 = 35\ \Omega + 15\ \Omega$

$I = V/R$

$= (10.0\ V)/(35\ \Omega + 15\ \Omega)$

$= 0.20\ A$

b. What should voltmeter 1 read?

$V = IR = (0.20\ A)(35\ \Omega) = 7.0\ V$

c. What should voltmeter 2 read?

$V = IR = (0.20\ A)(15\ \Omega) = 3.0\ V$

d. How much energy is supplied by the battery per minute?

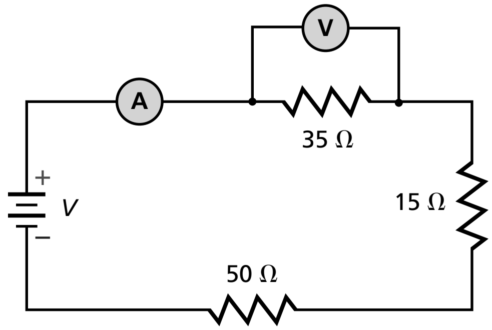
$E = Pt$

$= VIt$

$= (10.0\ V)(0.20\ A)(1\ min)(60\ s/min)$

$= 120\ J$

66. For **Figure 23-17,** the voltmeter reads 70.0 V.



■ **Figure 23-17**

a. Which resistor is the hottest?

50 Ω. Since $P = I^2R$ and I is constant in a series circuit, the largest value of resistance will produce the most power.

b. Which resistor is the coolest?

15 Ω. Since $P = I^2R$ and I is constant in a series circuit, the smallest value of resistance will produce the least power.

c. What will the ammeter read?

Use Ohm's law: $I = V/R$

$= (70.0\ V)/(35\ \Omega)$

$= 2.0\ A$

d. What is the power supplied by the battery?

First, find the total resistance:

$R = R_1 + R_2 + R_3$

$= 35\ \Omega + 15\ \Omega + 50\ \Omega$

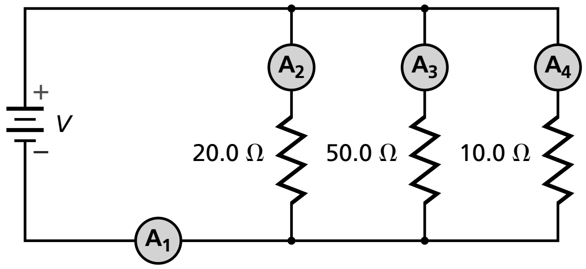
$= 0.1\ k\Omega$

$P = I^2R$

$= (2.0\ A)^2(0.1\ k\Omega)(1000\ \Omega/k\Omega)$

$= 4\times10^2\ W$

67. For **Figure 23-18,** the battery develops 110 V.



■ **Figure 23-18**

a. Which resistor is the hottest?

10.0 Ω. Since $P = V^2/R$ and V is constant in a parallel circuit, the smallest resistor will dissipate the most power.

b. Which resistor is the coolest?

50.0 Ω. Since $P = V^2/R$ and V is constant in a parallel circuit, the largest resistor will dissipate the least power.

c. What will ammeter 1 read?

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$R = \frac{1}{\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)}$$

$$= \frac{1}{\left(\frac{1}{20.0\ \Omega} + \frac{1}{50.0\ \Omega} + \frac{1}{10.0\ \Omega}\right)}$$

$= 5.88\ \Omega$

$$I = \frac{V}{R} = \frac{1.1\times10^2\ V}{5.88\ \Omega} = 19A$$

d. What will ammeter 2 read?

$$I = \frac{V}{R} = \frac{1.1\times10^2\ V}{20.0\ \Omega} = 5.5\ A$$

e. What will ammeter 3 read?

$$I = \frac{V}{R} = \frac{1.1\times10^2\ V}{50.0\ \Omega} = 2.2\ A$$

f. What will ammeter 4 read?

$$I = \frac{V}{R} = \frac{1.1\times10^2\ V}{10.0\ \Omega} = 11\ A$$

68. For Figure 23-18, ammeter 3 reads 0.40 A.

a. What is the battery voltage?

$V = IR = (0.40\ A)(50.0\ \Omega) = 2.0\times10^1\ V$

b. What will ammeter 1 read?

Find the equivalent resistance:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$R = \frac{1}{\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)}$$

$$= \frac{1}{\left(\frac{1}{20.0\ \Omega} + \frac{1}{50.0\ \Omega} + \frac{1}{10.0\ \Omega}\right)}$$

$$= \frac{1}{0.17\ \Omega}$$

$$= 5.88\ \Omega$$

$$I = \frac{V}{R} = \frac{2.0\times10^1\ \text{V}}{5.88\ \Omega} = 3.4\ \text{A}$$

c. What will ammeter 2 read?

$$I = \frac{V}{R} = \frac{2.0\times10^1\ \text{V}}{20.0\ \Omega} = 1.0\ \text{A}$$

d. What will ammeter 4 read?

$$I = \frac{V}{R} = \frac{2.0\times10^1\ \text{V}}{10.0\ \Omega} = 2.0\ \text{A}$$

69. What is the direction of the conventional current in the 50.0-Ω resistor in Figure 23-18?

down

70. The load across a battery consists of two resistors, with values of 15 Ω and 47 Ω, connected in series.

a. What is the total resistance of the load?

$$R = R_1 + R_2 = 15\ \Omega + 47\ \Omega$$

$$= 62\ \Omega$$

b. What is the voltage of the battery if the current in the circuit is 97 mA?

$$V = IR = (97\ \text{mA})(62\ \Omega) = 6.0\ \text{V}$$

71. **Holiday Lights** A string of 18 identical holiday tree lights is connected in series to a 120-V source. The string dissipates 64 W.

a. What is the equivalent resistance of the light string?

$$P = \frac{V^2}{R_{eq}}$$

$$R_{eq} = \frac{V^2}{P} = \frac{(120\ \text{V})^2}{64\ \text{W}} = 2.3\times10^2\ \Omega$$

b. What is the resistance of a single light?

***R* is the sum of the resistances of 18 lamps, so each resistance is**

$$\frac{2.3\times10^2\ \Omega}{18} = 13\ \Omega$$

c. What power is dissipated by each light?

$$\frac{64\ \text{W}}{18} = 3.6\ \text{W}$$

72. One of the lights in problem 71 burns out. The light shorts out the bulb filament when it burns out. This drops the resistance of the lamp to zero.

a. What is the resistance of the light string now?

There are now 17 lamps in series instead of 18 lamps. The resistance is $\left(\frac{17}{18}\right)(2.3\times10^2\ \Omega) = 2.2\times10^2\ \Omega$

b. Find the power dissipated by the string.

$$P = \frac{V^2}{R} = \frac{(120\ \text{V})^2}{2.2\times10^2\ \Omega} = 65\ \text{W}$$

c. Did the power increase or decrease when the bulb burned out?

It increased.

73. A 16.0-Ω and a 20.0-Ω resistor are connected in parallel. A difference in potential of 40.0 V is applied to the combination.

a. Compute the equivalent resistance of the parallel circuit.

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$R = \frac{1}{\left(\frac{1}{R_1} + \frac{1}{R_2}\right)}$$

$$= \frac{1}{\left(\frac{1}{16.0\ \Omega} + \frac{1}{20.0\ \Omega}\right)}$$

$$= 8.89\ \Omega$$

b. What is the total current in the circuit?

$$I = \frac{V}{R} = \frac{40.0\ \text{V}}{8.89\ \Omega} = 4.50\ \text{A}$$

c. What is the current in the 16.0-Ω resistor?

$$I_1 = \frac{V}{R_1} = \frac{40.0\ \text{V}}{16.0\ \Omega} = 2.50\ \text{A}$$

74. Amy needs 5.0 V for an integrated-circuit experiment. She uses a 6.0-V battery and two resistors to make a voltage divider. One resistor is 330 Ω. She decides to make the other resistor smaller. What value should it have?

$$V_2 = \frac{VR_2}{R_1 + R_2}$$

$$R_1 = \frac{VR_2}{V_2} - R_2$$

$$= \frac{(6.0\ \text{V})(330\ \Omega)}{5.0\ \text{V}} - 330\ \Omega = 66\ \Omega$$

75. Pete is designing a voltage divider using a 12-V battery and a 82-Ω resistor as R_B. What resistor should be used as R_A if the output voltage across R_B is to be 4.0 V?

$$V_B = \frac{VR_B}{R_A + R_B}$$

$$R_A + R_B = \frac{VR_B}{V_B}$$

$$R_A = \frac{VR_B}{V_B} - R_B$$

$$= \frac{(12\ \text{V})(82\ \Omega)}{4.0\ \text{V}} - 82\ \Omega$$

$$= 1.6\times10^2\ \Omega$$

Level 3

76. Television A typical television dissipates 275 W when it is plugged into a 120-V outlet.

a. Find the resistance of the television.

$P = IV$ and $I = \frac{V}{R}$, so $P = \frac{V^2}{R}$, or

$$R = \frac{V^2}{P} = \frac{(120\ \text{V})^2}{275\ \text{W}} = 52\ \Omega$$

b. The television and 2.5-Ω wires connecting the outlet to the fuse form a series circuit that works like a voltage divider. Find the voltage drop across the television.

$$V_A = \frac{VR_A}{R_A + R_B}$$

$$= \frac{(120\ \text{V})(52\ \Omega)}{52\ \Omega + 2.5\ \Omega}$$

$$= 110\ \text{V}$$

c. A 12-Ω hair dryer is plugged into the same outlet. Find the equivalent resistance of the two appliances.

$$\frac{1}{R} = \frac{1}{R_A} + \frac{1}{R_B}$$

$$R = \frac{1}{\left(\frac{1}{R_A} + \frac{1}{R_B}\right)}$$

$$= \frac{1}{\left(\frac{1}{52\ \Omega} + \frac{1}{12\ \Omega}\right)}$$

$$= 9.8\ \Omega$$

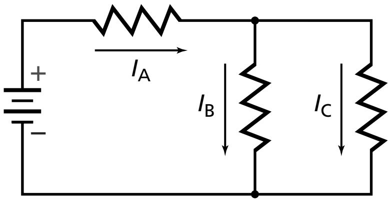
d. Find the voltage drop across the television and the hair dryer.

$$V_1 = \frac{VR_A}{R_A + R_B} = \frac{(120\ \text{V})(9.8\ \Omega)}{9.8\ \Omega + 2.5\ \Omega} = 96\ \text{V}$$

23.2 Applications of Circuits
pages 638–639

Level 1

77. Refer to **Figure 23-19** and assume that all the resistors are 30.0 Ω. Find the equivalent resistance.



■ **Figure 23-19**

The parallel combination of the two 30.0-Ω resistors has an equivalent resistance of 15.0 Ω.

So R = 30.0 Ω + 15.0 Ω = 45.0 Ω

78. Refer to Figure 23-19 and assume that each resistor dissipates 120 mW. Find the total dissipation.

$P = 3(120\ \text{mW}) = 360\ \text{mW}$

79. Refer to Figure 23-19 and assume that I_A = 13 mA and I_B = 1.7 mA. Find I_C.

$$I_C = I_A - I_B$$

$$= 13\ \text{mA} - 1.7\ \text{mA}$$

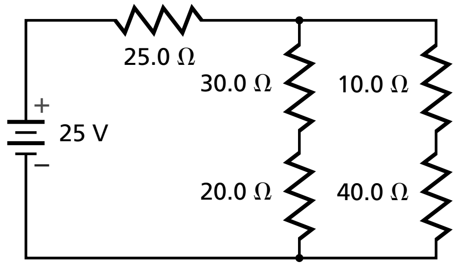
$$= 11\ \text{mA}$$

80. Refer to Figure 23-19 and assume that I_B = 13 mA and I_C = 1.7 mA. Find I_A.

$$I_A = I_B + I_C$$
$$= 13 \text{ mA} + 1.7 \text{ mA}$$
$$= 15 \text{ mA}$$

Level 2

81. Refer to **Figure 23-20** to answer the following questions.



■ **Figure 23-20**

a. Determine the total resistance.

The 30.0-Ω and 20.0-Ω resistors are in series.

$$R_1 = 30.0\ \Omega + 20.0\ \Omega = 50.0\ \Omega$$

The 10.0-Ω and 40.0-Ω resistors are in series.

$$R_2 = 10.0\ \Omega + 40.0\ \Omega = 50.0\ \Omega$$

R_1 and R_2 are in parallel.

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$R = \frac{1}{\left(\frac{1}{R_1} + \frac{1}{R_2}\right)}$$

$$= \frac{1}{\left(\frac{1}{50.0\ \Omega} + \frac{1}{50.0\ \Omega}\right)}$$

= 25.0 Ω and is in series with the 25.0-Ω resistor

$$R_{Total} = 25.0\ \Omega + 25.0\ \Omega = 50.0\ \Omega$$

b. Determine the current through the 25-Ω resistor.

use Ohm's law and R_{Total}

$$I = \frac{V}{R_{Total}} = \frac{25\text{ V}}{50.0\ \Omega} = 0.50\text{ A}$$

c. Which resistor is the hottest? Coolest?

$$P = I^2R = (0.50\text{ A})^2(25.0\ \Omega) = 6.25\text{ W}$$

Half the total current is in each parallel branch because the sum of the resistances in each branch are equal.

$$P = I^2R = (0.25\text{ A})^2(30.0\ \Omega) = 1.9\text{ W}$$

$$P = I^2R = (0.25\text{ A})^2(20.0\ \Omega) = 1.2\text{ W}$$

$$P = I^2R = (0.25\text{ A})^2(10.0\ \Omega) = 0.62\text{ W}$$

$$P = I^2R = (0.25\text{ A})^2(40.0\ \Omega) = 2.5\text{ W}$$

The 25.0-Ω resistor is the hottest.

The 10.0-Ω resistor is the coolest.

82. A circuit contains six 60-W lamps with a resistance of 240-Ω each and a 10.0-Ω heater connected in parallel. The voltage across the circuit is 120 V. Find the current in the circuit for the following situations.

a. Four lamps are turned on.

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$$

$$= \frac{1}{240\ \Omega} + \frac{1}{240\ \Omega} + \frac{1}{240\ \Omega} + \frac{1}{240\ \Omega}$$

$$= \frac{4}{240\ \Omega}$$

$$R = \frac{240\ \Omega}{4} = 0.060\text{ k}\Omega$$

$$I = \frac{V}{R} = \frac{120\text{ V}}{0.060\text{ k}\Omega} = 2.0\text{ A}$$

b. All of the lamps are turned on.

$$\frac{1}{R} = \frac{6}{240\ \Omega}$$

$$R = \frac{240\ \Omega}{6} = 0.040\text{ k}\Omega$$

$$I = \frac{V}{R} = \frac{120\text{ V}}{0.040\text{ k}\Omega} = 3.0\text{ A}$$

c. Six lamps and the heater are operating.

$$\frac{1}{R} = \frac{1}{0.040\text{ k}\Omega} + \frac{1}{10.0\ \Omega}$$

$$= \frac{5}{4.0\times10^1\ \Omega}$$

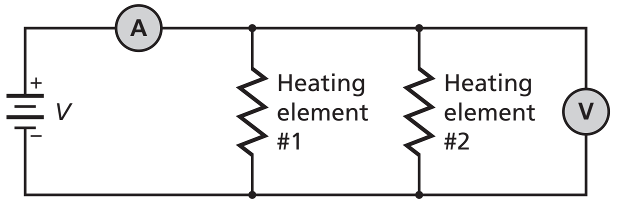
$$R = \frac{4.0\times10^1\ \Omega}{5} = 8.0\ \Omega$$

$$I = \frac{V}{R} = \frac{120\text{ V}}{8.0\ \Omega} = 15\text{ A}$$

83. If the circuit in problem 82 has a 12-A fuse, will the fuse melt if all the lamps and the heater are on?

Yes. The 15-A current will melt the 12-A fuse.

84. During a laboratory exercise, you are supplied with a battery of potential difference *V*, two heating elements of low resistance that can be placed in water, an ammeter of very small resistance, a voltmeter of extremely high resistance, wires of negligible resistance, a beaker that is well insulated and has negligible heat capacity, and 0.10 kg of water at 25°C. By means of a diagram and standard symbols, show how these components should be connected to heat the water as rapidly as possible.



85. If the voltmeter used in problem 84 holds steady at 45 V and the ammeter reading holds steady at 5.0 A, estimate the time in seconds required to completely vaporize the water in the beaker. Use 4.2 kJ/kg·°C as the specific heat of water and 2.3×10^{6} J/kg as the heat of vaporization of water.

$\Delta Q = mC\Delta T$

$= (0.10\text{ kg})(4.2\text{ kJ/kg}\cdot°\text{C})(75°\text{C})$

$= 32$ **kJ (energy needed to raise temperature of water to 100°C)**

$\Delta Q = mH_{v} = (0.10\text{ kg})(2.3\times10^{6}\text{ J/kg})$

$= 2.3\times10^{2}$ **kJ (energy needed to vaporize the water)**

$\Delta Q_{total} = 32\text{ kJ} + 2.3\times10^{2}\text{ kJ}$

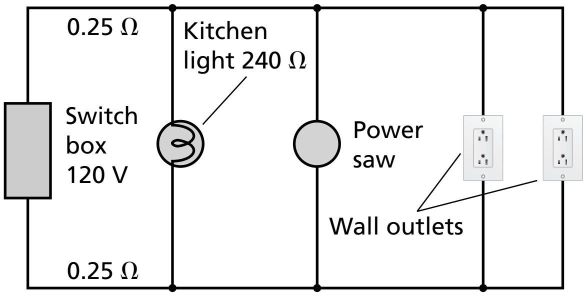
$= 2.6\times10^{2}$ **kJ (total energy needed) Energy is provided at the rate of**

$P = IV = (5.0\text{ A})(45\text{ V}) = 0.23\text{ kJ/s}.$

The time required is

$$t = \frac{2.6\times10^{2}\text{ kJ}}{0.23\text{ kJ/s}} = 1.1\times10^{3}\text{ s}$$

86. Home Circuit A typical home circuit is shown in **Figure 23-21.** The wires to the kitchen lamp each have a resistance of 0.25 Ω. The lamp has a resistance of 0.24 kΩ. Although the circuit is parallel, the lead lines are in series with each of the components of the circuit.



■ **Figure 23-21**

a. Compute the equivalent resistance of the circuit consisting of just the lamp and the lead lines to and from the lamp.

$R = 0.25\ \Omega + 0.25\ \Omega + 0.24\ \text{k}\Omega$

$= 0.24\ \text{k}\Omega$

b. Find the current to the lamp.

$$I = \frac{V}{R} = \frac{120\text{ V}}{0.24\text{ k}\Omega} = 0.50\text{ A}$$

c. Find the power dissipated in the lamp.

$P = IV = (0.50\text{ A})(120\text{ V}) = 6.0\times10^{1}\text{ W}$

Mixed Review

page 639

Level 1

87. A series circuit has two voltage drops: 3.50 V and 4.90 V. What is the supply voltage?

$V = 3.50\text{ V} + 4.90\text{ V} = 8.40\text{ V}$

88. A parallel circuit has two branch currents: 1.45 A and 1.00 A. What is the current in the energy source?

$I = 1.45\text{ A} + 1.00\text{ A} = 2.45\text{ A}$

89. A series-parallel circuit has three resistors, dissipating 5.50 W, 6.90 W, and 1.05 W, respectively. What is the supply power?

$P = 5.50\text{ W} + 6.90\text{ W} + 1.05\text{ W} = 13.45\text{ W}$

Level 2

90. Determine the maximum safe power in each of three 150-Ω, 5-W resistors connected in series.

All will dissipate the same power.

$P = (3)(5\text{ W}) = 15\text{ W}$

91. Determine the maximum safe power in each of three 92-Ω, 5-W resistors connected in parallel.

Each resistor will develop the same power.

$P = (3)(5\text{ W}) = 15\text{ W}$

92. A voltage divider consists of two 47-kΩ resistors connected across a 12-V battery. Determine the measured output for the following.

a. an ideal voltmeter

$$V_B = \frac{VR_B}{R_A + R_B}$$

$$= \frac{(12\text{ V})(47\text{ k}\Omega)}{47\text{ k}\Omega + 47\text{ k}\Omega}$$

$$= 6.0\text{ V}$$

b. a voltmeter with a resistance of 85 kΩ

The voltmeter resistance acts in parallel:

$$\frac{1}{R_B} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$= \frac{1}{47\text{ k}\Omega} + \frac{1}{85\text{ k}\Omega}$$

$$= \frac{1}{3.3\times10^{-5}\ \Omega}$$

$$R_B = 3.0\times10^{1}\text{ k}\Omega$$

$$V_B = \frac{VR_B}{R_A + R_B}$$

$$= \frac{(12\text{ V})(3.0\times10^{1}\text{ k}\Omega)}{47\text{ k}\Omega + 3.0\times10^{1}\text{ k}\Omega}$$

$$= 4.7\text{ V}$$

c. a voltmeter with a resistance of $10\times10^{6}\ \Omega$

The voltmeter resistance acts in parallel:

$$\frac{1}{R_B} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$= \frac{1}{47\times10^{3}\ \Omega} + \frac{1}{10\times10^{6}\ \Omega}$$

$$= \frac{1}{2.1\times10^{-5}\ \Omega}$$

$$R_B = 47\text{ k}\Omega$$

$$V_B = \frac{VR_B}{R_A + R_B}$$

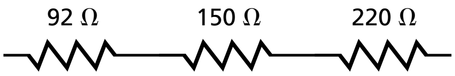
$$= \frac{(12\text{ V})(47\text{ k}\Omega)}{47\text{ k}\Omega + 47\text{ k}\Omega}$$

$$= 6.0\text{ V}$$

The meter approaches the ideal voltmeter.

Level 3

93. Determine the maximum safe voltage that can be applied across the three series resistors in **Figure 23-22** if all three are rated at 5.0 W.



■ **Figure 23-22**

Current is constant in a series circuit, so the largest resistor will develop the most power.

$$P = I^2R$$

$$I = \sqrt{\frac{P}{R}} = \sqrt{\frac{5.0\text{ W}}{220\ \Omega}} = 0.151\text{ A}$$

The total resistance is now needed.

$$R_{Total} = 92\ \Omega + 150\ \Omega + 220\ \Omega$$

$$= 462\ \Omega$$

Use Ohm's law to find the voltage.

$$V = IR$$

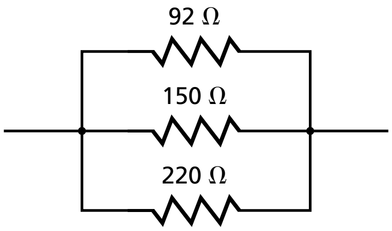
$$= (0.151\text{ A})(462\ \Omega)$$

$$= 7.0\times10^{1}\text{ V}$$

94. Determine the maximum safe total power for the circuit in problem 93.

$$P = V^2/R = \frac{(7.0\times10^{1}\text{ V})^2}{462\ \Omega} = 11\text{ W}$$

95. Determine the maximum safe voltage that can be applied across three parallel resistors of 92 Ω, 150 Ω, and 220 Ω, as shown in **Figure 23-23,** if all three are rated at 5.0 W.



■ **Figure 23-23**

The 92-Ω resistor will develop the most power because it will conduct the most current.

$$P = \frac{V^2}{R}$$

$$V = \sqrt{PR} = \sqrt{(5.0\ \text{W})(92\ \Omega)} = 21\ \text{V}$$

Thinking Critically

pages 639–640

96. Apply Mathematics Derive equations for the resistance of two equal-value resistors in parallel, three equal-value resistors in parallel, and *N* equal-value resistors in parallel.

$$\frac{1}{R_{eq2}} = \frac{1}{R} + \frac{1}{R} = \frac{2}{R}$$

$$R_{eq2} = \frac{R}{2}$$

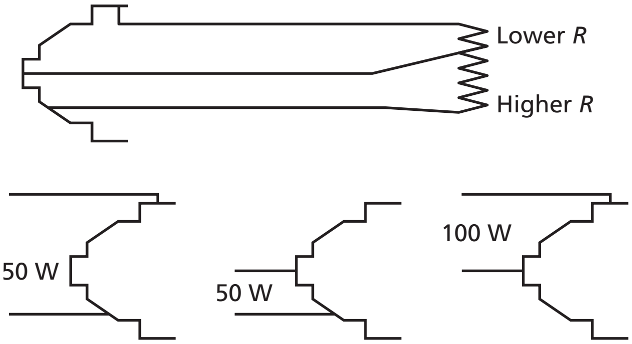
$$\frac{1}{R_{eq3}} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} = \frac{3}{R}$$

$$R_{eq3} = \frac{R}{3}$$

$$R_{eqN} = \frac{R}{N}$$

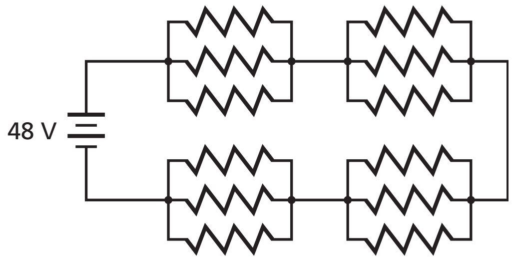
97. Apply Concepts Three-way lamps, of the type in **Figure 23-24,** having a rating of 50 W, 100 W, and 150 W, are common. Draw four partial schematic diagrams that show the lamp filaments and the switch positions for each brightness level, as well as the off position. (You do not need to show the energy source.) Label each diagram.

■ **Figure 23-24**

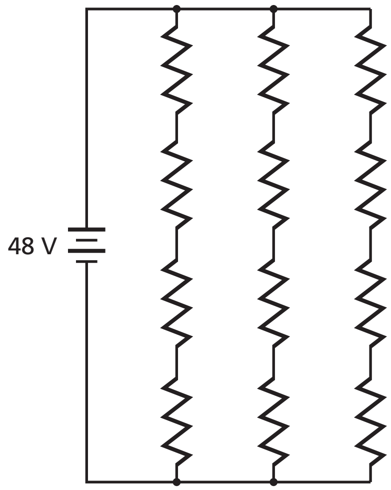


98. Apply Concepts Design a circuit that will light one dozen 12-V bulbs, all to the correct (same) intensity, from a 48-V battery.

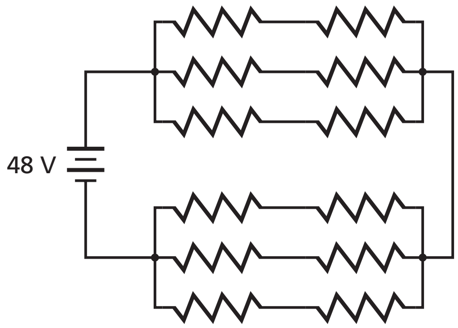
a. Design A requires that should one bulb burn out, all other bulbs continue to produce light.



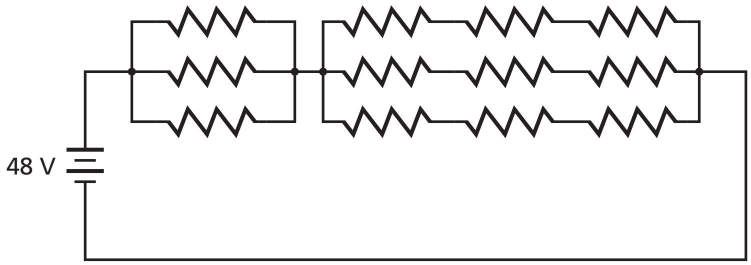
b. Design B requires that should one bulb burn out, those bulbs that continue working must produce the correct intensity.



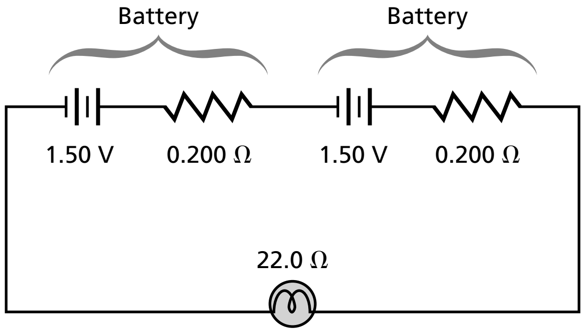
c. Design C requires that should one bulb burn out, one other bulb also will go out.



d. Design D requires that should one bulb burn out, either two others will go out or no others will go out.



99. **Apply Concepts** A battery consists of an ideal source of potential difference in series with a small resistance. The electric energy of the battery is produced by chemical reactions that occur in the battery. However, these reactions also result in a small resistance that, unfortunately, cannot be completely eliminated. A flashlight contains two batteries in series, as shown in **Figure 23-25.** Each has a potential difference of 1.50 V and an internal resistance of 0.200 Ω. The bulb has a resistance of 22.0 Ω.



■ **Figure 23-25**

a. What is the current through the bulb?

The circuit has two 1.50-V batteries in series with three resistors: 0.200 Ω, 0.200 Ω, and 22.0 Ω. The equivalent resistance is 22.4 Ω. The current is

$$I = \frac{V}{R}$$

$$= \frac{2(1.50)\text{ V}}{(2(0.200\ \Omega) + 22.0\ \Omega)}$$

$$= 0.134\text{ A}$$

b. How much power does the bulb dissipate?

The power dissipated is

$$P = I^2R$$

$$= (0.134\text{ A})^2(22.0\ \Omega)$$

$$= 0.395\text{ W}$$

c. How much greater would the power be if the batteries had no internal resistance?

$$P = IV = \frac{V^2}{R} = \frac{(3.00\text{ V})^2}{22.0\ \Omega} = 0.409\text{ W}$$

$$\Delta P = 0.409\text{ W} - 0.395\text{ W} = 0.014\text{ W}$$

Power would be 0.014 W greater.

100. Apply Concepts An ohmmeter is made by connecting a 6.0-V battery in series with an adjustable resistor and an ideal ammeter. The ammeter deflects full-scale with a current of 1.0 mA. The two leads are touched together and the resistance is adjusted so that 1.0 mA flows.

a. What is the resistance of the adjustable resistor?

$$V = IR$$

$$R = \frac{V}{I} = \frac{6.0\text{ V}}{1.0\times10^{-3}\text{ A}} = 6.0\text{ k}\Omega$$

b. The leads are now connected to an unknown resistance. What resistance would produce a current of half-scale, 0.50 mA? Quarter-scale, 0.25 mA? Three-quarters-scale, 0.75 mA?

$$R = \frac{V}{I} = \frac{6.0\text{ V}}{0.50\times10^{-3}\text{ A}} = 12\text{ k}\Omega$$

and $R_T = R_1 + R_e$, **so**

$$R_e = R_T - R_1$$

$$= 12\text{ k}\Omega - 6.0\text{ k}\Omega$$

$$= 6.0\text{ k}\Omega$$

$$R = \frac{V}{I} = \frac{6.0\text{ V}}{0.25\times10^{-3}\text{ A}} = 24\text{ k}\Omega$$

and $R_e = R_T - R_1$

$$= 24\text{ k}\Omega - 6.0\text{ k}\Omega$$

$$= 18\text{ k}\Omega$$

$$R = \frac{V}{I} = \frac{6.0\text{ V}}{0.75\times10^{-3}\text{ A}} = 8.0\text{ k}\Omega$$

and $R_e = R_T - R_1$

$$= 8.0\text{ k}\Omega - 6.0\text{ k}\Omega$$

$$= 2.0\text{ k}\Omega$$

c. Is the ohmmeter scale linear? Explain.

No. Zero ohms is at full-scale, 6 kΩ is at midscale, and infinite Ω (or open-circuit) is at zero-scale.

Writing in Physics

page 640

101. Research Gustav Kirchhoff and his laws. Write a one-page summary of how they apply to the three types of circuits presented in this chapter.

Key ideas are:

(1) Kirchhoff's Voltage Law (KVL) is conservation of energy applied to electric circuits.

(2) Kirchhoff's Current Law (KCL) is conservation of charge applied to electric circuits.

(3) KVL states that the algebraic sum of voltage drops around a closed loop is zero. In a series circuit there is one closed loop, and the sum of voltage drops in the resistances equals the source voltage. In a

parallel circuit, there is a closed loop for each branch, and KVL implies that the voltage drop in each branch is the same.

(4) KCL states that the algebraic sum of currents at a node is zero. In a series circuit, at every point the current in equals current out; therefore, the current is the same everywhere. In a parallel circuit, there is a common node at each end of the branches. KCL implies that the sum of the branch currents equals the source current.

Cumulative Review

page 640

102. Airplane An airplane flying through still air produces sound waves. The wave fronts in front of the plane are spaced 0.50 m apart and those behind the plane are spaced 1.50 m apart. The speed of sound is 340 m/s. (Chapter 15)

a. What would be the wavelength of the sound waves if the airplane were not moving?

1.00 m

b. What is the frequency of the sound waves produced by the airplane?

$f = v/\lambda = (340\text{ m/s})/(1.00\text{ m}) = 340\text{ Hz}$

c. What is the speed of the airplane?

The airplane moves forward 0.50 m for every 1.00 m that the sound waves move, so its speed is one-half the speed of sound, 170 m/s.

d. What is the frequency detected by an observer located directly in front of the airplane?

$$f = v/\lambda$$
$$= (340\text{ m/s})/(0.50\text{ m})$$
$$= 680\text{ Hz, or}$$
$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right)$$
$$= (340\text{ Hz})\left(\frac{340\text{ m/s} - 0}{340\text{ m/s} - 170\text{ m/s}}\right)$$
$$= 680\text{ Hz}$$

e. What is the frequency detected by an observer located directly behind the airplane?

$$f = v/\lambda$$
$$= (340\text{ m/s})/(1.50\text{ m})$$
$$= 230\text{ Hz, or}$$
$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right)$$
$$= (340\text{ Hz})\left(\frac{340\text{ m/s} - 0}{340\text{ m/s} - (-170\text{ m/s})}\right)$$
$$= 230\text{ Hz}$$

103. An object is located 12.6 cm from a convex mirror with a focal length of −18.0 cm. What is the location of the object's image? (Chapter 17)

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$
$$d_i = \frac{d_o f}{d_o - f}$$
$$= \frac{(12.6\text{ cm})(-18.0\text{ cm})}{12.6\text{ cm} - (-18.0\text{ cm})}$$
$$= -7.41\text{ cm}$$

104. The speed of light in a special piece of glass is 1.75×10^8 m/s. What is its index of refraction? (Chapter 18)

$$n = \frac{c}{v}$$
$$= \frac{3.00\times10^8\text{ m/s}}{1.75\times10^8\text{ m/s}}$$
$$= 1.71$$

105. Monocle An antireflective coating with an index of refraction of 1.4 is applied to a monocle with an index of refraction of 1.52. If the thickness of the coating is 75 nm, what is/are the wavelength(s) of light for which complete destructive interference will occur? (Chapter 19)

Because $n_{film} > n_{air}$, there is a phase inversion on the first reflection. Because $n_{monocle} > n_{film}$, there is a phase inversion on the second reflection.

For destructive interference:

$$2t = \left(m + \frac{1}{2}\right)\frac{\lambda}{n_{film}}$$

$$\lambda = \frac{2tn_{\text{film}}}{m + \frac{1}{2}}$$

$$= \frac{(2)(75\ \text{nm})(1.4)}{m + \frac{1}{2}}$$

$$= \left(m + \frac{1}{2}\right)^{-1}(2.1\times10^{2}\ \text{nm})$$

For $m = 0$

$$= \left(\frac{1}{2}\right)^{-1}(2.1\times10^{2}\ \text{nm})$$

$$= 4.2\times10^{2}\ \text{nm}$$

For $m = 1$

$$= \left(\frac{3}{2}\right)^{-1}(2.1\times10^{2}\ \text{nm})$$

$$= 2.8\times10^{2}\ \text{nm}$$

This is an ultraviolet wavelength, so it is not light. All other values of *m* give wavelengths that are shorter than the light. So $\lambda = 4.2\times10^{2}$ nm is the only wavelength of light for which destructive interference occurs.

106. Two charges of 2.0×10^{-5} C and 8.0×10^{-6} C experience a force between them of 9.0 N. How far apart are the two charges? (Chapter 20)

$$F = K\frac{q_Aq_B}{d^2}\text{, so } d = \sqrt{\frac{Kq_Aq_B}{F}}$$

$$= \sqrt{\frac{(9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)(2.0\times10^{-5}\ \text{C})(8.0\times10^{-6}\ \text{C})}{9.0\ \text{N}}} = 0.40\ \text{m}$$

107. A field strength, *E*, is measured a distance, *d*, from a point charge, *Q*. What would happen to the magnitude of *E* in the following situations? (Chapter 21)

$$E = \frac{KQ}{d^2}$$

a. *d* is tripled

$$\frac{E}{9}$$

b. *Q* is tripled

3*E*

c. both *d* and *Q* are tripled

$$\frac{E}{3}$$

d. the test charge *q′* is tripled

***E*; by definition, field strength is force per unit test charge.**

e. all three, *d*, *Q*, and *q′*, are tripled

$$\frac{E}{3}$$

108. The current flow in a 12-V circuit drops from 0.55 A to 0.44 A. Calculate the change in resistance. (Chapter 22)

$R_1 = V/I = 12\ \text{V}/0.55\ \text{A} = 21.8\ \Omega$

$R_2 = V/I = 12\ \text{V}/0.44\ \text{A} = 27.3\ \Omega$

$\Delta R = R_2 - R_1$

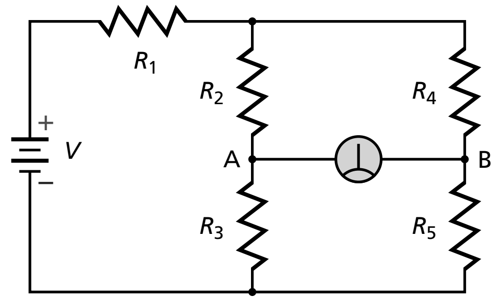
$$= \frac{12\ \text{V}}{0.44\ \text{A}} - \frac{12\ \text{V}}{0.55\ \text{A}}$$

$$= 5.5\ \Omega$$

Challenge Problem

page 628

When the galvanometer, a device used to measure very small currents or voltages, in this circuit measures zero, the circuit is said to be balanced.



1. Your lab partner states that the only way to balance this circuit is to make all the resistors equal. Will this balance the circuit? Is there more than one way to balance this circuit? Explain.

Yes; yes. You also can balance the circuit by adjusting the resistance values so that $R_7/R_3 = R_4/R_5$ remains equal.

2. Derive a general equation for a balanced circuit using the given labels. *Hint: Treat the circuit as a voltage divider.*

One definition of balance is that $V_{AB} = 0$. If this is so, then $V_{R3} = V_{R5}$. These voltage drops can be defined using Ohm's law:

$V_{R3} = I_1R_3$ and $V_{R5} = I_2R_5$

also, $$I_1 = \frac{V - (I_1 + I_2)R_1}{R_2 + R_3}$$

and $$I_2 = \frac{V - (I_1 + I_2)R_1}{R_4 + R_5}$$

substitute $$V_{R3} = \frac{R_3V - (I_1 + I_2)R_1R_3}{R_2 + R_3}$$

and $$V_{R5} = \frac{R_5V - (I_1 + I_2)R_1R_5}{R_4 + R_5}$$

$V_{R3} = V_{R5}$. Removing R_3 from the left numerator and R_5 from the right numerator gives the following:

$$\frac{V - (I_1 + I_2)R_1}{\left(\frac{R_2}{R_3} + 1\right)} = \frac{V - (I_1 + I_2)R_1}{\left(\frac{R_4}{R_5} + 1\right)}$$

$$\frac{1}{\left(\frac{R_2}{R_3} + 1\right)} = \frac{1}{\left(\frac{R_4}{R_5} + 1\right)}$$

$$\frac{R_3}{R_2} = \frac{R_5}{R_4}$$

3. Which of the resistors can be replaced with a variable resistor and then used to balance the circuit?

any resistor but R_1

4. Which of the resistors can be replaced with a variable resistor and then used as a sensitivity control? Why would this be necessary? How would it be used in practice?

R_1. A galvanometer is a sensitive instrument and can be damaged by too much current flow. If R_1 is adjustable, it is set for a high value before the circuit is energized. This limits the current flow through the galvanometer if the circuit happens to be way out of balance. As the balancing resistor is adjusted and as the meter reading approaches zero, the sensitivity then is increased by decreasing R_1.

CHAPTER

24 Magnetic Fields

Practice Problems

24.1 Magnets: Permanent and Temporary pages 643–651

page 647

1. If you hold a bar magnet in each hand and bring your hands close together, will the force be attractive or repulsive if the magnets are held in the following ways?

a. the two north poles are brought close together

repulsive

b. a north pole and a south pole are brought together

attractive

2. **Figure 24-7** shows five disk magnets floating above each other. The north pole of the top-most disk faces up. Which poles are on the top side of each of the other magnets?

■ **Figure 24-7**

south, north, south, north

3. A magnet attracts a nail, which, in turn, attracts many small tacks, as shown in Figure 24-3 on page 645. If the north pole of the permanent magnet is the left end, as shown, which end of the nail is the south pole?

the bottom (the point)

4. Why do magnetic compasses sometimes give false readings?

because Earth's magnetic field is distorted by objects made of iron, nickel, or cobalt in the vicinity of the compass, and by ore deposits of these same metals

page 650

5. A long, straight, current-carrying wire runs from north to south.

a. A compass needle placed above the wire points with its north pole toward the east. In what direction is the current flowing?

from south to north

b. If a compass is put underneath the wire, in which direction will the compass needle point?

west

6. How does the strength of a magnetic field, 1 cm from a current-carrying wire, compare with each of the following?

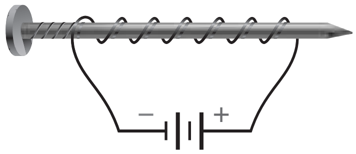
a. the strength of the field that is 2 cm from the wire

Because magnetic field strength varies inversely with the distance from the wire, the magnetic field at 1 cm will be twice as strong as the magnetic field at 2 cm.

b. the strength of the field that is 3 cm from the wire

Because magnetic field strength varies inversely with the distance from the wire, the magnetic field at 1 cm will be three times as strong as the magnetic field at 3 cm.

7. A student makes a magnet by winding wire around a nail and connecting it to a battery, as shown in **Figure 24-13.** Which end of the nail, the pointed end or the head, will be the north pole?



■ **Figure 24-13**

the pointed end

8. You have a spool of wire, a glass rod, an iron rod, and an aluminum rod. Which rod should you use to make an electromagnet to pick up steel objects? Explain.

Use the iron rod. Iron would be attracted to a permanent magnet and take on properties of a magnet, whereas aluminum or glass would not. This effect would support the magnetic field in the wire coil and thus make the strongest electromagnet.

9. The electromagnet in problem 8 works well, but you decide that you would like to make its strength adjustable by using a potentiometer as a variable resistor. Is this possible? Explain.

Yes. Connect the potentiometer in series with the power supply and the coil. Adjusting the potentiometer for more resistance will decrease the current flow and the strength of the field.

Section Review

24.1 Magnets: Permanent and Temporary pages 643–651

page 651

10. Magnetic Fields Is a magnetic field real, or is it just a means of scientific modeling?

Field lines are not real. The field is real.

11. Magnetic Forces Identify some magnetic forces around you. How could you demonstrate the effects of those forces?

Student answers may vary. Answers could include magnets on a refrigerator and Earth's magnetic field. The effects of these forces can be demonstrated by bringing another magnet, or a material that can be magnetized, nearby.

12. Magnetic Fields A current-carrying wire is passed through a card on which iron filings are sprinkled. The filings show the magnetic field around the wire. A second wire is close to and parallel to the first wire. There is an identical current in the second wire. If the two currents are in the same direction, how will the first magnetic field be affected? How will it be affected if the two currents are in opposite directions?

It would be approximately twice as large; it would be approximately zero.

13. Direction of a Magnetic Field Describe the right-hand rule used to determine the direction of a magnetic field around a straight, current-carrying wire.

If you grasp the wire with your right hand, with your thumb pointing in the direction of the conventional current, your fingers curl in the direction of the field.

14. Electromagnets A glass sheet is placed over an active electromagnet, and iron filings sprinkled on the sheet create a pattern on it. If this experiment is repeated with the polarity of the power supply reversed, what observable differences will result? Explain.

None. The filings would show the same field pattern but a compass would show the magnetic polarity reversal.

15. Critical Thinking Imagine a toy containing two parallel, horizontal metal rods, one above the other. The top rod is free to move up and down.

a. The top rod floats above the lower one. If the top rod's direction is reversed, however, it falls down onto the lower rod. Explain why the rods could behave in this way.

The metal rods could be magnets with their axes parallel. If the top

magnet is positioned so that its north and south poles are above the north and south poles of the bottom magnet, it will be repelled and float above. If the top magnet is turned end for end, it will be attracted to the bottom magnet.

b. Assume that the top rod was lost and replaced with another one. In this case, the top rod falls on top of the bottom rod no matter what its orientation is. What type of replacement rod must have been used?

If an ordinary iron bar is used on top, it will be attracted to the bottom magnet in any orientation.

Practice Problems

24.2 Forces Caused by Magnetic Fields pages 652–659

page 654

16. What is the name of the rule used to predict the direction of force on a current-carrying wire at right angles to a magnetic field? Identify what must be known to use this rule.

Third right-hand rule. The direction of the current and the direction of the field must be known.

17. A wire that is 0.50 m long and carrying a current of 8.0 A is at right angles to a 0.40-T magnetic field. How strong is the force that acts on the wire?

$F = BIL = (0.40 \text{ N/A·m})(8.0 \text{ A})(0.50 \text{ m})$

$= 1.6 \text{ N}$

18. A wire that is 75 cm long, carrying a current of 6.0 A, is at right angles to a uniform magnetic field. The magnitude of the force acting on the wire is 0.60 N. What is the strength of the magnetic field?

$F = BIL$

$$B = \frac{F}{IL} = \frac{0.60 \text{ N}}{(6.0 \text{ A})(0.75 \text{ m})} = 0.13 \text{ T}$$

19. A 40.0-cm-long copper wire carries a current of 6.0 A and weighs 0.35 N. A certain magnetic field is strong enough to balance the force of gravity on the wire. What is the strength of the magnetic field?

$F = BIL$, where F = weight of the wire

$$B = \frac{F}{IL} = \frac{0.35 \text{ N}}{(6.0 \text{ A})(0.400 \text{ m})} = 0.15 \text{ T}$$

20. How much current will be required to produce a force of 0.38 N on a 10.0 cm length of wire at right angles to a 0.49-T field?

$F = BIL$

$$I = \frac{F}{BL} = \frac{0.38 \text{ N}}{(0.49 \text{ T})(0.100 \text{ m})} = 7.8 \text{ A}$$

page 658

21. In what direction does the thumb point when using the third right-hand rule for an electron moving at right angles to a magnetic field?

opposite to the direction of the electron motion

22. An electron passes through a magnetic field at right angles to the field at a velocity of 4.0×10^6 m/s. The strength of the magnetic field is 0.50 T. What is the magnitude of the force acting on the electron?

$F = Bqv$

$= (0.50 \text{ T})(1.60\times10^{-19} \text{ C})(4.0\times10^6 \text{ m/s})$

$= 3.2\times10^{-13} \text{ N}$

23. A stream of doubly ionized particles (missing two electrons, and thus, carrying a net charge of two elementary charges) moves at a velocity of 3.0×10^4 m/s perpendicular to a magnetic field of 9.0×10^{-2} T. What is the magnitude of the force acting on each ion?

$F = Bqv$

$= (9.0\times10^{-2} \text{ T})(2)(1.60\times10^{-19} \text{ C})(3.0\times10^4 \text{ m/s})$

$= 8.6\times10^{-16} \text{ N}$

24. Triply ionized particles in a beam carry a net positive charge of three elementary charge units. The beam enters a magnetic field of 4.0×10^{-2} T. The particles have a speed of 9.0×10^6 m/s. What is the magnitude of the force acting on each particle?

$F = Bqv$

$= (4.0\times10^{-2}\ \text{T})(3)(1.60\times10^{-19}\ \text{C})(9.0\times10^{6}\ \text{m/s})$

$= 1.7\times10^{-13}\ \text{N}$

25. Doubly ionized helium atoms (alpha particles) are traveling at right angles to a magnetic field at a speed of 4.0×10^{4} m/s. The field strength is 5.0×10^{-2} T. What force acts on each particle?

$F = Bqv$

$= (5.0\times10^{-2}\ \text{T})(2)(1.60\times10^{-19}\ \text{C})(4.0\times10^{4}\ \text{m/s})$

$= 6.4\times10^{-16}\ \text{N}$

Section Review

24.2 Forces Caused by Magnetic Fields pages 652–659

page 659

26. Magnetic Forces Imagine that a current-carrying wire is perpendicular to Earth's magnetic field and runs east-west. If the current is east, in which direction is the force on the wire?

up, away from the surface of Earth

27. Deflection A beam of electrons in a cathode-ray tube approaches the deflecting magnets. The north pole is at the top of the tube; the south pole is on the bottom. If you are looking at the tube from the direction of the phosphor screen, in which direction are the electrons deflected?

to the left side of the screen

28. Galvanometers Compare the diagram of a galvanometer in Figure 24-18 on page 655 with the electric motor in Figure 24-20 on page 656. How is the galvanometer similar to an electric motor? How are they different?

Both the galvanometer and the electric motor use a loop of wire positioned between the poles of a permanent magnet. When a current passes through the loop, the magnetic field of the permanent magnet exerts a force on the loop. The loop in a galvanometer cannot rotate more than 180°. The loop in an electric motor rotates through many 360° turns. The motor's split-ring commutator allows the current in the loop to reverse as the loop becomes vertical in the magnetic field, enabling the loop to spin in the magnetic field. The galvanometer measures unknown currents; the electric motor has many uses.

29. Motors When the plane of the coil in a motor is perpendicular to the magnetic field, the forces do not exert a torque on the coil. Does this mean that the coil does not rotate? Explain.

Not necessarily; if the coil is already in rotation, then rotational inertia will carry it past the point of zero torque. It is the coil's acceleration that is zero, not the velocity.

30. Resistance A galvanometer requires 180 μA for full-scale deflection. What is the total resistance of the meter and the multiplier resistor for a 5.0-V full-scale deflection?

$$R = \frac{V}{I} = \frac{50\ \text{V}}{180\ \mu\text{A}} = 28\ \text{k}\Omega$$

31. Critical Thinking How do you know that the forces on parallel current-carrying wires are a result of magnetic attraction between wires, and not a result of electrostatics? *Hint: Consider what the charges are like when the force is attractive. Then consider what the forces are when three wires carry currents in the same direction.*

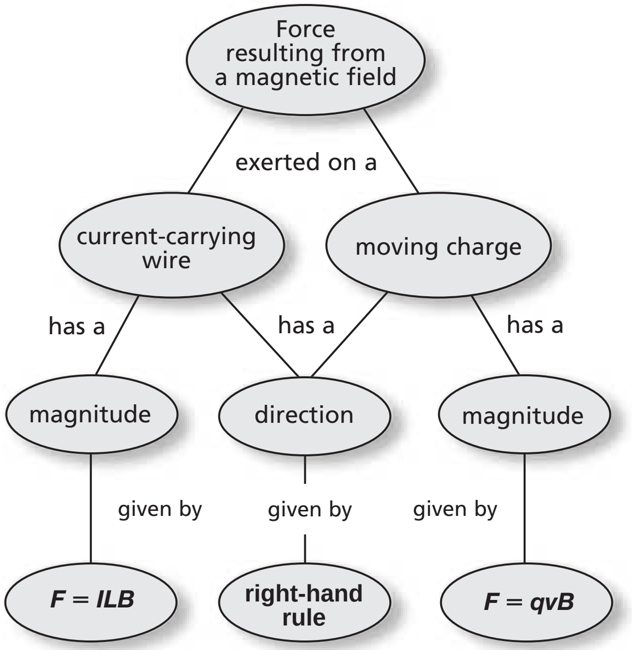
If the currents are in the same direction, the force is attractive. If it were due to electrostatic forces, the like charges would make the force repulsive. Three wires would all attract each other, which could never happen if the forces were due to electrostatic charges.

Chapter Assessment

Concept Mapping

page 664

32. Complete the following concept map using the following: *right-hand rule*, $F = qvB$, and $F = ILB$.



Mastering Concepts

page 664

33. State the rule for magnetic attraction and repulsion. (24.1)

Like poles repel one another; opposite poles attract.

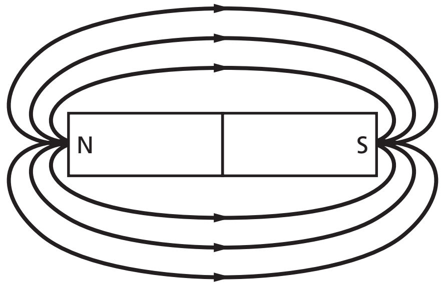
34. Describe how a temporary magnet differs from a permanent magnet. (24.1)

A temporary magnet is like a magnet only while under the influence of another magnet. A permanent magnet needs no outside influence.

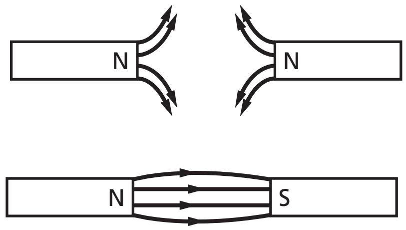
35. Name the three most important common magnetic elements. (24.1)

iron, cobalt, and nickel

36. Draw a small bar magnet and show the magnetic field lines as they appear around the magnet. Use arrows to show the direction of the field lines. (24.1)



37. Draw the magnetic field between two like magnetic poles and then between two unlike magnetic poles. Show the directions of the fields. (24.1)



38. If you broke a magnet in two, would you have isolated north and south poles? Explain. (24.1)

No, new poles would form on each of the broken ends.

39. Describe how to use the first right-hand rule to determine the direction of a magnetic field around a straight current-carrying wire. (24.1)

Grasp the wire with the right hand, keeping thumb pointing in the direction of the conventional current through the wire. Fingers will encircle the wire and point in the direction of the field.

40. If a current-carrying wire is bent into a loop, why is the magnetic field inside the loop stronger than the magnetic field outside? (24.1)

The magnetic field lines are concentrated inside the loop.

41. Describe how to use the second right-hand rule to determine the polarity of an electromagnet. (24.1)

Grasp the coil with the right hand, keeping the fingers encircling the coil in the direction of the conventional current flow through the loops. The thumb of the right hand will point toward the north pole of the electromagnet.

42. Each electron in a piece of iron is like a tiny magnet. The iron, however, may not be a magnet. Explain. (24.1)

The electrons are not all oriented and moving in the same direction; their magnetic fields have random directions.

43. Why will dropping or heating a magnet weaken it? (24.1)

The domains are jostled out of alignment.

44. Describe how to use the third right-hand rule to determine the direction of force on a current-carrying wire placed in a magnetic field. (24.2)

Point the fingers of your right hand in the direction of the magnetic field. Point your thumb in the direction of the conventional current in the wire. The palm of your hand then faces in the direction of the force on the wire.

45. A strong current suddenly is switched on in a wire. No force acts on the wire, however. Can you conclude that there is no magnetic field at the location of the wire? Explain. (24.2)

No, if a field is parallel to the wire, no force would result.

46. What kind of meter is created when a shunt is added to a galvanometer? (24.2)

an ammeter

Applying Concepts

pages 664–665

47. A small bar magnet is hidden in a fixed position inside a tennis ball. Describe an experiment that you could do to find the location of the north pole and the south pole of the magnet.

Use a compass. The north pole of the compass needle is attracted to the south pole of the magnet and vice versa.

48. A piece of metal is attracted to one pole of a large magnet. Describe how you could tell whether the metal is a temporary magnet or a permanent magnet.

Move it to the other pole. If the same end is attracted, it is a temporary magnet; if the same end is repelled and the other end is attracted, it is a permanent magnet.

49. Is the magnetic force that Earth exerts on a compass needle less than, equal to, or greater than the force that the compass needle exerts on Earth? Explain.

The forces are equal according to Newton's third law.

50. **Compass** Suppose you are lost in the woods but have a compass with you. Unfortunately, the red paint marking the north pole of the compass needle has worn off. You have a flashlight with a battery and a length of wire. How could you identify the north pole of the compass?

Connect the wire to the battery so that the current is away from you in one section. Hold the compass directly above and close to that section of the wire. By the right-hand rule, the end of the compass needle that points right is the north pole.

51. A magnet can attract a piece of iron that is not a permanent magnet. A charged rubber rod can attract an uncharged insulator. Describe the different microscopic processes producing these similar phenomena.

The magnet causes the domains in the iron to point in the same direction. The charged rod separates the positive and negative charges in the insulator.

52. A current-carrying wire runs across a laboratory bench. Describe at least two ways in which you could find the direction of the current.

Use a compass to find the direction of the magnetic field. Bring up a strong magnet and find the direction of the force on the wire, then use the right-hand rule.

53. In which direction, in relation to a magnetic field, would you run a current-carrying wire so that the force on it, resulting from the field, is minimized, or even made to be zero?

Run the wire parallel to the magnetic field.

54. Two wires carry equal currents and run parallel to each other.

a. If the two currents are in opposite directions, where will the magnetic field from the two wires be larger than the field from either wire alone?

The magnetic field will be larger anywhere between the two wires.

b. Where will the magnetic field from both be exactly twice as large as from one wire?

The magnetic field will be twice as large along a line directly between the wires that is equal in distance from each wire.

c. If the two currents are in the same direction, where will the magnetic field be exactly zero?

The magnetic field will be zero along a line directly between the wires that is equal in distance from each wire.

55. How is the range of a voltmeter changed when the resistor's resistance is increased?

The range of the voltmeter increases.

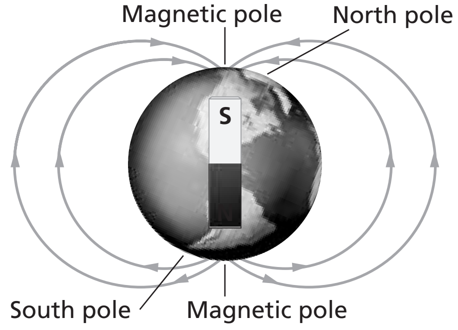
56. A magnetic field can exert a force on a charged particle. Can the field change the particle's kinetic energy? Explain.

No, the force is always perpendicular to the velocity. No work is done. The energy is not changed.

57. A beam of protons is moving from the back to the front of a room. It is deflected upward by a magnetic field. What is the direction of the field causing the deflection?

Facing the front of the room, the velocity is forward, the force is upward, and therefore, using the third right-hand rule, B is to the left.

58. Earth's magnetic field lines are shown in **Figure 24-23.** At what location, poles or equator, is the magnetic field strength greatest? Explain.



■ **Figure 24-23**

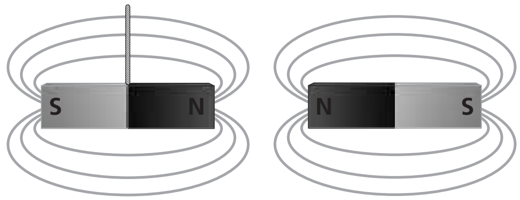
Earth's magnetic field strength is greatest at the poles. The field lines are closer together at the poles.

Mastering Problems

24.1 Magnets: Permanent and Temporary pages 665–666

Level 1

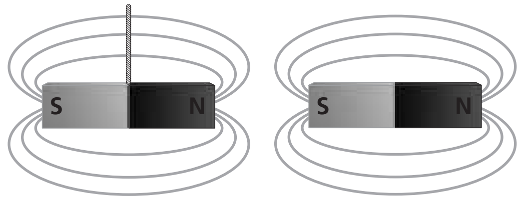
59. As the magnet below in **Figure 24-24** moves toward the suspended magnet, what will the magnet suspended by the string do?



■ **Figure 24-24**

Move to the left or begin to turn. Like poles repel.

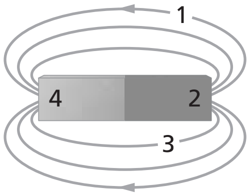
60. As the magnet in **Figure 24-25** moves toward the suspended magnet, what will the magnet that is suspended by the string do?



■ **Figure 24-25**

Move to the right. Unlike poles attract.

61. Refer to **Figure 24-26** to answer the following questions.



■ **Figure 24-26**

a. Where are the poles?

4 and 2, by definition

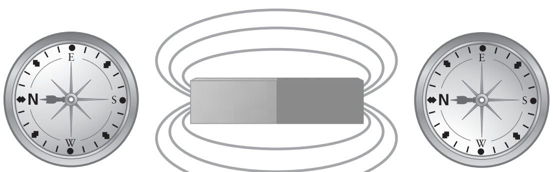
b. Where is the north pole?

2, by definition and field direction

c. Where is the south pole?

4, by definition and field direction

62. **Figure 24-27** shows the response of a compass in two different positions near a magnet. Where is the south pole of the magnet located?



■ **Figure 24-27**

At the right end, unlike poles attract.

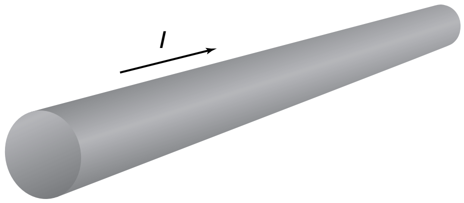
63. A wire that is 1.50 m long and carrying a current of 10.0 A is at right angles to a uniform magnetic field. The force acting on the wire is 0.60 N. What is the strength of the magnetic field?

$$F = ILB$$

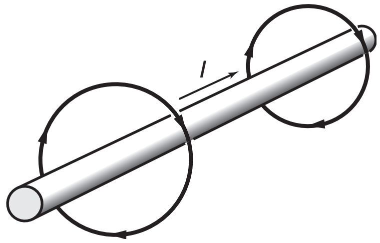
$$B = \frac{F}{IL} = \frac{0.60\ \text{N}}{(10.0\ \text{A})(1.50\ \text{m})} = 0.040\ \text{N/A·m}$$

$$= 0.040\ \text{T}$$

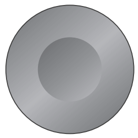
64. A conventional current flows through a wire, as shown in **Figure 24-28.** Copy the wire segment and sketch the magnetic field that the current generates.



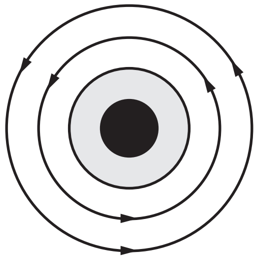
■ **Figure 24-28**



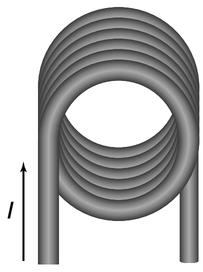
65. The current is coming straight out of the page in **Figure 24-29.** Copy the figure and sketch the magnetic field that the current generates.



■ **Figure 24-29**



66. **Figure 24-30** shows the end view of an electromagnet with current flowing through it.



■ **Figure 24-30**

a. What is the direction of the magnetic field inside the loops?

down into the page

b. What is the direction of the magnetic field outside the loops?

up (out of the page)

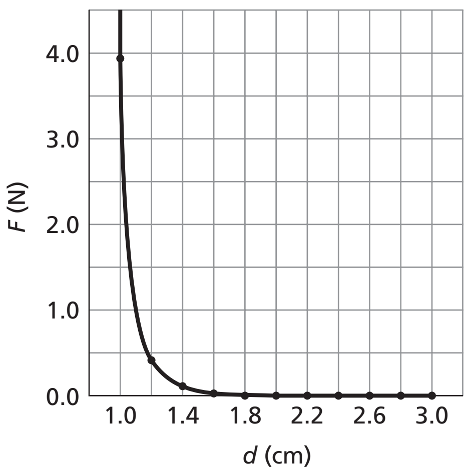
Level 2

67. Ceramic Magnets The repulsive force between two ceramic magnets was measured and found to depend on distance, as given in **Table 24-1.**

Table 24-1

Separation, *d* (cm)	Force, *F* (N)
1.0	3.93
1.2	0.40
1.4	0.13
1.6	0.057
1.8	0.030
2.0	0.018
2.2	0.011
2.4	0.0076
2.6	0.0053
2.8	0.0038
3.0	0.0028

a. Plot the force as a function of distance.



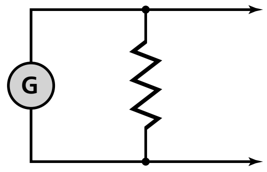
b. Does this force follow an inverse square law?

No.

24.2 Forces Caused by Magnetic Fields pages 666–667

Level 1

68. The arrangement shown in **Figure 24-31** is used to convert a galvanometer to what type of device?



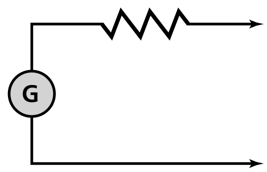
■ **Figure 24-31**

Ammeter, much of the current flows through the resistor and allows the measurement of higher currents.

69. What is the resistor shown in Figure 24-31 called?

Shunt; by definition shunt is another word for parallel.

70. The arrangement shown in **Figure 24-32** is used to convert a galvanometer to what type of device?



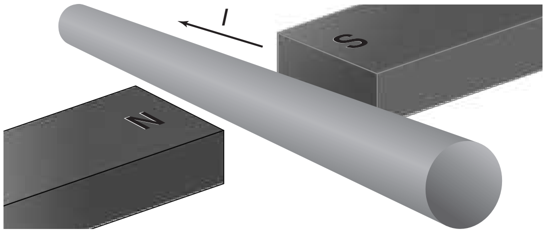
■ **Figure 24-32**

Voltmeter; the added resistance decreases the current for any given voltage.

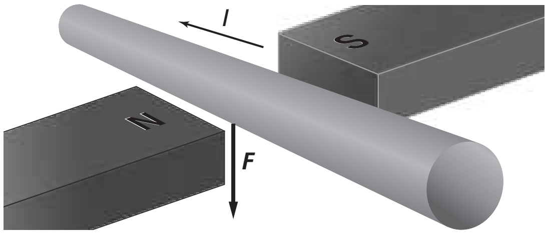
71. What is the resistor shown in Figure 24-32 called?

Multiplier; by definition since it multiplies the voltage range of the meter

72. A current-carrying wire is placed between the poles of a magnet, as shown in **Figure 24-33.** What is the direction of the force on the wire?



■ **Figure 24-33**



73. A wire that is 0.50 m long and carrying a current of 8.0 A is at right angles to a uniform magnetic field. The force on the wire is 0.40 N. What is the strength of the magnetic field?

$$F = ILB$$

$$B = \frac{F}{IL} = \frac{0.40\ \text{N}}{(8.0\ \text{A})(0.50\ \text{m})} = 0.10\ \text{T}$$

74. The current through a wire that is 0.80 m long is 5.0 A. The wire is perpendicular to a 0.60-T magnetic field. What is the magnitude of the force on the wire?

$$F = ILB = (5.0\ \text{A})(0.80\ \text{m})(0.60\ \text{N/A·m})$$
$$= 2.4\ \text{N}$$

75. A wire that is 25 cm long is at right angles to a 0.30-T uniform magnetic field. The current through the wire is 6.0 A. What is the magnitude of the force on the wire?

$$F = ILB = (6.0\ \text{A})(0.25\ \text{m})(0.30\ \text{N/A·m})$$
$$= 0.45\ \text{N}$$

76. A wire that is 35 cm long is parallel to a 0.53-T uniform magnetic field. The current through the wire is 4.5 A. What force acts on the wire?

If the wire is parallel to the field, no cutting is taking place, so no force is produced.

77. A wire that is 625 m long is perpendicular to a 0.40-T magnetic field. A 1.8-N force acts on the wire. What current is in the wire?

$$F = ILB$$

$$I = \frac{F}{BL} = \frac{1.8\ \text{N}}{(0.40\ \text{T})(625\ \text{m})}$$
$$= 0.0072\ \text{A}$$
$$= 7.2\ \text{mA}$$

78. The force on a 0.80-m wire that is perpendicular to Earth's magnetic field is 0.12 N. What is the current in the wire? Use 5.0×10^{-5} T for Earth's magnetic field.

$$F = ILB$$

$$I = \frac{F}{BL} = \frac{0.12\ \text{N}}{(5.0\times10^{-5}\ \text{T})(0.80\ \text{m})}$$
$$= 3.0\times10^{3}\ \text{A}$$
$$= 3.0\ \text{kA}$$

79. The force acting on a wire that is at right angles to a 0.80-T magnetic field is 3.6 N. The current in the wire is 7.5 A. How long is the wire?

$$F = ILB$$

$$L = \frac{F}{BI} = \frac{3.6\ \text{N}}{(0.80\ \text{T})(7.5\ \text{A})} = 0.60\ \text{m}$$

Level 2

80. A power line carries a 225-A current from east to west, parallel to the surface of Earth.

a. What is the magnitude of the force resulting from Earth's magnetic field acting on each meter of the wire? Use $B_{\text{Earth}} = 5.0\times10^{-5}$ T.

$$F = ILB$$

$$\frac{F}{L} = IB = (225\ \text{A})(5.0\times10^{-5}\ \text{T})$$
$$= 0.011\ \text{N/m}$$

b. What is the direction of the force?

The force would be downward.

c. In your judgment, would this force be important in designing towers to hold this power line? Explain.

No; the force is much smaller than the weight of the wires.

81. Galvanometer A galvanometer deflects full-scale for a 50.0-μA current.

a. What must be the total resistance of the series resistor and the galvanometer to make a voltmeter with 10.0-V full-scale deflection?

$$V = IR$$

$$R = \frac{V}{I} = \frac{10.0\ \text{V}}{50.0\times10^{-6}\ \text{A}} = 2.00\times10^{5}\ \Omega$$

$$= 2.00\times10^{2}\ \text{k}\Omega$$

b. If the galvanometer has a resistance of 1.0 kΩ, what should be the resistance of the series (multiplier) resistor?

Total resistance = 2.00×10^{2} kΩ, so the series resistor is 2.00×10^{2} kΩ − 1.0 kΩ = 199 kΩ.

82. The galvanometer in problem 81 is used to make an ammeter that deflects full-scale for 10 mA.

a. What is the potential difference across the galvanometer (1.0 kΩ resistance) when a current of 50 μA passes through it?

$$V = IR = (50\times10^{-6}\ \text{A})(1.0\times10^{3}\ \Omega)$$

$$= 0.05\ \text{V}$$

b. What is the equivalent resistance of parallel resistors having the potential difference calculated in a circuit with a total current of 10 mA?

$$V = IR$$

$$R = \frac{V}{I} = \frac{5\times10^{-2}\ \text{V}}{0.01\ \text{A}} = 5\ \Omega$$

c. What resistor should be placed parallel with the galvanometer to make the resistance calculated in part b?

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}\ \text{so}$$

$$\frac{1}{R_1} = \frac{1}{R} - \frac{1}{R_2} = \frac{1}{5\ \Omega} - \frac{1}{1.0\times10^{3}\ \Omega}$$

$$\text{so } R_1 = 5\ \Omega$$

83. A beam of electrons moves at right angles to a magnetic field of 6.0×10^{-2} T. The electrons have a velocity of 2.5×10^{6} m/s. What is the magnitude of the force on each electron?

$$F = Bqv$$

$$= (6.0\times10^{-2}\ \text{T})(1.6\times10^{-19}\ \text{C})(2.5\times10^{6}\ \text{m/s})$$

$$= 2.4\times10^{-14}\ \text{N}$$

84. Subatomic Particle A muon (a particle with the same charge as an electron) is traveling at 4.21×10^{7} m/s at right angles to a magnetic field. The muon experiences a force of 5.00×10^{-12} N.

a. How strong is the magnetic field?

$$F = qvB$$

$$B = \frac{F}{qv}$$

$$= \frac{5.00\times10^{-12}\ \text{N}}{(1.60\times10^{-19}\ \text{C})(4.21\times10^{7}\ \text{m/s})}$$

$$= 0.742\ \text{T}$$

b. What acceleration does the muon experience if its mass is 1.88×10^{-28} kg?

$$F = ma$$

$$a = \frac{F}{m} = \frac{5.00\times10^{-12}\ \text{N}}{1.88\times10^{-28}\ \text{kg}}$$

$$= 2.66\times10^{16}\ \text{m/s}^2$$

85. A singly ionized particle experiences a force of 4.1×10^{-13} N when it travels at right angles through a 0.61-T magnetic field. What is the velocity of the particle?

$$F = qvB$$

$$v = \frac{F}{Bq} = \frac{4.1\times10^{-13}\ \text{N}}{(0.61\ \text{T})(1.60\times10^{-19}\ \text{C})}$$

$$= 4.2\times10^{6}\ \text{m/s}$$

86. A room contains a strong, uniform magnetic field. A loop of fine wire in the room has current flowing through it. Assume that you rotate the loop until there is no tendency for it to rotate as a result of the field. What is the direction of the magnetic field relative to the plane of the coil?

The magnetic field is perpendicular to the plane of the coil. The right-hand rule would be used to find the direction of the field produced by the coil. The field in the room is in the same direction.

87. A force of 5.78×10^{-16} N acts on an unknown particle traveling at a 90° angle through a magnetic field. If the velocity of the particle is 5.65×10^{4} m/s and the field is 3.20×10^{-2} T, how many elementary charges does the particle carry?

$F = qvB$

$$q = \frac{F}{Bv} = \frac{5.78\times10^{-16}\text{ N}}{(3.20\times10^{-2}\text{ T})(5.65\times10^{4}\text{ m/s})}$$

$$= 3.20\times10^{-19}\text{ C}$$

$$\text{N} = (3.20\times10^{-19}\text{ C})\left(\frac{1\text{ charge}}{1.60\times10^{-19}\text{ C}}\right)$$

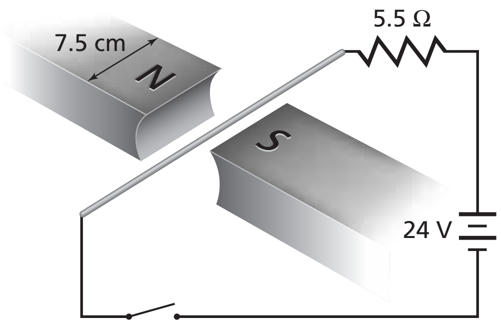
$$= 2\text{ charges}$$

Mixed Review

pages 667–668

Level 2

88. A copper wire of insignificant resistance is placed in the center of an air gap between two magnetic poles, as shown in **Figure 24-34.** The field is confined to the gap and has a strength of 1.9 T.



■ **Figure 24-34**

a. Determine the force on the wire (direction and magnitude) when the switch is open.

0 N. With no current, there is no magnetic field produced by the wire and copper is not a magnetic material.

b. Determine the force on the wire (direction and magnitude) when the switch is closed.

Up, 0.62 N. The direction of the force is given by the third right-hand rule.

$$I = \frac{V}{R}$$

$$F = ILB = \frac{VLB}{R}$$

$$= \frac{(24\text{ V})(0.075\text{ m})(1.9\text{ T})}{5.5\ \Omega}$$

$$= 0.62\text{ N}$$

c. Determine the force on the wire (direction and magnitude) when the switch is closed and the battery is reversed.

Down, 0.62 N. The direction of the force is given by the third right-hand rule and the magnitude of the force is the same as in part b.

d. Determine the force on the wire (direction and magnitude) when the switch is closed and the wire is replaced with a different piece having a resistance of 5.5 Ω.

Up, 0.31 N. The direction of the force is given by the third right-hand rule.

$$I = \frac{V}{R}$$

$$F = ILB = \frac{VLB}{R}$$

$$= \frac{(24\text{ V})(0.075\text{ m})(1.9\text{ T})}{5.5\ \Omega + 5.5\ \Omega}$$

$$= 0.31\text{ N}$$

89. Two galvanometers are available. One has 50.0-μA full-scale sensitivity and the other has 500.0-μA full-scale sensitivity. Both have the same coil resistance of 855 Ω. Your challenge is to convert them to measure a current of 100.0 mA, full-scale.

a. Determine the shunt resistor for the 50.0-μA meter.

Find the voltage across the meter coil at full scale.

$$V = IR = (50.0\ \mu\text{A})(855\ \Omega) = 0.0428\text{ V}$$

Calculate the shunt resistor.

$$R = \frac{V}{I} = \frac{0.0428\text{ V}}{100.0\text{ mA} - 50.0\ \mu\text{A}}$$

$$= 0.428\ \Omega$$

b. Determine the shunt resistor for the 500.0-μA meter.

Find the voltage across the meter coil at full scale.

$$V = IR = (500.0\ \mu\text{A})(855\ \Omega) = 0.428\text{ V}$$

Calculate the shunt resistor.

$$R = \frac{V}{I} = \frac{0.428\ \text{V}}{100.0\ \text{mA} - 500.0\ \mu\text{A}}$$

$$= 4.30\ \Omega$$

c. Determine which of the two is better for actual use. Explain.

The 50.0-μA meter is better. Its much lower shunt resistance will do less to alter the total resistance of the circuit being measured. An ideal ammeter has a resistance of 0 Ω.

90. Subatomic Particle A beta particle (high-speed electron) is traveling at right angles to a 0.60-T magnetic field. It has a speed of 2.5×10^{7} m/s. What size force acts on the particle?

$$F = Bqv$$

$$= (0.60\ \text{T})(1.6\times10^{-19}\ \text{C})(2.5\times10^{7}\ \text{m/s})$$

$$= 2.4\times10^{-12}\ \text{N}$$

91. The mass of an electron is 9.11×10^{-31} kg. What is the magnitude of the acceleration of the beta particle described in problem 90?

$$F = ma$$

$$a = \frac{F}{m} = \frac{2.4\times10^{-12}\ \text{N}}{9.11\times10^{-31}\ \text{kg}}$$

$$= 2.6\times10^{18}\ \text{m/s}^2$$

92. A magnetic field of 16 T acts in a direction due west. An electron is traveling due south at 8.1×10^{5} m/s. What are the magnitude and the direction of the force acting on the electron?

$$F = Bqv$$

$$= (16\ \text{T})(1.6\times10^{-19}\ \text{C})(8.1\times10^{5}\ \text{m/s})$$

$= 2.1\times10^{-12}$ **N, upward (right-hand rule—remembering that electron flow is opposite to current flow)**

93. Loudspeaker The magnetic field in a loudspeaker is 0.15 T. The wire consists of 250 turns wound on a 2.5-cm-diameter cylindrical form. The resistance of the wire is 8.0 Ω. Find the force exerted on the wire when 15 V is placed across the wire.

$$I = \frac{V}{R}$$

$$L = (\text{\# of turns})(\text{circumference}) = n\pi d$$

$$F = BIL$$

$$F = \frac{BVn\pi d}{R}$$

$$= \frac{(0.15\ \text{T})(15\ \text{V})(250)(\pi)(0.025\ \text{m})}{8.0\ \Omega}$$

$$= 5.5\ \text{N}$$

94. A wire carrying 15 A of current has a length of 25 cm in a magnetic field of 0.85 T. The force on a current-carrying wire in a uniform magnetic field can be found using the equation $F = ILB \sin \theta$. Find the force on the wire when it makes the following angles with the magnetic field lines of

a. 90°

$$F = ILB \sin \theta$$

$$= (15\ \text{A})(0.25\ \text{m})(0.85\ \text{T})(\sin 90°)$$

$$= 3.2\ \text{N}$$

b. 45°

$$F = ILB \sin \theta$$

$$= (15\ \text{A})(0.25\ \text{m})(0.85\ \text{T})(\sin 45°)$$

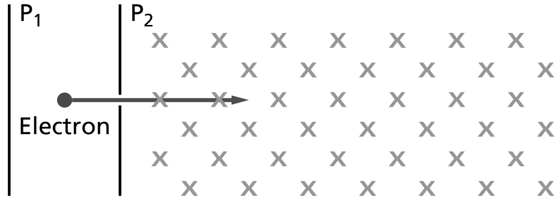
$$= 2.3\ \text{N}$$

c. 0°

sin 0° = 0

so F = 0 N

95. An electron is accelerated from rest through a potential difference of 20,000 V, which exists between plates P_1 and P_2, shown in **Figure 24-35.** The electron then passes through a small opening into a magnetic field of uniform field strength, B. As indicated, the magnetic field is directed into the page.



■ **Figure 24-35**

a. State the direction of the electric field between the plates as either P_1 to P_2 or P_2 to P_1.

from P_2 to P_1

b. In terms of the information given, calculate the electron's speed at plate P_2.

$$KE = q\Delta V = (1.6\times10^{-19}\ \text{C})(20{,}000\ \text{J/C}) = 3.2\times10^{-15}\ \text{J}$$

$$KE = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{(2)(3.2\times10^{-15}\ \text{J})}{9.11\times10^{-31}\ \text{kg}}} = 8\times10^{7}\ \text{m/s}$$

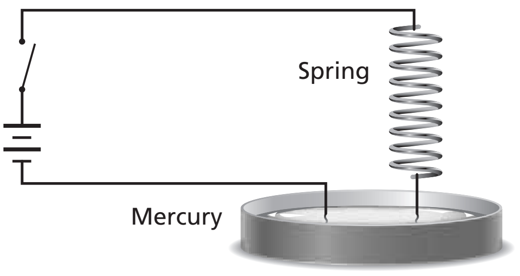
c. Describe the motion of the electron through the magnetic field.

clockwise

Thinking Critically

page 668

96. Apply Concepts A current is sent through a vertical spring, as shown in **Figure 24-36.** The end of the spring is in a cup filled with mercury. What will happen? Why?



■ **Figure 24-36**

When the current passes through the coil, the magnetic field increases and forces cause the spring to compress. The wire comes out of the mercury, the circuit opens, the magnetic field decreases, and the spring drops down. The spring will oscillate up and down.

97. Apply Concepts The magnetic field produced by a long, current-carrying wire is represented by $B = (2\times10^{-7}\ \text{T·m/A})(I/d)$, where B is the field strength in teslas, I is the current in amps, and d is the distance from the wire in meters. Use this equation to estimate some magnetic fields that you encounter in everyday life.

a. The wiring in your home seldom carries more than 10 A. How does the magnetic field that is 0.5 m from such a wire compare to Earth's magnetic field?

$I = 10$ A, $d = 0.5$ m, so

$$B = \frac{(2\times10^{-7}\ \text{T·m/A})I}{d} = \frac{(2\times10^{-7}\ \text{T·m/A})(10\ \text{A})}{0.5\ \text{m}} = 4\times10^{-6}\ \text{T}$$

Earth's field is 5×10^{-5} T, so Earth's field is about 12 times stronger than that of the wire.

b. High-voltage power transmission lines often carry 200 A at voltages as high as 765 kV. Estimate the magnetic field on the ground under such a line, assuming that it is about 20 m high. How does this field compare with a magnetic field in your home?

$I = 200$ A, $d = 20$ m, so

$$B = \frac{(2\times10^{-7}\ \text{T·m/A})I}{d} = \frac{(2\times10^{-7}\ \text{T·m/A})(200\ \text{A})}{20\ \text{m}} = 2\times10^{-6}\ \text{T}$$

This is half as strong as the field in part a.

c. Some consumer groups have recommended that pregnant women not use electric blankets in case the magnetic fields cause health problems. Estimate the distance that a fetus might be from such a wire, clearly stating your assumptions. If such a blanket carries 1 A, find the magnetic field at the location of the fetus. Compare this with Earth's magnetic field.

Assume only one wire runs over "the fetus, and use the center of the fetus (where the vital organs are) as a reference point. At an early stage, the fetus might be 5 cm from the blanket. At later stages, the center of the fetus may be 10 cm away.

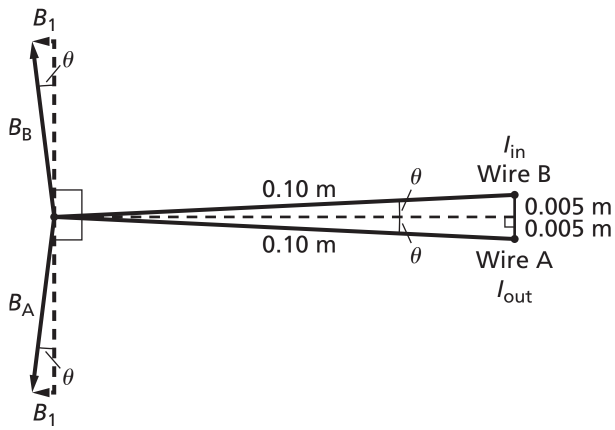
$I = 1$ A, $d = 0.05$ m, so

$$B = \frac{(2\times10^{-7}\ \text{T·m/A})I}{d} = \frac{(2\times10^{-7}\ \text{T·m/A})(1\ \text{A})}{0.05\ \text{m}}$$

$= 4\times10^{-6}$ T

Earth's magnetic field of 5×10^{-5} T is about 12 times stronger.

98. Add Vectors In almost all cases described in problem 97, a second wire carries the same current in the opposite direction. Find the net magnetic field that is a distance of 0.10 m from each wire carrying 10 A. The wires are 0.01 m apart. Make a scale drawing of the situation. Calculate the magnitude of the field from each wire and use a right-hand rule to draw vectors showing the directions of the fields. Finally, find the vector sum of the two fields. State its magnitude and direction.



From each wire $I = 10$ A, $d = 0.10$ m, so

$$B = \frac{(2\times10^{-7}\ \text{T·m/A})(10\ \text{A})}{0.10\ \text{m}} = 2\times10^{-5}\ \text{T}$$

From the diagram, only the components parallel to the line from the center of the wires contribute to the net field strength. The component from each wire is $B_1 = B \sin\theta$, where $\sin\theta = \frac{0.005\ \text{m}}{0.10\ \text{m}} = 0.05$, so $B_1 = (2\times10^{-5}\ \text{T})(0.05) = 1\times10^{-6}$ T. But, each wire contributes the same amount, so the total field is 2×10^{-6} T, about 1/25 Earth's field.

Writing In Physics

page 668

99. Research superconducting magnets and write a one-page summary of proposed future uses for such magnets. Be sure to describe any hurdles that stand in the way of the practical application of these magnets.

Student answers may vary. Superconducting magnets currently are used in magnetic resonance imaging (MRI), a medical technology. They are being tested for use in magnetically levitated high-speed trains, and it is hoped that superconducting magnets will help to make nuclear fusion energy practical. A drawback of superconducting magnets is that they require extremely low temperatures (near absolute zero). Scientists are trying to develop materials that are superconductive at higher temperatures.

Cumulative Review

page 668

100. How much work is required to move a charge of 6.40×10^{-3} C through a potential difference of 2500 V? (Chapter 21)

$$W = qV = (6.40\times10^{-3}\ \text{C})(2500\ \text{V}) = 16\ \text{J}$$

101. The current flow in a 120-V circuit increases from 1.3 A to 2.3 A. Calculate the change in power. (Chapter 22)

$$P = IV$$

$$P_1 = I_1V,\ P_2 = I_2V$$

$$\begin{aligned}\Delta P &= P_2 - P_1 = I_2V - I_1V\\ &= V(I_2 - I_1)\\ &= (120\ \text{V})(2.3\ \text{A} - 1.3\ \text{A})\\ &= 120\ \text{W}\end{aligned}$$

102. Determine the total resistance of three, 55-Ω resistors connected in parallel and then series-connected to two 55-Ω resistors connected in series. (Chapter 23)

$$\frac{1}{R_{\text{parallel}}} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} = \frac{1}{55\ \Omega} + \frac{1}{55\ \Omega} + \frac{1}{55\ \Omega} = \frac{3}{55\ \Omega}$$

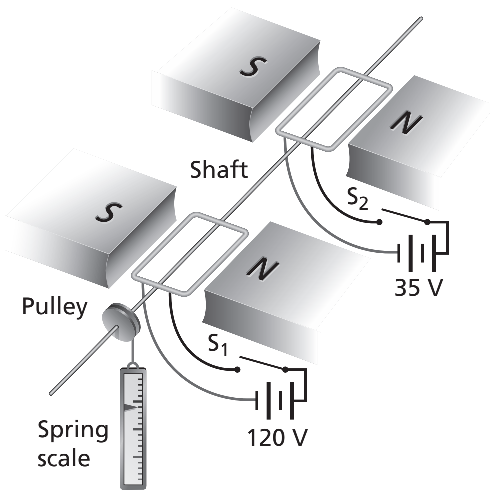
$$R_{\text{parallel}} = 18\ \Omega$$

$$\begin{aligned}R_{\text{equiv}} &= R_{\text{parallel}} + R + R\\ &= 18\ \Omega + 55\ \Omega + 55\ \Omega\\ &= 128\ \Omega\end{aligned}$$

Challenge Problem

page 656

The figure shows two identical motors with a common shaft. For simplicity, the commutators are not shown. Each armature coil consists of 48 turns of wire with rectangular dimensions of 17 cm wide by 35 cm deep. The armature resistance is 12 Ω. The red wire travels to the left (along half the width) and then back to the rear of the motor (along the depth). The magnetic field is 0.21 T. The diameter of the pulley is 7.2 cm. A rope fixed to the pulley and the floor prevents the motor shaft from turning.



1. Given $F = ILB$, derive an equation for the torque on the armature for the position shown.

Torque is defined as the product of the force and the lever arm. In the case of the motor armature position shown, the lever arm is equal to half of the width of the armature coil (the shaft is the center of rotation and is at the midpoint of the coil width). The length of the wire acted upon by the field is equal to the depth of the coil. This length is effectively increased by *n*, the number of turns in the coil. Finally, the torque is doubled because as one side is pushed up by the magnetic field, the other side is pushed down according to the third right-hand rule.

$\tau = 2nBI\text{(depth)(width/2)}$

Simplifying and replacing (depth)(width) with area, A, gives:

$\tau = nBIA$

The torque produced by the motor armature, in the position shown, is equal to the number of turns times the field strength times the armature current times the area of the armature coil.

2. With S_1 closed and S_2 open, determine the torque on the shaft and the force on the spring scale.

$$\tau = nBIA$$
$$= (48)(0.21\ \text{T})\left(\frac{120\ \text{V}}{12\ \Omega}\right)(0.35\ \text{m})(0.17\ \text{m})$$
$$= 6.0\ \text{N·m}$$

Because the shaft cannot turn, the system is in equilibrium and the force on the spring scale is found by considering half the pulley diameter:

$$F_{\text{spring scale}} = \frac{6.0\ \text{N·m}}{0.036\ \text{m}} = 170\ \text{N}$$

3. With both switches closed, determine the torque on the shaft and the force on the spring scale.

Both motors produce counterclockwise torque:

$$\tau_1 = (48)(0.21\ \text{T})\left(\frac{120\ \text{V}}{12\ \Omega}\right)(0.35\ \text{m})(0.17\ \text{m})$$
$$= 6.0\ \text{N·m}$$
$$\tau_2 = (48)(0.21\ \text{T})\left(\frac{35\ \text{V}}{12\ \Omega}\right)(0.35\ \text{m})(0.17\ \text{m})$$
$$= 1.7\ \text{N·m}$$
$$\tau_{\text{net}} = 7.7\ \text{N·m counterclockwise}$$
$$F_{\text{spring scale}} = \frac{7.7\ \text{N·m}}{0.036\ \text{m}} = 210\ \text{N}$$

4. What happens to torque if the armature is in a different position?

The torque is reduced when there is any rotation from the position shown because the lever arm is reduced. With 90° rotation, the force on the armature will be up and down (canceling) with the effective lever arm equal to zero. With the shown position as $\theta = 0°$:

$\tau = nBIA \cos\theta$

Electromagnetic Induction

Practice Problems

25.1 Electric Current from Changing Magnetic Fields pages 671–678

page 675

1. A straight wire, 0.5 m long, is moved straight up at a speed of 20 m/s through a 0.4-T magnetic field pointed in the horizontal direction.

   a. What *EMF* is induced in the wire?

   $$EMF = BLv = (0.4\text{ T})(0.5\text{ m})(20\text{ m/s}) = 4\text{ V}$$

   b. The wire is part of a circuit of total resistance of 6.0 Ω. What is the current in the circuit?

   $$I = \frac{EMF}{R} = \frac{4\text{ V}}{6.0\ \Omega} = 0.7\text{ A}$$

2. A straight wire, 25 m long, is mounted on an airplane flying at 125 m/s. The wire moves in a perpendicular direction through Earth's magnetic field ($B = 5.0\times10^{-5}$ T). What *EMF* is induced in the wire?

   $$EMF = BLv = (5.0\times10^{-5}\text{ T})(25\text{ m})(125\text{ m/s}) = 0.16\text{ V}$$

3. A straight wire, 30.0 m long, moves at 2.0 m/s in a perpendicular direction through a 1.0-T magnetic field.

   a. What *EMF* is induced in the wire?

   $$EMF = BLv = (1.0\text{ T})(30.0\text{ m})(2.0\text{ m/s}) = 6.0\times10^{1}\text{ V}$$

   b. The total resistance of the circuit of which the wire is a part is 15.0 Ω. What is the current?

   $$I = \frac{EMF}{R} = \frac{6.0\times10^{1}\text{ V}}{1.50\ \Omega} = 4.0\text{ A}$$

4. A permanent horseshoe magnet is mounted so that the magnetic field lines are vertical. If a student passes a straight wire between the poles and pulls it toward herself, the current flow through the wire is from right to left. Which is the north pole of the magnet?

   Using the right-hand rule, the north pole is at the bottom.

page 678

5. A generator develops a maximum voltage of 170 V.

   a. What is the effective voltage?

   $$V_{eff} = (0.707)V_{max} = (0.707)(170\text{ V}) = 1.2\times10^{2}\text{ V}$$

   b. A 60-W lightbulb is placed across the generator with an I_{max} of 0.70 A. What is the effective current through the bulb?

   $$I_{eff} = (0.707)I_{max} = (0.707)(0.70\text{ A}) = 0.49\text{ A}$$

   c. What is the resistance of the lightbulb when it is working?

   $$R = \frac{V_{eff}}{I_{eff}} = \frac{\frac{V_{max}}{\sqrt{2}}}{\frac{I_{max}}{\sqrt{2}}} = \frac{V_{max}}{I_{max}} = \frac{170\text{ V}}{0.70\text{ A}} = 2.4\times10^{2}\ \Omega$$

6. The RMS voltage of an AC household outlet is 117 V. What is the maximum voltage across a lamp connected to the outlet? If the RMS current through the lamp is 5.5 A, what is the maximum current in the lamp?

   $$V_{max} = \frac{V_{eff}}{0.707} = \frac{117\text{ V}}{0.707} = 165\text{ V}$$

   $$I_{max} = \frac{I_{eff}}{0.707} = \frac{5.5\text{ A}}{0.707} = 7.8\text{ A}$$

7. An AC generator delivers a peak voltage of 425 V.

a. What is the V_{eff} in a circuit placed across the generator?

$$V_{eff} = \frac{V_{max}}{\sqrt{2}} = \frac{425\ V}{\sqrt{2}} = 3.01\times10^2\ V$$

b. The resistance is $5.0\times10^2\ \Omega$. What is the effective current?

$$I_{eff} = \frac{V_{eff}}{R} = \frac{3.01\times10^2\ V}{5.0\times10^2\ \Omega} = 0.60\ A$$

8. If the average power dissipated by an electric light is 75 W, what is the peak power?

$$P = \frac{1}{2}P_{max}$$

$$P_{max} = (2)P = (2)(75\ W) = 1.5\times10^2\ W$$

Section Review

25.1 Electric Current from Changing Magnetic Fields pages 671–678

page 678

9. Generator Could you make a generator by mounting permanent magnets on a rotating shaft and keeping the coil stationary? Explain.

Yes, only relative motion between the coil and the magnetic field is important.

10. Bike Generator A bike generator lights the headlamp. What is the source of the energy for the bulb when the rider travels along a flat road?

the stored chemical energy of the bike rider

11. Microphone Consider the microphone shown in Figure 25-3. When the diaphragm is pushed in, what is the direction of the current in the coil?

clockwise from the left

12. Frequency What changes to the generator are required to increase the frequency?

increase the number of magnetic pole pairs

13. Output Voltage Explain why the output voltage of an electric generator increases when the magnetic field is made stronger. What else is affected by strengthening the magnetic field?

The magnitude of the induced voltage is directly related to the strength of the magnetic field. A greater voltage is induced in the conductor(s) if the field strength is increased. The current and the power in the generator circuit also were affected.

14. Generator Explain the fundamental operating principle of an electric generator.

Michael Faraday discovered that a voltage is induced in a length of electric wire moving in a magnetic field. The induced voltage may be increased by using a stronger magnetic field, increasing the velocity of the conductor, or increasing the effective length of the conductor.

15. Critical Thinking A student asks, "Why does AC dissipate any power? The energy going into the lamp when the current is positive is removed when the current is negative. The net is zero." Explain why this reasoning is wrong.

Power is the rate at which energy is transferred. Power is the product of *I* and *V.* When *I* is positive, so is *V* and therefore, *P* is positive. When *I* is negative, so is *V;* thus, *P* is positive again. Energy is always transferred in the lamp.

Practice Problems

25.2 Changing Magnetic Fields Induce *EMF* pages 679–685

page 684

For the following problems, effective currents and voltages are indicated.

16. A step-down transformer has 7500 turns on its primary coil and 125 turns on its secondary coil. The voltage across the primary circuit is 7.2 kV. What voltage is being applied across the secondary circuit? If the current in the secondary circuit is 36 A, what is the current in the primary circuit?

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$V_s = \frac{V_p N_s}{N_p} = \frac{(7.2\times10^3\ \text{V})(125)}{7500}$$

$$= 1.2\times10^2\ \text{V}$$

$$V_p I_p = V_s I_s$$

$$I_p = \frac{V_s I_s}{V_p} = \frac{(1.2\times10^2\ \text{V})(36\ \text{A})}{7.2\times10^3\ \text{V}} = 0.60\ \text{A}$$

17. A step-up transformer has 300 turns on its primary coil and 90,000 turns on its secondary coil. The *EMF* of the generator to which the primary circuit is attached is 60.0 V. What is the *EMF* in the secondary circuit? The current in the secondary circuit is 0.50 A. What current is in the primary circuit?

$$V_s = \frac{V_p N_s}{N_p} = \frac{(60.0\ \text{V})(90{,}000)}{300}$$

$$= 1.80\times10^4\ \text{V}$$

$$I_p = \frac{V_s I_s}{V_p} = \frac{(1.80\times10^4\ \text{V})(0.50\ \text{A})}{60.0\ \text{V}}$$

$$= 1.5\times10^2\ \text{A}$$

Section Review

25.2 Changing Magnetic Fields Induce *EMF* pages 679–685

page 685

18. Coiled Wire and Magnets You hang a coil of wire with its ends joined so that it can swing easily. If you now plunge a magnet into the coil, the coil will swing. Which way will it swing relative to the magnet and why?

Away from the magnet. The changing magnetic field induces a current in the coil, producing a magnetic field. This field opposes the field of the magnet, and thus, the force between coil and magnet is repulsive.

19. Motors If you unplugged a running vacuum cleaner from a wall outlet, you would be much more likely to see a spark than you would be if you unplugged a lighted lamp from the wall. Why?

The inductance of the motor creates a back-*EMF* that causes the spark. The bulb has very low self-inductance, so there is no back-*EMF*.

20. Transformers and Current Explain why a transformer may only be operated on alternating current.

In order to magnetically link the primary and secondary coils, a varying current must flow in the primary coil. This changing current sets up a magnetic field that builds, expanding outwards, and collapses as the current flow direction changes.

21. Transformers Frequently, transformer coils that have only a few turns are made of very thick (low-resistance) wire, while those with many turns are made of thin wire. Why?

More current flows through the coil with fewer turns, so the resistance must be kept low to prevent voltage drops and I^2R power loss and heating.

22. Step-Up Transformers Refer to the step-up transformer shown in Figure 25-13. Explain what will happen to the primary current if the secondary coil is short-circuited.

According to the transformer equations, the ratio of primary to secondary current is equal to the ratio of turns and doesn't change. Thus, if the secondary current increases, so does the primary.

23. Critical Thinking Would permanent magnets make good transformer cores? Explain.

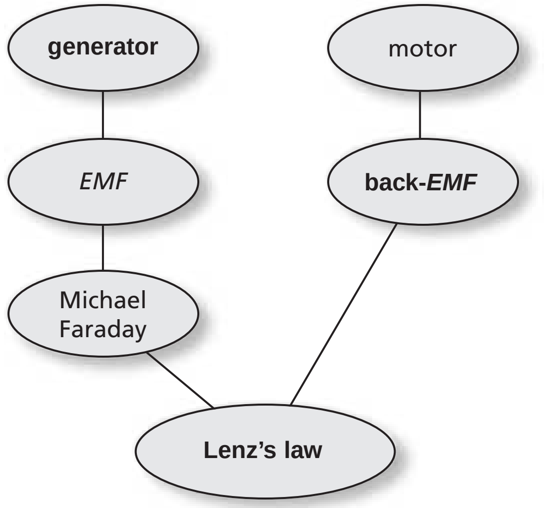
No, the induced voltage depends on a changing magnetic field through the core. Permanent magnets are "permanent" because they are made of materials that resist such changes in magnetic fields.

Chapter Assessment

Concept Mapping

page 690

24. Complete the following concept map using the following terms: *generator, back-EMF, Lenz's law.*



Mastering Concepts

page 690

25. What is the armature of an electric generator? (25.1)

The armature of an electric generator consists of a number of wire loops wound around an iron core and placed in a strong magnetic field. As it rotates in the magnetic field, the loops cut through magnetic field lines and an electric current is induced.

26. Why is iron used in an armature? (25.1)

Iron is used in an armature to increase the strength of the magnetic field.

For problems 27–29, refer to ***Figure 25-16.***

27. A single conductor moves through a magnetic field and generates a voltage. In what direction should the wire be moved, relative to the magnetic field to generate the minimum voltage? (25.1)

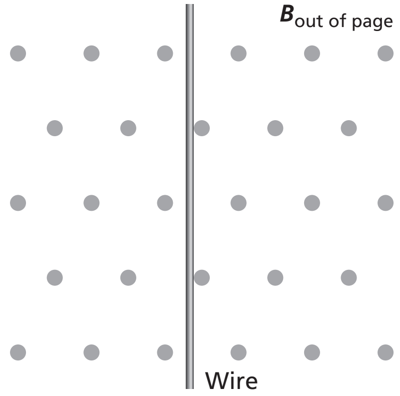
The minimum amount of voltage (0 V), is generated when the conductor is moving parallel to the magnetic lines of force.

28. What is the polarity of the voltage induced in the wire when it passes the south pole of the magnetic field? (25.1)

A conductor moving by a south magnetic pole will have a positive induced voltage.

29. What is the effect of increasing the net conductor length in an electric generator? (25.1)

Increasing the conductor length results in a net increase in induced voltage.



■ **Figure 25-16**

30. How were Oersted's and Faraday's results similar? How were they different? (25.1)

They are similar in that they each show a relationship between electricity and magnetism. They are different in that a steady electric current produces a magnetic field, but a change in magnetic field is needed to produce an electric current.

31. You have a coil of wire and a bar magnet. Describe how you could use them to generate an electric current. (25.1)

Either move the magnet into or out of the coil, or move the coil up and down over the end of the magnet.

32. What does *EMF* stand for? Why is the name inaccurate? (25.1)

Electromotive force; it is not a force but an electric potential (energy per unit of charge).

33. What is the difference between a generator and a motor? (25.1)

In a generator, mechanical energy turns an armature in a magnetic field. The induced voltage produces current, thus producing electric energy. In a motor, voltage is placed across an armature coil in a magnetic field. The voltage produces current in the coil and the armature turns, producing mechanical energy.

34. List the major parts of an AC generator. (25.1)

An AC generator consists of a permanent magnet, an armature, a set of brushes, and a slip ring.

35. Why is the effective value of an AC current less than its maximum value? (25.1)

In an alternating-current generator, as the armature turns, the generated power varies between some maximum value and zero. The average power is equal to one-half the maximum power. The effective current is the constant value of current that would cause the average power to be dissipated in the load, R.

$$P_{avg} = \frac{1}{2}P_{max} = \frac{1}{2}I_{max}{}^2R = I_{eff}{}^2R$$

$$I_{eff} = \frac{I_{max}}{\sqrt{2}} < I_{max}$$

36. Hydroelectricity Water trapped behind a dam turns turbines that rotate generators. List all the forms of energy that take part in the cycle that includes the stored water and the electricity produced. (25.1)

There is potential energy in the stored water, kinetic energy in the falling water and turning turbine, and electric energy in the generator. In addition, there are frictional losses in the turbine and generator resulting in thermal energy.

37. State Lenz's law. (25.2)

An induced current always acts in such a direction that its magnetic field opposes the change by which the current is induced.

38. What causes back-*EMF* in an electric motor? (25.2)

This is Lenz's law. Once the motor starts turning, it behaves as a generator and will generate current in opposition to the current being put into the motor.

39. Why is there no spark when you close a switch and put current through an inductor, but there is a spark when you open the switch? (25.2)

The spark is from the back-*EMF* that tries to keep the current flowing. The back-*EMF* is large because the current has dropped quickly to zero. When closing the switch, the current increase isn't so fast because of the resistance in the wires.

40. Why is the self-inductance of a coil a major factor when the coil is in an AC circuit but a minor factor when the coil is in a DC circuit? (25.2)

An alternating current is always changing in the magnitude and direction. Therefore, self-induction is a constant factor. A direct current eventually becomes steady, and thus, after a short time, there is no changing magnetic field.

41. Explain why the word *change* appears so often in this chapter. (25.2)

As Faraday discovered, only a changing magnetic field induces *EMF.*

42. Upon what does the ratio of the *EMF* in the primary circuit of a transformer to the *EMF* in the secondary circuit of the transformer depend? (25.2)

The ratio of number of turns of wire in the primary coil to the number of turns of wire in the secondary coil determines the *EMF* ratio.

Applying Concepts

pages 690–692

43. Use unit substitution to show that the units of *BLv* are volts.

The unit of *BLv* is (T)(m)(m/s).

T = N/A·m and A = C/s.

So, *BLv* = (N·s/C·m)(m)(m/s) = N·m/C

Because J = N·m and V = J/C, the unit of *BLv* is V (volts).

44. When a wire is moved through a magnetic field, does the resistance of the closed circuit affect current only, *EMF* only, both, or neither?

current only

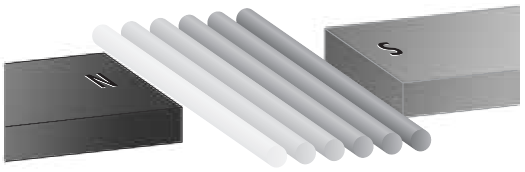
45. **Biking** As Logan slows his bike, what happens to the *EMF* produced by his bike's generator? Use the term *armature* in your explanation.

As Logan slows his bike, the rotation of the armature in the magnetic field of the generator slows, and the *EMF* is reduced.

46. The direction of AC voltage changes 120 times each second. Does this mean that a device connected to an AC voltage alternately delivers and accepts energy?

No; the signs of the current and voltage reverse at the same time, and, therefore, the product of the current and the voltage is always positive.

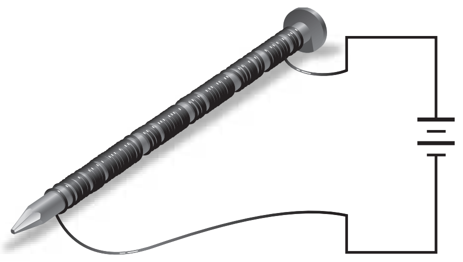
47. A wire is moved horizontally between the poles of a magnet, as shown in **Figure 25-17.** What is the direction of the induced current?



■ **Figure 25-17**

No current is induced because the direction of the velocity is parallel to the magnetic field.

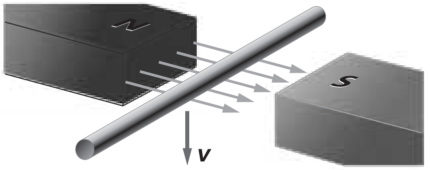
48. You make an electromagnet by winding wire around a large nail, as shown in **Figure 25-18.** If you connect the magnet to a battery, is the current larger just after you make the connection or several tenths of a second after the connection is made? Or, is it always the same? Explain.



■ **Figure 25-18**

It is larger several tenths of a second after the connection is made. The back-*EMF* opposes current just after the connection is made.

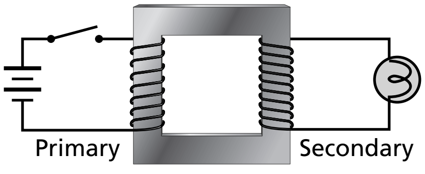
49. A segment of a wire loop is moving downward through the poles of a magnet, as shown in **Figure 25-19.** What is the direction of the induced current?



■ **Figure 25-19**

The current direction is out-of-page to the left along the path of the wire.

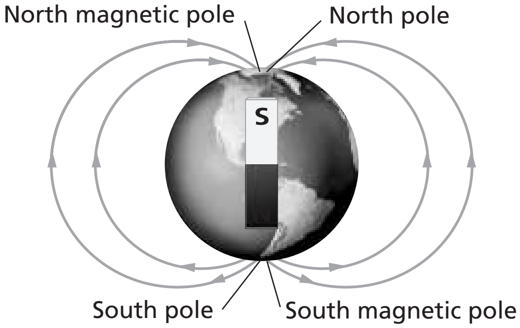
50. A transformer is connected to a battery through a switch. The secondary circuit contains a lightbulb, as shown in **Figure 25-20.** Will the lamp be lighted as long as the switch is closed, only at the moment the switch is closed, or only at the moment the switch is opened? Explain.



■ **Figure 25-20**

The bulb will light because there is a current in the secondary circuit. This will happen whenever the primary current changes, so the bulb will glow either when the switch is closed or when it is opened.

51. Earth's Magnetic Field The direction of Earth's magnetic field in the northern hemisphere is downward and to the north as shown in **Figure 25-21.** If an east-west wire moves from north to south, in which direction is the current?



■ **Figure 25-21**

The current is from west to east.

52. You move a length of copper wire down through a magnetic field, *B*, as shown in Figure 25-19.

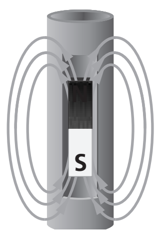
a. Will the induced current move to the right or left in the wire segment in the diagram?

The right-hand rule will show the current moving left.

b. As soon as the wire is moved in the field, a current appears in it. Thus, the wire segment is a current-carrying wire located in a magnetic field. A force must act on the wire. What will be the direction of the force acting on the wire as a result of the induced current?

The force will act in an upward direction.

53. A physics instructor drops a magnet through a copper pipe, as illustrated in **Figure 25-22.** The magnet falls very slowly, and the students in the class conclude that there must be some force opposing gravity.



■ **Figure 25-22**

a. What is the direction of the current induced in the pipe by the falling magnet if the south pole is toward the bottom?

Induced *EMF* is perpendicular to both the field and velocity, so the current must be circumferential. Field lines move in toward the south pole and out from the north pole. By the right-hand rule, current is clockwise near the south pole and counterclockwise near the north pole.

b. The induced current produces a magnetic field. What is the direction of the field?

Near the south pole, the field inside the pipe is down; near the north pole, it is up.

c. How does this field reduce the acceleration of the falling magnet?

Induced field exerts an upward force on both poles.

54. Generators Why is a generator more difficult to rotate when it is connected to a circuit and supplying current than it is when it is standing alone?

When the armature of a generator is rotated, a force that opposes the direction of rotation is produced as a result of induced current (Lenz's law). When standing alone, however, no current is generated and consequently no opposing force is produced.

55. Explain why the initial start-up current is so high in an electric motor. Also explain how Lenz's law applies at the instant $t > 0$.

If the armature (conductors) are not rotating, no lines of force are being cut, and no voltage is induced. Therefore, the back-*EMF* is zero. Since there is no current in the armature, no magnetic field is formed around the stationary conductor. It should be noted that this explanation only holds true at the instant of startup, at time just greater than 0. The instant the armature begins to rotate, it will be cutting the lines of force and will have an induced voltage. This voltage, the back-*EMF,* will have a

polarity such that it produces a magnetic field opposing the field that created it. This reduces the current in the motor. Therefore, the motion of the motor increases its apparent resistance.

56. Using Figure 25-10 in conjunction with Lenz's law, explain why all practical transformer cores incorporate a laminated core.

A laminated core is constructed from thin sheets of steel, separated by a very thin coating of varnish (insulation). Eddy currents are greatly reduced because of this insulation. Current in the core is caused by the changing magnetic flux within the core. The eddy currents exist due to the induced voltage within the magnetic core.

57. A practical transformer is constructed with a laminated core that is not a superconductor. Because the eddy currents cannot be completely eliminated, there is always a small core loss. This results, in part, in a net loss of power within the transformer. What fundamental law makes it impossible to bring this loss to zero?

Lenz's law

58. Explain the process of mutual induction within a transformer.

An AC current applied to the primary coil of a transformer, results in a changing current flow through the coil winding. This current, in turn, generates a magnetic flux, alternately building and collapsing as the direction of current changes. This strong magnetic field radiates outward in all directions from the primary coil. When the magnetic field reaches the stationary secondary coil on the other side of the core, a voltage is induced within that coil. The voltage or *EMF* induced depends upon the rate at which the magnetic field alternates (supply frequency), number of turns on the coil, and the strength of the magnetic flux. Since the magnetic flux is responsible for inducing a voltage in the secondary coil, we say that it is magnetically linked.

59. Shawn drops a magnet, north pole down, through a vertical copper pipe.

a. What is the direction of the induced current in the copper pipe as the bottom of the magnet passes?

clockwise around the pipe, as viewed from above

b. The induced current produces a magnetic field. What is the direction of the induced magnetic field?

down the pipe, at the location of the south pole of the magnet (or opposite the magnet's field)

Mastering Problems

25.1 Electric Current from Changing Magnetic Fields

pages 692–693

Level 1

60. A wire, 20.0-m long, moves at 4.0 m/s perpendicularly through a magnetic field. An *EMF* of 40 V is induced in the wire. What is the strength of the magnetic field?

$EMF = BLv$

$$B = \frac{EMF}{Lv} = \frac{40\text{ V}}{(20.0\text{ m})(4.0\text{ m/s})}$$

$= 0.5\text{ T}$

61. **Airplanes** An airplane traveling at 9.50×10^2 km/h passes over a region where Earth's magnetic field is 4.5×10^{-5} T and is nearly vertical. What voltage is induced between the plane's wing tips, which are 75 m apart?

$EMF = BLv$

$= (4.5\times10^{-5}\text{ T})(75\text{ m})(9.50\times10^{2}\text{ km/h})(1000\text{ m/km})(1\text{ h}/3600\text{ s})$

$= 0.89\text{ V}$

62. A straight wire, 0.75-m long, moves upward through a horizontal 0.30-T magnetic field, as shown in **Figure 25-23,** at a speed of 16 m/s.

a. What *EMF* is induced in the wire?

$EMF = BLv$

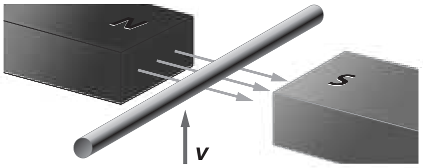
$= (0.30\text{ T})(0.75\text{ m})(16\text{ m/s})$

$= 3.6\text{ V}$

b. The wire is part of a circuit with a total resistance of 11 Ω. What is the current?

$EMF = IR$

$I = \frac{EMF}{R} = \frac{3.6\text{ V}}{11\ \Omega} = 0.33\text{ A}$



■ **Figure 25-23**

63. At what speed would a 0.20-m length of wire have to move across a 2.5-T magnetic field to induce an *EMF* of 10 V?

$EMF = BLv$

$v = \frac{EMF}{BL} = \frac{10\text{ V}}{(2.5\text{ T})(0.20\text{ m})}$

$= 20\text{ m/s}$

64. An AC generator develops a maximum *EMF* of 565 V. What effective *EMF* does the generator deliver to an external circuit?

$V_{eff} = \frac{V_{max}}{\sqrt{2}} = \frac{565\text{ V}}{\sqrt{2}} = 4.00\times10^{2}\text{ V}$

65. An AC generator develops a maximum voltage of 150 V. It delivers a maximum current of 30.0 A to an external circuit.

a. What is the effective voltage of the generator?

$V_{eff} = (0.707)V_{max} = (0.707)(150\text{ V})$

$= 110\text{ V}$

b. What effective current does the generator deliver to the external circuit?

$I_{eff} = (0.707)I_{max} = (0.707)(30.0\text{ V})$

$= 21.2\text{ A}$

c. What is the effective power dissipated in the circuit?

$P_{eff} = I_{eff}V_{eff} = \left(\frac{I_{max}}{\sqrt{2}}\right)\left(\frac{V_{max}}{\sqrt{2}}\right)$

$= \frac{1}{2}I_{max}V_{max} = \left(\frac{1}{2}\right)(150\text{ V})(30.0\text{ A})$

$= 2.3\text{ kW}$

66. **Electric Stove** An electric stove is connected to an AC source with an effective voltage of 240 V.

a. Find the maximum voltage across one of the stove's elements when it is operating.

$V_{eff} = (0.707)V_{max}$

$V_{max} = \frac{V_{eff}}{0.707} = \frac{240\text{ V}}{0.707} = 340\text{ V}$

b. The resistance of the operating element is 11 Ω. What is the effective current?

$V_{eff} = I_{eff}R$

$I_{eff} = \frac{V_{eff}}{R} = \frac{240\text{ V}}{11\ \Omega} = 22\text{ A}$

67. You wish to generate an *EMF* of 4.5 V by moving a wire at 4.0 m/s through a 0.050-T magnetic field. How long must the wire be, and what should be the angle between the field and direction of motion to use the shortest wire?

$EMF = BLv$

$L = \frac{EMF}{Bv} = \frac{4.5\text{ V}}{(0.050\text{ T})(4.0\text{ m/s})}$

$= 23\text{ m}$

This is the shortest length of wire assuming that the wire and the direction of motion are each perpendicular to the field.

Level 2

68. A 40.0-cm wire is moved perpendicularly through a magnetic field of 0.32 T with a velocity of 1.3 m/s. If this wire is connected into a circuit of 10.0-Ω resistance, what is the current?

$EMF = BLv$

$= (0.32\text{ T})(0.400\text{ m})(1.3\text{ m/s})$

$= 0.17\text{ V}$

$I = \frac{EMF}{R} = \frac{0.17\text{ V}}{10.0\ \Omega} = 17\text{ mA}$

69. You connect both ends of a copper wire with a total resistance of 0.10 Ω to the terminals of a galvanometer. The galvanometer has a resistance of 875 Ω. You then move a 10.0-cm segment of the wire upward at 1.0 m/s through a 2.0×10^{-2}-T magnetic field. What current will the galvanometer indicate?

$EMF = BLv$

$= (2.0\times10^{-2}\text{ T})(0.100\text{ m})(1.0\text{ m/s})$

$= 2.0\times10^{-3}\text{ V}$

$I = \frac{V}{R} = \frac{2.0\times10^{-3}\text{ V}}{875\ \Omega} = 2.3\times10^{-6}\text{ A}$

$= 2.3\ \mu\text{A}$

70. The direction of a 0.045-T magnetic field is 60.0° above the horizontal. A wire, 2.5-m long, moves horizontally at 2.4 m/s.

a. What is the vertical component of the magnetic field?

The vertical component of magnetic field is

$B \sin 60.0° = (0.045\text{ T})(\sin 60.0°)$

$= 0.039\text{ T}$

b. What *EMF* is induced in the wire?

$EMF = BLv$

$= (0.039\text{ T})(2.5\text{ m})(2.4\text{ m/s})$

$= 0.23\text{ V}$

71. Dams A generator at a dam can supply 375 MW (375×10^6 W) of electrical power. Assume that the turbine and generator are 85 percent efficient.

a. Find the rate at which falling water must supply energy to the turbine.

$\text{eff} = \frac{P_{out}}{P_{in}} \times 100$

$P_{in} = P_{out} \times \frac{100}{\text{eff}}$

$= 375\text{ MW}\left(\frac{100}{85}\right)$

$= 440\text{ MW input}$

b. The energy of the water comes from a change in potential energy, $PE = mgh$. What is the change in PE needed each second?

$440\text{ MW} = 440\text{ MJ/s}$

$= 4.4\times10^8\text{ J each second}$

c. If the water falls 22 m, what is the mass of the water that must pass through the turbine each second to supply this power?

$PE = mgh$

$m = \frac{PE}{gh} = \frac{4.4\times10^8\text{ J}}{(9.80\text{ m/s}^2)(22\text{ m})}$

$= 2.0\times10^6\text{ kg}$

72. A conductor rotating in a magnetic field has a length of 20 cm. If the magnetic-flux density is 4.0 T, determine the induced voltage when the conductor is moving perpendicular to the line of force. Assume that the conductor travels at a constant velocity of 1 m/s.

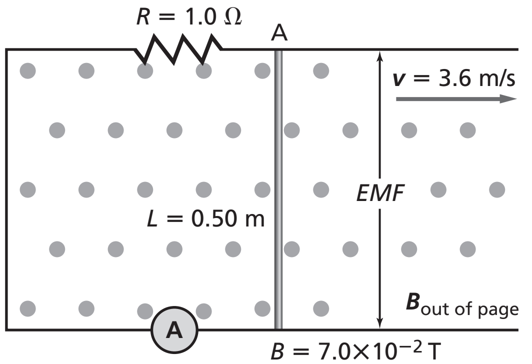
When the conductor is moving perpendicular to the line of force

$E_{ind} = BLv$

$= (4.0\text{ T})(0.20\text{ m})(1\text{ m/s})$

$= 0.8\text{ V}$

73. Refer to Example Problem 1 and **Figure 25-24** to determine the following.



■ Figure 25-24

a. induced voltage in the conductor

$EMF_{ind} = BLv$

$= (7.0\times10^{-2}\text{ T})(0.50\text{ m})(3.6\text{ m/s})$

$= 0.13\text{ V}$

b. current (I)

$I = \frac{EMF_{ind}}{R} = \frac{0.13\text{ V}}{1.0\ \Omega} = 0.13\text{ A}$

c. direction of flux rotation around the conductor

Flux rotates clockwise around the conductor when viewed from above.

d. polarity of point A relative to point B

Point A is negative relative to point B.

25.2 Changing Magnetic Fields Induce EMF
page 693

Level 1

74. The primary coil of a transformer has 150 turns. It is connected to a 120-V source. Calculate the number of turns on the secondary coil needed to supply the following voltages.

a. 625 V

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$N_s = \left(\frac{V_s}{V_p}\right)N_p = \left(\frac{625\text{ V}}{120\text{ V}}\right)(150)$$

= 781 turns, which rounds to 780

b. 35 V

$$N_s = \left(\frac{V_s}{V_p}\right)N_p = \left(\frac{35\text{ V}}{120\text{ V}}\right)(150)$$

= 44 turns

c. 6.0 V

$$N_s = \left(\frac{V_s}{V_p}\right)N_p = \left(\frac{6.0\text{ V}}{120\text{ V}}\right)(150)$$

= 7.5 turns

75. A step-up transformer has 80 turns on its primary coil and 1200 turns on its secondary coil. The primary circuit is supplied with an alternating current at 120 V.

a. What voltage is being applied across the secondary circuit?

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$$V_s = \frac{V_p N_s}{N_p} = \frac{(120\text{ V})(1200)}{80} = 1.8\text{ kV}$$

b. The current in the secondary circuit is 2.0 A. What current is in the primary circuit?

$$V_p I_p = V_s I_s$$

$$I_p = \frac{V_s I_s}{V_p} = \frac{(1.8\times10^3\text{ V})(2.0\text{ A})}{120\text{ V}}$$

$$= 3.0\times10^1\text{ A}$$

c. What are the power input and output of the transformer?

$$V_p I_p = (120\text{ V})(30.0\text{ A}) = 3.6\text{ kW}$$

$$V_s I_s = (1800\text{ V})(2.0\text{ A}) = 3.6\text{ kW}$$

76. Laptop Computers The power supply in a laptop computer requires an effective voltage of 9.0 V from a 120-V line.

a. If the primary coil has 475 turns, how many does the secondary coil have?

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$N_s = \frac{V_s N_p}{V_p} = \frac{(9.0\text{ V})(475)}{120\text{ V}}$$

= 36 turns

b. A 125-mA current is in the computer. What current is in the primary circuit?

$$V_p I_p = V_s I_s$$

$$I_p = \frac{V_s I_s}{V_p} = \frac{(9.0\text{ V})(125\text{ mA})}{7200\text{ V}}$$

= 9.4 mA

Level 2

77. Hair Dryers A hair dryer manufactured for use in the United States uses 10 A at 120 V. It is used with a transformer in England, where the line voltage is 240 V.

a. What should be the ratio of the turns of the transformer?

$$\frac{V_p}{V_s} = \frac{N_p}{N_s} = \frac{240\text{ V}}{120\text{ V}} = \frac{2.0}{1.0}$$

or 2 to 1

b. What current will the hair dryer now draw?

$$V_p I_p = V_s I_s$$

$$I_p = \frac{V_s I_s}{V_p} = \frac{(120\text{ V})(10\text{ A})}{240\text{ V}} = 5\text{ A}$$

78. A 150-W transformer has an input voltage of 9.0 V and an output current of 5.0 A.

a. Is this a step-up or step-down transformer?

$$P_{out} = V_s I_s$$

$$V_s = \frac{P_{out}}{I_s} = \frac{150\text{ W}}{5.0\text{ A}} = 3.0\times10^1\text{ V}$$

step-up transformer

b. What is the ratio of V_{output} to V_{input}?

$P = V_s I_s$

$$V_s = \frac{P}{I_s} = \frac{150\ W}{5.0\ A} = 3.0\times10^1\ V$$

$$\frac{V_{output}}{V_{input}} = \frac{3.0\times10^1\ V}{9.0\ V} = \frac{1.0\times10^1}{3.0}$$

or 10 to 3

79. Scott connects a transformer to a 24-V source and measures 8.0 V at the secondary circuit. If the primary and secondary circuits were reversed, what would the new output voltage be?

The turns ratio is

$$\frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{8.0\ V}{24\ V} = \frac{1.0}{3.0}$$

Reversed, it would be $\frac{3.0}{1.0}$.

Thus, the voltage would now be found by

$$\frac{N_s}{N_p} = \frac{V_s}{V_p}$$

$$V_s = \left(\frac{N_s}{N_p}\right)V_p = (3.0)(24\ V) = 72\ V$$

Mixed Review

pages 693–694

Level 1

80. A step-up transformer's primary coil has 500 turns. Its secondary coil has 15,000 turns. The primary circuit is connected to an AC generator having an *EMF* of 120 V.

a. Calculate the *EMF* of the secondary circuit.

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$$V_s = \frac{V_p N_s}{N_p} = \frac{(120\ V)(15{,}000)}{500}$$

$$= 3.6\times10^3\ V$$

b. Find the current in the primary circuit if the current in the secondary circuit is 3.0 A.

$V_p I_p = V_s I_s$

$$I_p = \frac{V_s I_s}{V_p} = \frac{(3600\ V)(3.0\ A)}{120\ V} = 9.0\times10^1\ A$$

c. What power is drawn by the primary circuit? What power is supplied by the secondary circuit?

$$V_p I_p = (120\ V)(9.0\times10^1\ A) = 1.1\times10^4\ W$$

$$V_s I_s = (3600\ V)(3.0\ A) = 1.1\times10^4\ W$$

81. With what speed must a 0.20-m-long wire cut across a magnetic field for which *B* is 2.5 T if it is to have an *EMF* of 10 V induced in it?

$EMF = BLv$

$$v = \frac{EMF}{BL} = \frac{10\ V}{(2.5\ T)(0.20\ m)}$$

$$= 20\ m/s$$

82. At what speed must a wire conductor 50-cm long be moved at right angles to a magnetic field of induction 0.20 T to induce an *EMF* of 1.0 V in it?

$EMF = BLv$

$$v = \frac{EMF}{BL} = \frac{1.0\ V}{(0.20\ T)(0.5\ m)}$$

$$= 1\times10^1\ m/s$$

83. A house lighting circuit is rated at 120-V effective voltage. What is the peak voltage that can be expected in this circuit?

$V_{eff} = (0.707)V_{max}$

$$V_{max} = \frac{V_{eff}}{0.707} = \frac{120\ V}{0.707} = 170\ V$$

84. **Toaster** A toaster draws 2.5 A of alternating current. What is the peak current through this toaster?

$I_{eff} = (0.707)I_{max}$

$$I_{max} = \frac{I_{eff}}{0.707} = \frac{2.5\ A}{0.707} = 3.5\ A$$

85. The insulation of a capacitor will break down if the instantaneous voltage exceeds 575 V. What is the largest effective alternating voltage that may be applied to the capacitor?

$$V_{eff} = \frac{V_{max}}{\sqrt{2}} = \frac{575}{\sqrt{2}} = 407\ V$$

86. **Circuit Breaker** A magnetic circuit breaker will open its circuit if the instantaneous current reaches 21.25 A. What is the largest effective current the circuit will carry?

$$I_{eff} = \frac{I_{max}}{\sqrt{2}} = \frac{21.25\ \text{A}}{\sqrt{2}} = 15.03\ \text{A}$$

87. The electricity received at an electrical substation has a potential difference of 240,000 V. What should the ratio of the turns of the step-down transformer be to have an output of 440 V?

$$\frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{440\ \text{V}}{240{,}000\ \text{V}} = \frac{1}{545}$$

primary : secondary = 545 : 1

88. An alternating-current electric generator supplies a 45-kW industrial electric heater. If the system voltage is 660 V_{rms}, what is the peak current supplied?

$$I_{rms} = \frac{45\ \text{kW}}{660\ \text{V}} = 68\ \text{A}$$

Therefore, $I_{peak} = \frac{68\ \text{A}}{0.707} = 96\ \text{A}$

89. A certain step-down transformer has 100 turns on the primary coil and 10 turns on the secondary coil. If a 2.0-kW resistive load is connected to the transformer, what is the effective primary current that flows? Assume that the secondary voltage is 60.0 V_{pk}.

$$V_{s,\,eff} = \frac{V_{s,\,peak}}{\sqrt{2}} = \frac{60.0\ \text{V}}{\sqrt{2}} = 42.4\ \text{V}$$

$$I_{s,\,eff} = \frac{P}{V_{s,\,eff}} = \frac{2.0\times10^3\ \text{W}}{42.4\ \text{V}} = 47\ \text{A}$$

$$I_{p,\,eff} = \left(\frac{N_s}{N_p}\right)I_{s,\,eff} = \left(\frac{10}{100}\right)(47\ \text{A}) = 4.7\ \text{A}$$

90. A transformer rated at 100 kVA has an efficiency of 98 percent.

a. If the connected load consumes 98 kW of power, what is the input power to the transformer?

$P_{out} = 98\ \text{kW}$

$$P_{in} = \frac{98\ \text{kW}}{0.98} = 1.0\times10^2\ \text{kW}$$

b. What is the maximum primary current with the transformer consuming its rated reactive power? Assume that $V_P = 600$ V.

$$I = \frac{100\ \text{kVA}}{600\ \text{V}} = 200\ \text{A}$$

Level 2

91. A wire, 0.40-m long, cuts perpendicularly across a magnetic field for which *B* is 2.0 T at a velocity of 8.0 m/s.

a. What *EMF* is induced in the wire?

$EMF = BLv$

$= (2.0\ \text{T})(0.40\ \text{m})(8.0\ \text{m/s})$

$= 6.4\ \text{V}$

b. If the wire is in a circuit with a resistance of 6.4 Ω, what is the size of the current in the wire?

$EMF = IR$

$$I = \frac{EMF}{R} = \frac{6.4\ \text{V}}{6.4\ \Omega} = 1.0\ \text{A}$$

92. A coil of wire, which has a total length of 7.50 m, is moved perpendicularly to Earth's magnetic field at 5.50 m/s. What is the size of the current in the wire if the total resistance of the wire is 5.0×10^{-2} mΩ? Assume Earth's magnetic field is 5×10^{-5} T.

$EMF = BLv$ and $V = IR$, but $EMF = V$, so $IR = BLv$, and

$$I = \frac{BLv}{R} = \frac{(5.0\times10^{-5}\ \text{T})(7.50\ \text{m})(5.50\ \text{m/s})}{5.0\times10^{-2}\ \text{m}\Omega}$$

$= 4.1\times10^{-2}\ \text{A} = 41\ \text{mA}$

93. The peak value of the alternating voltage applied to a 144-Ω resistor is 1.00×10^2 V. What power must the resistor be able to handle?

$P = IV$ and $V = IR$, so $I = \frac{V}{R}$ therefore,

$$P_{max} = \left(\frac{V}{R}\right)V = \frac{V^2}{R} = \frac{(1.00\times10^2\ \text{V})^2}{144\ \Omega}$$

$= 69.4\ \text{W}$

The average power is $P_{max}/2$ so the resistor must dissipate 34.7 W.

94. **Television** The CRT in a television uses a step-up transformer to change 120 V to 48,000 V. The secondary side of the transformer has 20,000 turns and an output of 1.0 mA.

a. How many turns does the primary side have?

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$N_p = \frac{N_s V_p}{V_s} = \frac{(20{,}000)(120\text{ V})}{48\ 000\text{ V}}$$

$$= 50\text{ turns}$$

b. What is the input current?

$$V_p I_p = V_s I_s$$

$$I_p = \frac{V_s I_s}{V_p} = \frac{(48{,}000\text{ V})(1.0\times10^{-3}\text{ A})}{120\text{ V}}$$

$$= 0.40\text{ A}$$

Thinking Critically

page 694

95. Apply Concepts Suppose that an "anti-Lenz's law" existed that meant a force was exerted to increase the change in a magnetic field. Thus, when more energy was demanded, the force needed to turn the generator would be reduced. What conservation law would be violated by this new "law"? Explain.

It would violate the law of conversation of energy. More energy would come out than went in. A generator would create energy, not just change it from one form to another.

96. Analyze Real transformers are not 100 percent efficient. Write an expression for transformer efficiency in percent using power. A step-down transformer that has an efficiency of 92.5 percent is used to obtain 28.0 V from a 125-V household voltage. The current in the secondary circuit is 25.0 A. What is the current in the primary circuit?

Efficiency

$$e = \frac{P_s}{P_p} \times 100$$

Secondary power:

$$P_s = V_s I_s = (28.0\text{ V})(25.0\text{ A})$$

$$= 7.00\times10^2\text{ W}$$

Primary power:

$$P_p = \frac{(100)P_s}{e} = \frac{(100)(7.00\times10^2\text{ W})}{92.5} = 757\text{ W}$$

Primary current:

$$I_p = \frac{P_p}{V_p} = \frac{757\text{ W}}{125\text{ V}} = 6.05\text{ A}$$

97. Analyze and Conclude A transformer that supplies eight homes has an efficiency of 95 percent. All eight homes have operating electric ovens that each draw 35 A from 240-V lines. How much power is supplied to the ovens in the eight homes? How much power is dissipated as heat in the transformer?

Secondary power:

$$P_s = (\#\text{ of homes})V_s I_s$$

$$= (8)(240\text{ V})(35\text{ A}) = 67\text{ kW}$$

67 kW is supplied to the ovens in the eight homes.

Primary power:

$$P_p = \frac{(100)P_s}{e} = \frac{(100)(67\text{ W})}{95} = 71\text{ kW}$$

The difference between these two is the power dissipated as heat, 4 kW.

Writing in Physics

page 694

98. Common tools, such as an electric drill, are typically constructed using a universal motor. Using your local library, and other sources, explain how this type of motor may operate on either AC or DC current.

A series DC Motor uses both an armature and series coil. When operated on alternating current, the polarity on both fields changes simultaneously. Therefore, the polarity of the magnetic field remains unchanged, and hence the direction of rotation is constant.

Cumulative Review

page 694

99. Light is emitted by a distant star at a frequency of 4.56×10^{14} Hz. If the star is moving toward Earth at a speed of 2750 km/s, what frequency light will be detected by observers on Earth? (Chapter 16)

$$f_{obs} = f\left(1 \pm \frac{v}{c}\right)$$

Because they are moving toward each other

$$f_{obs} = f\left(1 + \frac{v}{c}\right)$$

$$= (4.56\times10^{14}\ \text{Hz})\left(1 + \frac{2.75\times10^{6}\ \text{m/s}}{3.00\times10^{8}\ \text{m/s}}\right)$$

$$= 4.60\times10^{4}\ \text{Hz}$$

100. A distant galaxy emits light at a frequency of 7.29×10^{14} Hz. Observers on Earth receive the light at a frequency of 6.14×10^{14} Hz. How fast is the galaxy moving, and in what direction? (Chapter 16)

The galaxy is moving away from Earth because the observed frequency is lower than the emitted frequency. To find the speed:

$$f_{obs} = f\left(1 + \frac{v}{c}\right)$$

Because the observed light has a lower frequency, the galaxy must be moving away from Earth. So, use the negative form of the equation above

$$f_{obs} = f\left(1 - \frac{v}{c}\right)$$

$$\frac{f_{obs}}{f} = 1 - \frac{v}{c}$$

$$\frac{v}{c} = 1 - \frac{f_{obs}}{f}$$

$$v = c\left(1 - \frac{f_{obs}}{f}\right)$$

$$= (3.00\times10^{8}\ \text{m/s})\left(1 - \frac{6.14\times10^{14}\ \text{Hz}}{7.29\times10^{14}\ \text{Hz}}\right)$$

$$= 4.73\times10^{7}\ \text{m/s}$$

101. How much charge is on a 22-μF capacitor with 48 V applied to it? (Chapter 21)

$$C = \frac{q}{\Delta V}$$

$$q = C\Delta V$$

$$= (22\times10^{-6}\ \text{F})(48\ \text{V})$$

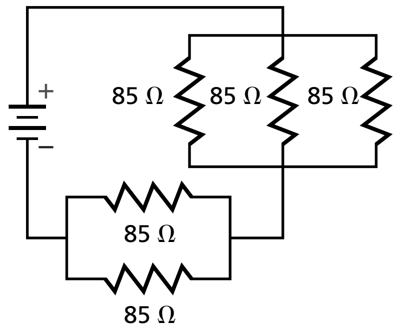
$$= 1.1\times10^{-3}\ \text{C}$$

102. Find the voltage across a 22-Ω, 5.0-W resistor operating at half of its rating. (Chapter 22)

$$P = V^2/R$$

$$V = \sqrt{PR} = \sqrt{\left(\frac{5.0\ \text{W}}{2}\right)(22\ \Omega)} = 7.4\ \text{V}$$

103. Determine the total resistance of three, 85-Ω resistors connected in parallel and then series-connected to two 85-Ω resistors connected in parallel, as shown in **Figure 25-25.** (Chapter 23)



■ **Figure 25-25**

$$\frac{1}{R_{3\ \text{in parallel}}} = \frac{1}{85\ \Omega} + \frac{1}{85\ \Omega} + \frac{1}{85\ \Omega}$$

$$R_{3\ \text{in parallel}} = 28.3\ \Omega$$

$$\frac{1}{R_{2\ \text{in parallel}}} = \frac{1}{85\ \Omega} + \frac{1}{85\ \Omega}$$

$$R_{2\ \text{in parallel}} = 42.5\ \Omega$$

$$R = R_{3\ \text{in parallel}} + R_{2\ \text{in parallel}}$$

$$= 28.3\ \Omega + 42.5\ \Omega$$

$$= 71\ \Omega$$

104. An electron with a velocity of 2.1×10^{6} m/s is at right angles to a 0.81-T magnetic field. What is the force on the electron produced by the magnetic field? What is the electron's acceleration? The mass of an electron is 9.11×10^{-31} kg. (Chapter 24)

$$F = Bqv$$

$$= (0.81\ \text{T})(1.60\times10^{-19}\ \text{C})(2.1\times10^{6}\ \text{m/s})$$

$$= 2.7\times10^{-13}\ \text{N}$$

$$F = ma$$

$$a = \frac{F}{m} = \frac{2.7\times10^{-13}\ \text{N}}{9.11\times10^{-31}\ \text{kg}}$$

$$= 3.0\times10^{17}\ \text{m/s}^2$$

Challenge Problem

page 685

A distribution transformer (T_1) has its primary coil connected to a 3.0-kV AC source. The secondary coil is connected to the primary coil of a second transformer (T_2) by copper conductors. Finally, the secondary coil of transformer T_2 connects to a load that uses 10.0 kW of power. Transformer T_1 has a turn ratio of 5:1, and T_2 has a load voltage of 120 V. The transformer efficiencies are 100.0 percent and 97.0 percent, respectively.

1. Calculate the load current.

$$I_L = \frac{P_L}{V_L} = \frac{10.0\text{ kW}}{120\text{ V}} = 83\text{ A}$$

2. How much power is being dissipated by transformer T_2?

$$P_2 = \frac{P_L}{0.970} = \frac{10.0\text{ kW}}{0.970} = 10.3\text{ kW}$$

P_2 is power input to transformer T_2. Of the 10.3 kW, 0.3 kW is dissipated by T_2; the other 10.0 kW is dissipated in the load.

3. What is the secondary current of transformer T_1?

$$V_{s1} = \left(\frac{1}{5}\right)(3.0\times10^3\text{ V}) = 6.0\times10^2\text{ V}$$

$$I_{s1} = \frac{P_2}{V_{s1}} = \frac{10.3\times10^3\text{ W}}{6.0\times10^2\text{ V}} = 17\text{ A}$$

4. How much current is the AC source supplying to T_1?

$$I_{p1} = \left(\frac{1}{5}\right)I_{s1} = \left(\frac{1}{5}\right)(17\text{ A}) = 3.4\text{ A}$$

CHAPTER

26 Electromagnetism

Practice Problems

26.1 Interactions of Electric and Magnetic Fields and Matter pages 697–704

page 700

Assume that all charged particles move perpendicular to a uniform magnetic field.

1. A proton moves at a speed of 7.5×10^{3} m/s as it passes through a magnetic field of 0.60 T. Find the radius of the circular path. Note that the charge carried by the proton is equal to that of the electron, but is positive.

$$Bqv = \frac{mv^2}{r}$$

$$r = \frac{mv}{Bq}$$

$$= \frac{(1.67\times10^{-27}\text{ kg})(7.5\times10^{3}\text{ m/s})}{(0.60\text{ T})(1.60\times10^{-19}\text{ C})}$$

$$= 1.3\times10^{-4}\text{ m}$$

2. Electrons move through a magnetic field of 6.0×10^{-2} T balanced by an electric field of 3.0×10^{3} N/C. What is the speed of the electrons?

$$Bqv = Eq$$

$$v = \frac{E}{B} = \frac{3.0\times10^{3}\text{ N/C}}{6.0\times10^{-2}\text{ T}}$$

$$= 5.0\times10^{4}\text{ m/s}$$

3. Calculate the radius of the circular path that the electrons in problem 2 follow in the absence of the electric field.

$$Bqv = \frac{mv^2}{r}$$

$$r = \frac{mv}{Bq}$$

$$= \frac{(9.11\times10^{-31}\text{ kg})(5.0\times10^{4}\text{ m/s})}{(6.0\times10^{-2}\text{ T})(1.60\times10^{-19}\text{ C})} = 4.7\times10^{-6}\text{ m}$$

4. Protons passing without deflection through a magnetic field of 0.60 T are balanced by an electric field of 4.5×10^{3} N/C. What is the speed of the moving protons?

$$Bqv = Eq$$

$$v = \frac{E}{B} = \frac{4.5\times10^{3}\text{ N/C}}{0.60\text{ T}}$$

$$= 7.5\times10^{3}\text{ m/s}$$

page 703

5. A beam of singly ionized (1+) oxygen atoms is sent through a mass spectrometer. The values are $B = 7.2\times10^{-2}$ T, $q = 1.60\times10^{-19}$ C, $r = 0.085$ m, and $V = 110$ V. Find the mass of an oxygen atom.

$$m = \frac{B^2r^2q}{2V} = \frac{(7.2\times10^{-2}\ \text{T})^2(0.085\ \text{m})^2(1.60\times10^{-19}\ \text{C})}{(2)(110\ \text{V})} = 2.7\times10^{-26}\ \text{kg}$$

6. A mass spectrometer analyzes and gives data for a beam of doubly ionized (2+) argon atoms. The values are $q = 2(1.60\times10^{-19}$ C), $B = 5.0\times10^{-2}$ T, $r = 0.106$ m, and $V = 66.0$ V. Find the mass of an argon atom.

$$m = \frac{B^2r^2q}{2V} = \frac{(5.0\times10^{-2}\ \text{T})^2(0.106\ \text{m})^2(2)(1.60\times10^{-19}\ \text{C})}{(2)(66.0\ \text{V})} = 6.8\times10^{-26}\ \text{kg}$$

7. A stream of singly ionized (1+) lithium atoms is not deflected as it passes through a magnetic field of 1.5×10^{-3} T that is perpendicular to an electric field of 6.0×10^{2} N/C. What is the speed of the lithium atoms as they pass through the two fields?

$$Bqv = Eq$$

$$v = \frac{E}{B} = \frac{6.0\times10^{2}\ \text{N/C}}{1.5\times10^{-3}\ \text{T}}$$

$$= 4.0\times10^{5}\ \text{m/s}$$

8. In Example Problem 2, the mass of a neon isotope is determined. Another neon isotope is found to have a mass of 22 proton masses. How far apart on the photographic film would these two isotopes land?

Use the charge-to-mass ratio to find the ratio of the radii of the two isotopes.

$$\frac{q}{m} = \frac{2V}{B^2r^2}$$

Thus, $r = \frac{1}{B}\sqrt{\frac{2Vm}{q}}$ **and,** $\frac{r_{22}}{r_{20}} = \frac{\frac{1}{B}\sqrt{\frac{2Vm_{22}}{q}}}{\frac{1}{B}\sqrt{\frac{2Vm_{20}}{q}}} = \sqrt{\frac{m_{22}}{m_{20}}}$

The radius of the isotope with a mass of 22 proton masses, then, is

$$r_{22} = r_{20}\sqrt{\frac{m_{22}}{m_{20}}}$$

$$= r_{20}\sqrt{\frac{22m_p}{20m_p}}$$

$$= \sqrt{\frac{22}{20}}r_{20}$$

$$= \sqrt{\frac{22}{20}}(0.053\ \text{m})$$

$$= 0.056\ \text{m}$$

The difference in the radii is $r_{22} - r_{20} = 0.056\ \text{m} - 0.053\ \text{m} = 0.003\ \text{m} = 3\ \text{mm}$

Section Review

26.1 Interactions of Electric and Magnetic Fields and Matter pages 697–704

page 704

9. Cathode-Ray Tube Describe how a cathode-ray tube forms an electron beam.

Electrons are emitted by the cathode, accelerated by a potential difference, and passed through slits to form a beam.

10. Magnetic Field The radius of the circular path of an ion in a mass spectrometer is given by $r = (1/B)\sqrt{2Vm/q}$. Use this equation to explain how a mass spectrometer is able to separate ions of different masses.

Assuming all of the ions have the same charge, the only variable that is not constant in the equation is the ion mass, *m.* As *m* increases, the radius of the ion's path also increases. This results in separate paths for each unique mass.

11. Magnetic Field A modern mass spectrometer can analyze molecules having masses of hundreds of proton masses. If the singly charged ions of these molecules are produced using the same accelerating voltage, how would the mass spectrometer's magnetic field have to be changed for the ions to hit the film?

Since $r = (1/B)\sqrt{2Vm/q}$, as *m* increases, so too must *B*. If *m* is raised by a factor of about 10, *B* would have to increase by a factor of about 3 because to keep *r* constant, *B* must increase as $\sqrt{m}$.

12. Path Radius A proton moves at a speed of 4.2×10^{4} m/s as it passes through a magnetic field of 1.20 T. Find the radius of the circular path.

$$\frac{q}{m} = \frac{v}{Br}$$

$$r = \frac{vm}{qB} = \frac{(4.2\times10^{4}\text{ m/s})(1.67\times10^{-27}\text{ kg})}{(1.60\times10^{-19}\text{ C})(1.20\text{ T})} = 3.7\times10^{-4}\text{ m}$$

13. Mass A beam of doubly ionized (2+) oxygen atoms is accelerated by a potential difference of 232 V. The oxygen then enters a magnetic field of 75 mT and follows a curved path with a radius of 8.3 cm. What is the mass of the oxygen atom?

$$\frac{q}{m} = \frac{2V}{B^2r^2}$$

$$m = \frac{qB^2r^2}{2V} = \frac{(2)(1.60\times10^{-19}\text{ C})(75\times10^{-3}\text{ T})^2(8.3\times10^{-2}\text{ m})^2}{(2)(232\text{ V})}$$

$$= 2.7\times10^{-26}\text{ kg}$$

14. **Critical Thinking** Regardless of the energy of the electrons used to produce ions, J. J. Thomson never could remove more than one electron from a hydrogen atom. What could he have concluded about the positive charge of a hydrogen atom?

It must be only a single elementary charge.

Practice Problems

26.2 Electric and Magnetic Fields in Space pages 705–713

page 706

15. What is the speed in air of an electromagnetic wave having a frequency of 3.2×10^{19} Hz?

All electromagnetic waves travel through air or a vacuum at *c*, 3.00×10^{8} m/s.

16. What is the wavelength of green light having a frequency of 5.70×10^{14} Hz?

$$\lambda = \frac{c}{f} = \frac{3.00\times10^{8}\text{ m/s}}{5.70\times10^{14}\text{ Hz}} = 5.26\times10^{-7}\text{ m}$$

17. An electromagnetic wave has a frequency of 8.2×10^{14} Hz. What is the wavelength of the wave?

$$\lambda = \frac{c}{f} = \frac{3.00\times10^{8}\text{ m/s}}{8.2\times10^{14}\text{ Hz}} = 3.7\times10^{-7}\text{ m}$$

18. What is the frequency of an electromagnetic wave having a wavelength of 2.2×10^{-2} m?

$$\lambda = \frac{c}{f}$$

$$f = \frac{c}{\lambda} = \frac{3.00\times10^{8}\text{ m/s}}{2.2\times10^{-2}\text{ m}} = 1.4\times10^{10}\text{ Hz}$$

page 707

19. What is the speed of an electromagnetic wave traveling through the air? Use $c = 299{,}792{,}458$ m/s in your calculation.

$$v = \frac{c}{\sqrt{K}} = \frac{299{,}792{,}458\text{ m/s}}{\sqrt{1.00054}}$$

$$= 2.99712\times10^{8}\text{ m/s}$$

20. For light traveling through water, the dielectric constant is 1.77. What is the speed of light traveling through water?

$$v = \frac{c}{\sqrt{K}} = \frac{3.00\times10^{8}\text{ m/s}}{\sqrt{1.77}}$$

$$= 2.25\times10^{8}\text{ m/s}$$

21. The speed of light traveling through a material is 2.43×10^{8} m/s. What is the dielectric constant of the material?

$$v = \frac{c}{\sqrt{K}}$$

$$K = \left(\frac{c}{v}\right)^2 = \left(\frac{3.00\times10^{8}\text{ m/s}}{2.43\times10^{8}\text{ m/s}}\right)^2 = 1.52$$

Section Review

26.2 Electric and Magnetic Fields in Space pages 705–713

page 713

22. **Wave Propagation** Explain how electromagnetic waves are able to propagate through space.

The changing electric field induces a changing magnetic field, and the changing magnetic field induces a changing electric field. The waves propagate as these two fields regenerate each other.

23. **Electromagnetic Waves** What are some of the primary characteristics of electromagnetic waves? Do electromagnetic waves behave differently from the way that other waves, such as sound waves, behave? Explain.

Electromagnetic waves can be described by frequency and wavelength. They behave similarly to other waves in that they reflect, refract, diffract, interfere, and can be Doppler shifted. The difference between the electromagnetic waves and other waves, such as sound waves, is that electromagnetic waves can travel through a vacuum and can be polarized.

24. Frequency An electromagnetic wave is found to have a wavelength of 1.5×10^{-5} m. What is the frequency of the wave?

$$\lambda = \frac{c}{f}$$

$$f = \frac{c}{\lambda} = \frac{3.00\times10^{8}\text{ m/s}}{1.5\times10^{-5}\text{ m}} = 2.0\times10^{13}\text{ Hz}$$

25. TV Signals Television antennas normally have metal rod elements that are oriented horizontally. From this information, what can you deduce about the directions of the electric fields in television signals?

They also must be horizontal.

26. Parabolic Receivers Why is it important for a parabolic dish's receiving antenna to be properly aligned with the transmitter?

Parabolic dish antennas are only able to receive signals within a very narrow range of angles. It is, therefore, necessary to carefully align the dish receiver with the transmitting antennas to maximize the received signal strength.

27. Antenna Design Television channels 2 through 6 have frequencies just below the FM radio band, while channels 7 through 13 have much higher frequencies. Which signals would require a longer antenna: those of channel 7 or those of channel 6? Provide a reason for your answer.

The signals of channel 6 would require a longer antenna. Lower-frequency waves would have longer wavelengths.

28. Dielectric Constant The speed of light traveling through an unknown material is 1.98×10^{8} m/s. Given that the speed of light in a vacuum is 3.00×10^{8} m/s, what is the dielectric constant of the unknown material?

$$v = \frac{c}{\sqrt{K}}$$

$$K = \left(\frac{c}{v}\right)^2 = \left(\frac{3.00\times10^{8}\text{ m/s}}{1.98\times10^{8}\text{ m/s}}\right)^2 = 2.30$$

29. Critical Thinking Most of the UV radiation from the Sun is blocked by the ozone layer in Earth's atmosphere. In recent years, scientists have discovered that the ozone layer over both Antarctica and the Arctic Ocean is thinning. Use what you have learned about electromagnetic waves and energy to explain why some scientists are very concerned about the thinning ozone layer.

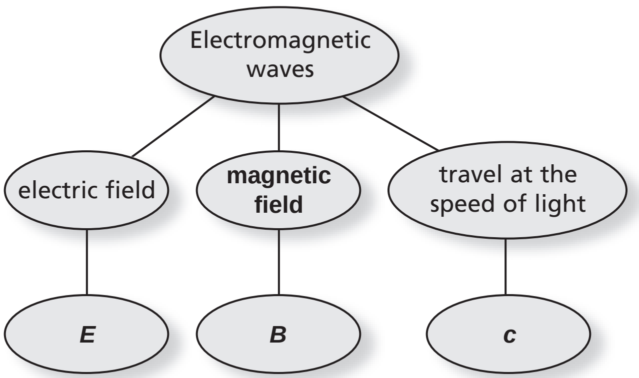
If the entire ozone layer is thinning, the amount of UV radiation from the Sun that is blocked by the ozone layer will decrease, allowing more UV rays to reach the surface of Earth. The wavelengths of UV waves are short enough, and their energies are high enough, to damage skin molecules. Thus, the resulting increase in UV rays to which humans would be exposed could increase the prevalence of skin cancer.

Chapter Assessment

Concept Mapping

page 718

30. Complete the following concept map using the following term and symbols: *E, c, magnetic field.*



Mastering Concepts

page 718

31. What are the mass and charge of an electron? (26.1)

The mass of an electron is 9.11×10^{-31} kg.
Its charge is -1.60×10^{-19} C.

32. What are isotopes? (26.1)

Isotopes are atoms of the same element that have different masses.

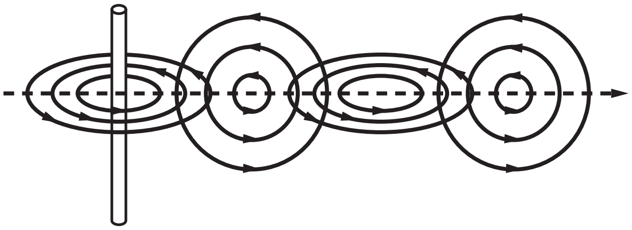
33. The direction of an induced magnetic field is always at what angle to the changing electric field? (26.2)

An induced magnetic field is always at right angles to the changing electric field.

34. Why must an AC generator be used to propagate electromagnetic waves? If a DC generator were used, when would it create electromagnetic waves? (26.2)

An AC generator supplies the changing electric field, which in turn generates a changing magnetic field. A DC generator would only generate a changing electric field when turned on or off.

35. A vertical antenna wire transmits radio waves. Sketch the antenna and the electric and magnetic fields that it creates. (26.2)



36. What happens to a quartz crystal when a voltage is applied across it? (26.2)

Quartz crystals bend or deform when voltage is placed across them. The quartz crystal then will vibrate at a set frequency.

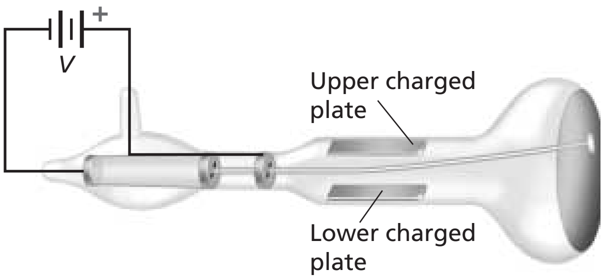
37. How does an antenna's receiving circuit select electromagnetic radio waves of a certain frequency and reject all others? (26.2)

By adjusting the capacitance of the antenna circuit, the oscillation frequency of the circuit equals the frequency of the desired radio waves. Resonance occurs, causing the electrons in the circuit to oscillate at that frequency.

Applying Concepts

page 718

38. The electrons in a Thomson tube travel from left to right, as shown in **Figure 26-14.** Which deflection plate should be charged positively to bend the electron beam upward?



■ **Figure 26-14**

The top plate should be charged positively.

39. The Thomson tube in question 38 uses a magnetic field to deflect the electron beam. What would the direction of the magnetic field need to be to bend the beam downward?

The magnetic field would be directed into the plane of the paper.

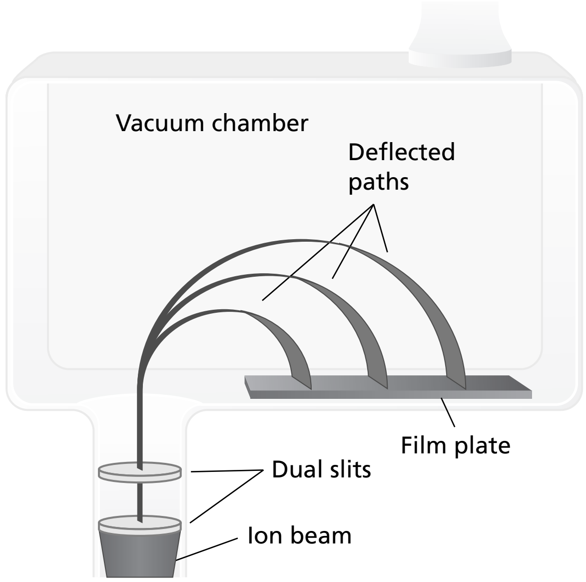
40. Show that the units of E/B are the same as the units for velocity.

$$\frac{\mathbf{E}}{\mathbf{B}} = \frac{\frac{\mathbf{N}}{\mathbf{C}}}{\frac{\mathbf{N}}{\mathbf{A \cdot m}}} = \frac{\mathbf{A \cdot m}}{\mathbf{C}}$$

Because 1 A is 1 C/s, this becomes

$$\frac{\mathbf{E}}{\mathbf{B}} = \frac{\mathbf{C \cdot m}}{\mathbf{s \cdot C}} = \frac{\mathbf{m}}{\mathbf{s}}$$

41. The vacuum chamber of a mass spectrometer is shown in **Figure 26-15.** If a sample of ionized neon is being tested in the mass spectrometer, in what direction must the magnetic field be directed to bend the ions into a clockwise semicircle?



■ **Figure 26-15**

The magnetic field is found by the right-hand rule and would be directed out from and perpendicular to the plane of the paper.

42. If the sign of the charge on the particles in question 41 is changed from positive to negative, do the directions of either or both of the fields have to be changed to keep the particles undeflected? Explain.

You can either change both fields or neither field, but you cannot change only one field.

43. For each of the following properties, identify whether radio waves, light waves, or X rays have the largest value.

a. wavelength

Radio waves have the longest wavelengths.

b. frequency

X rays have the highest frequencies.

c. velocity

All travel at the same velocity, which is the speed of light.

44. **TV Waves** The frequency of television waves broadcast on channel 2 is about 58 MHz. The waves broadcast on channel 7 are about 180 MHz. Which channel requires a longer antenna?

Channel 2 waves have a lower frequency and a longer wavelength, so channel 2 requires a longer antenna. The length of an antenna is directly proportional to wavelength.

45. Suppose the eyes of an alien being are sensitive to microwaves. Would you expect such a being to have larger or smaller eyes than yours? Why?

The eyes would be much larger, because the wavelength of microwave radiation is much larger than that of visible light.

Mastering Problems

26.1 Interactions of Electric and Magnetic Fields and Matter

page 719

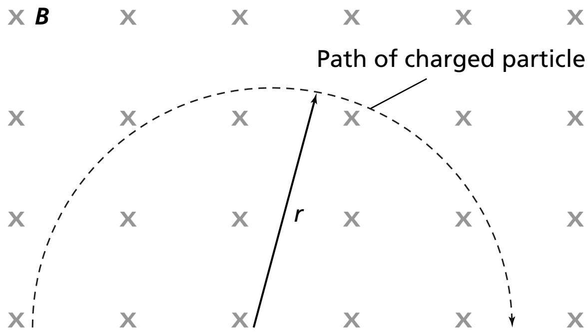
Level 1

46. Electrons moving at 3.6×10^4 m/s pass through an electric field with an intensity of 5.8×10^3 N/C. How large a magnetic field must the electrons also experience for their path to be undeflected?

$$v = \frac{E}{B}$$

$$B = \frac{E}{v} = \frac{5.8\times10^3\text{ N/C}}{3.6\times10^4\text{ m/s}} = 0.16\text{ T}$$

47. A proton moves across a 0.36-T magnetic field, as shown in **Figure 26-16.** If the proton moves in a circular path with a radius of 0.20 m, what is the speed of the proton?



■ **Figure 26-16**

$$\frac{q}{m} = \frac{2v}{Br}$$

$$v = \frac{Brq}{m} = \frac{(0.36\text{ T})(0.20\text{ m})(1.60\times10^{-19}\text{ C})}{1.67\times10^{-27}\text{ kg}}$$

$$= 6.9\times10^6\text{ m/s}$$

48. A proton enters a 6.0×10^{-2}-T magnetic field with a speed of 5.4×10^{4} m/s. What is the radius of the circular path it follows?

$$r = \frac{mv}{Bq} = \frac{(1.67\times10^{-27}\text{ kg})(5.4\times10^{4}\text{ m/s})}{(6.0\times10^{-2}\text{ T})(1.60\times10^{-19}\text{ C})} = 9.4\times10^{-3}\text{ m}$$

49. An electron is accelerated by a 4.5-kV potential difference. How strong a magnetic field must be experienced by the electron if its path is a circle of radius 5.0 cm?

$$B = \frac{1}{r}\sqrt{\frac{2Vm}{q}} = \frac{1}{0.050\text{ m}}\sqrt{\frac{(2)(4.5\times10^{3}\text{ V})(9.11\times10^{-31}\text{ kg})}{1.60\times10^{-19}\text{ C}}}$$

$$= 4.5\times10^{-3}\text{ T}$$

50. A mass spectrometer yields the following data for a beam of doubly ionized (2+) sodium atoms: $B = 8.0\times10^{-2}$ T, $q = 2(1.60\times10^{-19}$ C), $r = 0.077$ m, and $V = 156$ V. Calculate the mass of a sodium atom.

$$\frac{q}{m} = \frac{2V}{B^2r^2}$$

$$m = \frac{qB^2r^2}{2V} = \frac{(2)(1.60\times10^{-19}\text{ C})(8.0\times10^{-2}\text{ T})^2(0.077\text{ m})^2}{(2)(156\text{ V})} = 3.9\times10^{-26}\text{ kg}$$

Level 2

51. An alpha particle has a mass of approximately 6.6×10^{-27} kg and has a charge of 2+. Such a particle is observed to move through a 2.0-T magnetic field along a path of radius 0.15 m.

a. What speed does the particle have?

$$\frac{q}{m} = \frac{v}{Br}$$

$$v = \frac{Bqr}{m} = \frac{(2.0\text{ T})(2)(1.60\times10^{-19}\text{ C})(0.15\text{ m})}{6.6\times10^{-27}\text{ kg}}$$

$$= 1.5\times10^{7}\text{ m/s}$$

b. What is its kinetic energy?

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{Bqr}{m}\right)^2 = \frac{q^2B^2r^2}{2m} = \frac{(2)(1.60\times10^{-19}\text{ C})(2.0\text{ T})^2(0.15\text{ m})^2}{(2)(6.6\times10^{-27}\text{ kg})}$$

$$= 7.0\times10^{-13}\text{ J}$$

c. What potential difference would be required to give it this kinetic energy?

$$KE = qV$$

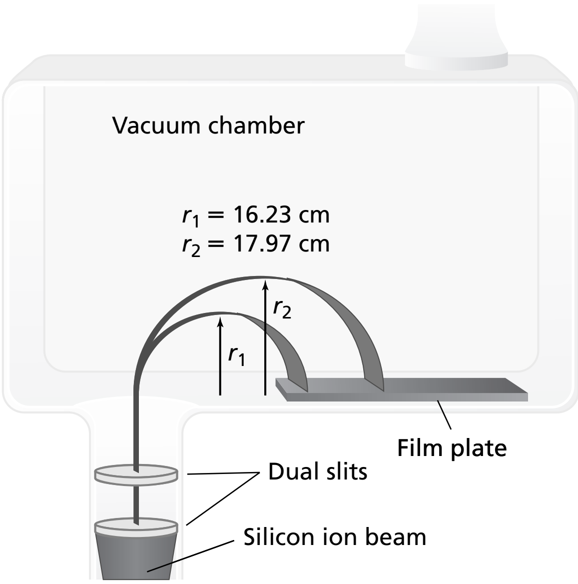
$$V = \frac{KE}{q} = \frac{7.0\times10^{-13}\text{ J}}{(2)(1.60\times10^{-19}\text{ C})} = 2.2\times10^{6}\text{ V}$$

52. A mass spectrometer analyzes carbon-containing molecules with a mass of 175×10^{3} proton masses. What percent differentiation is needed to produce a sample of molecules in which only carbon isotopes of mass 12, and none of mass 13, are present?

The difference between carbon-12 and carbon-13 is one proton mass. To distinguish between these, a percent differentiation of one proton mass out of 175×10^3 is needed, or

$$\frac{1}{175{,}000}\times 100 = \frac{1}{1750}\text{ percent.}$$

53. Silicon Isotopes In a mass spectrometer, ionized silicon atoms have curvatures, as shown in **Figure 26-17.** If the smaller radius corresponds to a mass of 28 proton masses, what is the mass of the other silicon isotope?



■ **Figure 26-17**

$$\frac{q}{m} = \frac{2V}{B^2r^2}$$

so m is proportional to r^2

$$\frac{m_2}{m_1} = \frac{{r_2}^2}{{r_1}^2}$$

$$m_2 = m_1\left(\frac{r_2}{r_1}\right)^2$$

$$= (28\ m_p)\left(\frac{17.97\text{ cm}}{16.23\text{ cm}}\right)^2 = 34m_p$$

$$m_2 = 34m_p = (34)(1.67\times10^{-27}\text{ kg})$$

$$= 5.7\times10^{-26}\text{ kg}$$

26.2 Electric and Magnetic Fields in Space page 719

Level 1

54. Radio Waves The radio waves reflected by a parabolic dish are 2.0 cm long. How long should the antenna be that detects the waves?

The antenna is $\frac{\lambda}{2}$, or 1.0 cm long.

55. TV A television signal is transmitted on a carrier frequency of 66 MHz. If the wires on a receiving antenna are placed $\frac{1}{4}\lambda$ apart, determine the physical distance between the receiving antenna wires.

$$\frac{1}{4}\lambda = \left(\frac{1}{4}\right)\frac{c}{f}$$

$$= \frac{3.00\times10^8\text{ m/s}}{(4)(66\times10^6\text{ Hz})}$$

$$= 1.1\text{ m}$$

56. Bar-Code Scanner A bar-code scanner uses a laser light source with a wavelength of about 650 nm. Determine the frequency of the laser light source.

$$f = \frac{c}{\lambda} = \frac{3.00\times10^8\text{ m/s}}{650\times10^{-9}\text{ m}} = 4.6\times10^{14}\text{ Hz}$$

57. What is the optimum length of a receiving antenna that is to receive a 101.3-MHz radio signal?

Optimum antenna length is

$$\frac{1}{2}\lambda = \left(\frac{1}{2}\right)\frac{c}{f}$$

$$= \frac{3.00\times10^8\text{ m/s}}{(2)(101.3\times10^6\text{ Hz})}$$

$$= 1.48\text{ m}$$

Level 2

58. An EM wave with a frequency of 100-MHz is transmitted through a coaxial cable having a dielectric constant of 2.30. What is the velocity of the wave's propagation?

$$v = \frac{c}{\sqrt{K}} = \frac{3.00\times10^8\text{ m/s}}{\sqrt{2.30}} = 1.98\times10^8\text{ m/s}$$

59. **Cell Phone** A certain cellular telephone transmitter operates on a carrier frequency of 8.00×10^8 Hz. What is the optimal length of a cell phone antenna designed to receive this signal? Note that single-ended antennas, such as those used by cell phones, generate peak *EMF* when their length is one-fourth the wavelength of the wave.

For a single-ended antenna, optimum antenna length is

$$\frac{1}{4}\lambda = \left(\frac{1}{4}\right)\frac{c}{f}$$

$$= \frac{3.00\times10^8 \text{ m/s}}{(4)(8.00\times10^8 \text{ Hz})}$$

$$= 0.0938 \text{ m}$$

Mixed Review

page 720

Level 1

60. The mass of a doubly ionized (2+) oxygen atom is found to be 2.7×10^{-26} kg. If the mass of an atomic mass unit (amu) is equal to 1.67×10^{-27} kg, how many atomic mass units are in the oxygen atom?

$$(2.7\times10^{-26} \text{ kg})\left(\frac{1 \text{ amu}}{1.67\times10^{-27} \text{ kg}}\right) = 16 \text{ amu}$$

61. **Radio** An FM radio station broadcasts on a frequency of 94.5 MHz. What is the antenna length that would give the best reception for this station?

Optimum antenna length is

$$\frac{1}{2}\lambda = \left(\frac{1}{2}\right)\frac{c}{f}$$

$$= \frac{3.00\times10^8 \text{ m/s}}{(2)(94.5\times10^6 \text{ Hz})}$$

$$= 1.59 \text{ m}$$

Level 2

62. At what frequency does a cell phone with an 8.3-cm-long antenna send and receive signals? Recall from question 59 that single-ended antennas, such as those used by cell phones, generate peak *EMF* when their length is one-fourth the wavelength of the wave they are broadcasting or receiving.

The antenna length is

$$0.083 \text{ m} = \frac{1}{4}\lambda = \left(\frac{1}{4}\right)\frac{c}{f}$$

The frequency, then, is

$$f = \frac{c}{(4)(0.083 \text{ m})}$$

$$= \frac{3.00\times10^8 \text{ m/s}}{(4)(0.083 \text{ m})}$$

$$= 9.0\times10^8 \text{ Hz}$$

63. An unknown particle is accelerated by a potential difference of 1.50×10^2 V. The particle then enters a magnetic field of 50.0 mT, and follows a curved path with a radius of 9.80 cm. What is the ratio of q/m?

$$\frac{q}{m} = \frac{2V}{B^2r^2}$$

$$= \frac{(2)(1.50\times10^2 \text{ V})}{(50.0\times10^{-3} \text{ T})^2(9.80\times10^{-2} \text{ m})^2}$$

$$= 1.25\times10^7 \text{ C/kg}$$

Thinking Critically

page 720

64. **Apply Concepts** Many police departments use radar guns to catch speeding drivers. A radar gun is a device that uses a high-frequency electromagnetic signal to measure the speed of a moving object. The frequency of the radar gun's transmitted signal is known. This transmitted signal reflects off of the moving object and returns to the receiver on the radar gun. Because the object is moving relative to the radar gun, the frequency of the returned signal is different from that of the originally transmitted signal. This phenomenon is known as the Doppler shift. When the object is moving toward the radar gun, the frequency of the returned signal is greater than the frequency of the original signal. If the initial transmitted signal has a frequency of 10.525 GHz and the returned signal shows a Doppler shift of 1850 Hz, what is the speed of the moving object? Use the following equation:

$$v_{\text{target}} = \frac{cf_{\text{Doppler}}}{2f_{\text{transmitted}}}$$

Where,

v_{target} = velocity of target (m/s)

c = speed of light (m/s)

$f_{Doppler}$ = Doppler shift frequency (Hz)

$f_{transmitted}$ = frequency of transmitted wave (Hz)

$$v_{target} = \frac{cf_{Doppler}}{2f_{transmitted}} = \frac{(3.00\times10^{8}\text{ m/s})(1850\text{ Hz})}{(2)(10.525\times10^{9}\text{ Hz})} = 26.4\text{ m/s}$$

65. Apply Concepts H. G. Wells wrote a science-fiction novel called *The Invisible Man*, in which a man drinks a potion and becomes invisible, although he retains all of his other faculties. Explain why an invisible person would not be able to see.

To see, you must detect the light, which means the light will be absorbed or scattered. Essentially, an invisible person would be completely transparent so light would just pass through the eye without ever being absorbed or scattered.

66. Design an Experiment You are designing a mass spectrometer using the principles discussed in this chapter, but with an electronic detector replacing the photographic film. You want to distinguish singly ionized (1+) molecules of 175 proton masses from those with 176 proton masses, but the spacing between adjacent cells in your detector is 0.10 mm. The molecules must have been accelerated by a potential difference of at least 500.0 V to be detected. What are some of the values of *V*, *B*, and *r* that your apparatus should have?

The charge-to-mass ratio for isotopes in a mass spectrometer is $\frac{q}{m} = \frac{2V}{B^2r^2}$ **so the radius of the isotope's path is** $r = \frac{1}{B}\sqrt{\frac{2Vm}{q}}$.

The difference in the radii for the two isotopes is

$$\begin{aligned} 0.10\times10^{-3}\text{ m} &= r_{176} - r_{175} \\ &= \frac{1}{B}\sqrt{\frac{2V}{q}}\left(\sqrt{m_{176}} - \sqrt{m_{175}}\right) \\ &= \frac{1}{B}\sqrt{\frac{2V}{q}}\left(\sqrt{176m_p} - \sqrt{175m_p}\right) \\ &= \frac{1}{B}\sqrt{\frac{2Vm_p}{q}}\left(\sqrt{176} - \sqrt{175}\right) \end{aligned}$$

The magnetic field, then, is

$$\begin{aligned} B &= \frac{\left(\sqrt{176} - \sqrt{175}\right)}{0.10\times10^{-3}\text{ m}}\sqrt{\frac{2Vm_p}{q}} \\ &= \frac{\left(\sqrt{176} - \sqrt{175}\right)}{0.10\times10^{-3}\text{ m}}\sqrt{\frac{(2)(500.0\text{ V})(1.67\times10^{-27}\text{kg})}{1.60\times10^{-19}\text{ C}}} \\ &= 1.2\text{ T} \end{aligned}$$

The radius for the isotope with a mass equal to 176 proton masses

is $r_{76} = \frac{1}{B}\sqrt{\frac{2V(176m_p)}{q}} = \frac{1}{1.2\text{ T}}\sqrt{\frac{(2)(5.00\text{ V})(176)(1.67\times10^{-27}\text{ kg})}{1.60\times10^{-19}\text{ C}}}$

$$= 3.6\times10^{-2}\text{ m}$$

When designing the spectrometer, you can choose any value of *V* and *B*, provided *V* is at least 500.0 V. However, since *q*/*m* is constant, *V* will be proportional to B^2r^2.

Writing in Physics

page 720

67. Compose a 1–2 page report in which you outline the operation of a typical television, DVD, or VCR infrared remote-control unit. Explain why the simultaneous use of multiple remote-control units typically does not cause the units to interfere with each other. Your report should include block diagrams and sketches.

Remote controls use a broad range of IR frequencies that are pulse-code modulated. Each button on the remote produces a unique sequence of short and long pulses. Because of the wide range of frequencies used by different manufacturers and the unique pulse codes used, it is very unlikely that different remote controls will interfere with each other.

Cumulative Review

page 720

68. A He–Ne laser (λ = 633 nm) is used to illuminate a slit of unknown width, forming a pattern on a screen that is located 0.95 m behind the slit. If the first dark band is 8.5 mm from the center of the central bright band, how wide is the slit? (Chapter 19)

$$\lambda = \frac{x_1 w}{L}$$

$$w = \frac{\lambda L}{x_1}$$

$$= \frac{(633\times10^{-9}\text{ m})(0.95\text{ m})}{8.5\times10^{-3}\text{ m}}$$

$$= 7.1\times10^{-5}\text{ m}$$

69. The force between two identical metal spheres with the charges shown in **Figure 26-18** is *F*. If the spheres are touched together and returned to their original positions, what is the new force between them? (Chapter 20)

■ **Figure 26-18**

The spheres share charges equally when they are touched together, so they each carry –1*q* of charge. The force varies with the product of the charges, so the new force is to the old force as 1*q* × 1*q* is to 4*q* × 2*q*, or 1:8. Therefore, the new force is *F*/8. The direction of the new force will be repulsive, rather than attractive.

70. What is the electric field strength between two parallel plates spaced 1.2 cm apart if a potential difference of 45 V is applied to them? (Chapter 21)

$$E = \frac{\Delta V}{d} = \frac{45\text{ V}}{0.012\text{ m}} = 3.8\times10^{3}\text{ V/m or N/C}$$

71. Calculate the daily cost of operating an air compressor that runs one-fourth of the time and draws 12.0 A from a 245-V circuit if the cost is $0.0950 per kWh. (Chapter 22)

$$\text{cost} = (E)(\text{rate})$$

$$= (IVt)(\text{rate})$$

$$= (120\text{ A})(245\text{ V})(6\text{ h})\left(\frac{\$0.0950}{\text{kWh}}\right)\left(\frac{1\text{ kW}}{1000\text{ W}}\right)$$

$$= \$1.68$$

72. A 440-cm length of wire carrying 7.7 A is at right angles to a magnetic field. The force on the wire is 0.55 N. What is the strength of the field? (Chapter 24)

$$F = BIL$$

$$B = \frac{F}{IL}$$

$$= \frac{0.55\text{ N}}{(7.7\text{ A})(4.4\text{ m})}$$

$$= 0.016\text{ T}$$

73. A north-south wire is moved toward the east through a magnetic field that is pointing down, into Earth. What is the direction of the induced current? (Chapter 25)

north

Challenge Problems

page 709

Visible light makes up only a very small portion of the entire electromagnetic spectrum. The wavelengths for some of the colors of visible light are shown in **Table 26-1.**

Table 26-1	
Wavelengths of Visible Light	
Color	**Wavelength (nm)**
Violet–Indigo	390 to 455
Blue	455 to 492
Green	492 to 577
Yellow	577 to 597
Orange	597 to 622
Red	622 to 700

1. Which color of light has the longest wavelength?

red

2. Which color travels the fastest in a vacuum?

They all travel at the same speed, *c*.

3. Waves with longer wavelengths diffract around objects in their path more than waves with shorter wavelengths. Which color will diffract the most? The least?

Red light will diffract the most. Violet light will diffract the least.

4. Calculate the frequency range for each color of light given in Table 26-1.

The frequency is $f = \frac{c}{\lambda}$.

For $\lambda = 390$ **nm,**

$$f = \frac{3.00\times10^{8}\text{ m/s}}{3.90\times10^{-7}\text{ m}} = 7.69\times10^{14}\text{ Hz}$$

For $\lambda = 455$ **nm,**

$$f = \frac{3.00\times10^{8}\text{ m/s}}{4.55\times10^{-7}\text{ m}} = 6.59\times10^{14}\text{ Hz}$$

For $\lambda = 492$ **nm,**

$$f = \frac{3.00\times10^{8}\text{ m/s}}{4.92\times10^{-7}\text{ m}} = 6.10\times10^{14}\text{ Hz}$$

For $\lambda = 577$ **nm,**

$$f = \frac{3.00\times10^{8}\text{ m/s}}{5.77\times10^{-7}\text{ m}} = 5.20\times10^{14}\text{ Hz}$$

For $\lambda = 597$ **nm,**

$$f = \frac{3.00\times10^{8}\text{ m/s}}{5.97\times10^{-7}\text{ m}} = 5.03\times10^{14}\text{ Hz}$$

For $\lambda = 622$ **nm,**

$$f = \frac{3.00\times10^{8}\text{ m/s}}{6.22\times10^{-7}\text{ m}} = 4.82\times10^{14}\text{ Hz}$$

For $\lambda = 700$ **nm,**

$$f = \frac{3.00\times10^{8}\text{ m/s}}{7.00\times10^{-7}}\text{ m} = 4.29\times10^{14}\text{ Hz}$$

(4×10^{14} **Hz to one significant digit)**

Thus, the ranges are

Violet: 6.59×10^{14} **Hz to** 7.69×10^{14} **Hz**
Blue: 6.10×10^{14} **Hz to** 6.59×10^{14} **Hz**
Green: 5.20×10^{14} **Hz to** 6.10×10^{14} **Hz**
Yellow: 5.03×10^{14} **Hz to** 5.20×10^{14} **Hz**
Orange: 4.82×10^{14} **Hz to** 5.03×10^{14} **Hz**
Red: 4.29×10^{14} **Hz to** 4.82×10^{14} **Hz**

Quantum Theory

Practice Problems

27.1 A Particle Model of Waves pages 723–734

page 730

1. An electron has an energy of 2.3 eV. What is the energy of the electron in joules?

$$(2.3\text{ eV})\left(\frac{1.60\times10^{-19}\text{ J}}{1\text{ eV}}\right) = 3.7\times10^{-19}\text{ J}$$

2. What is the energy in eV of an electron with a velocity of 6.2×10^6 m/s?

$$KE = \frac{1}{2}mv^2$$

$$= \left(\frac{1}{2}\right)(9.11\times10^{-31}\text{ kg})(6.2\times10^6\text{ m/s})^2$$

$$= (1.75\times10^{-17}\text{ J})\left(\frac{1\text{ eV}}{1.60\times10^{-19}\text{ J}}\right)$$

$$= 1.1\times10^2\text{ eV}$$

3. What is the velocity of the electron in problem 1?

$$m = 9.11\times10^{-31}\text{ kg},\ KE = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{(2)(3.7\times10^{-19}\text{ J})}{9.11\times10^{-31}\text{ kg}}}$$

$$= 9.0\times10^5\text{ m/s}$$

4. The stopping potential for a photoelectric cell is 5.7 V. Calculate the maximum kinetic energy of the emitted photoelectrons in eV.

$$KE = -qV_0$$

$$= -(-1.60\times10^{-19}\text{ C})(5.7\text{ J/C})\left(\frac{1\text{ eV}}{1.60\times10^{-19}\text{ J}}\right)$$

$$= 5.7\text{ eV}$$

5. The stopping potential required to prevent current through a photocell is 3.2 V. Calculate the maximum kinetic energy in joules of the photoelectrons as they are emitted.

$$KE = -qV_0$$

$$= -(-1.60\times10^{-19}\text{ C})(3.2\text{ J/C})$$

$$= 5.1\times10^{-19}\text{ J}$$

page 732

6. The threshold wavelength of zinc is 310 nm. Find the threshold frequency, in Hz, and the work function, in eV, of zinc.

$$f_0 = \frac{c}{\lambda_0} = \frac{3.00\times10^8\text{ m/s}}{310\times10^{-9}\text{ m}} = 9.7\times10^{14}\text{ Hz}$$

$$W = hf_0$$

$$= (6.63\times10^{-34}\text{ J/Hz})(9.7\times10^{14}\text{ Hz})\left(\frac{1\text{ eV}}{1.60\times10^{-19}\text{ J}}\right)$$

$$= 4.0\text{ eV}$$

7. The work function for cesium is 1.96 eV. What is the kinetic energy, in eV, of photoelectrons ejected when 425-nm violet light falls on the cesium?

$$KE_{max} = \frac{1240\text{ eV·nm}}{\lambda} - hf_0$$

$$= \frac{1240\text{ eV·nm}}{425\text{ nm}} - 1.96\text{ eV}$$

$$= 0.960\text{ eV}$$

8. When a metal is illuminated with 193-nm ultraviolet radiation, electrons with energies of 3.5 eV are emitted. What is the work function of the metal?

$$KE = hf - hf_0$$

$$hf_0 = hf - KE = \frac{hc}{\lambda} - KE$$

$$= \frac{1240\text{ eV·nm}}{\lambda} - KE$$

$$= \frac{1240\text{ eV·nm}}{193\text{ nm}} - 3.5\text{ eV}$$

$$= 2.9\text{ eV}$$

9. A metal has a work function of 4.50 eV. What is the longest-wavelength radiation that will cause it to emit photoelectrons?

$$hf_0 = 4.50\text{ eV, so } \frac{hc}{\lambda_0} = 4.50\text{ eV}$$

$$\text{Thus, } \lambda_0 = \frac{1240\text{ eV·nm}}{4.50\text{ eV}} = 276\text{ nm}$$

Section Review

27.1 A Particle Model of Waves pages 723–734

page 734

10. Photoelectric Effect Why is high-intensity, low-frequency light unable to eject electrons from a metal, whereas low-intensity, high-frequency light can? Explain.

Light, a form of electromagnetic radiation, is quantized and massless, yet it does have kinetic energy. Each incident photon interacts with a single electron. If the incident photon does not have sufficient energy, it cannot eject an electron. Because energy is directly related to frequency, low frequency light does not have sufficient energy to eject an electron, whereas high frequency light does.

11. Frequency and Energy of Hot-Body Radiation As the temperature of a body is increased, how does the frequency of peak intensity change? How does the total amount of radiated energy change?

Both frequency of peak intensity and total energy radiated increase. The peak frequency increases as T, whereas the total energy increases as T^4.

12. Photoelectric and Compton Effects An experimenter sends an X ray into a target. An electron, but no other radiation, emerges from the target. Explain whether this event is a result of the photoelectric effect or the Compton effect.

It is a result of the photoelectric effect, which is the capture of a photon by an electron in matter and the transfer of the photon's energy to the electron.

13. Photoelectric and Compton Effects Distinguish the photoelectric effect from the Compton effect.

The Compton effect is the scattering of a photon by matter, resulting in a photon of lower energy and momentum. The photoelectric effect is the emission of electrons from a metal sample when radiation of sufficient energy is incident on it.

14. Photoelectric Effect Green light (λ = 532 nm) strikes an unknown metal, causing electrons to be ejected. The ejected electrons can be stopped by a potential of 1.44 V. What is the work function, in eV, of the metal?

$$E_{\text{green light}} = \frac{hc}{\lambda} = \frac{1240\text{ eV·nm}}{532\text{ nm}} = 2.33\text{ eV}$$

$$KE_{\text{ejected electron}} = -qV$$

$$= -(-1.60\times10^{-19}\text{ C})(1.44\text{ J/C})\left(\frac{1\text{ eV}}{1.60\times10^{-19}\text{ J}}\right)$$

$$= 1.44\text{ eV}$$

$$W = E_{\text{green light}} - KE_{\text{ejected electron}}$$

$$= 2.33\text{ eV} - 1.44\text{ eV}$$

$$= 0.89\text{ eV}$$

15. Energy of a Photon What is the energy, in eV, of the photons produced by a laser pointer having a 650-nm wavelength?

$$E = \frac{hc}{\lambda} = \frac{1240\text{ eV·nm}}{650\text{ nm}} = 1.9\text{ eV}$$

16. Photoelectric Effect An X ray is absorbed in a bone and releases an electron. If the X ray has a wavelength of approximately 0.02 nm, estimate the energy, in eV, of the electron.

$$E = \frac{hc}{\lambda} = \frac{1240\text{ eV·nm}}{0.02\text{ nm}} = 6\times10^4\text{ eV}$$

17. Compton Effect An X ray strikes a bone, collides with an electron, and is scattered. How does the wavelength of the scattered X ray compare to the wavelength of the incoming X ray?

The scattered X ray has a longer wavelength than the incoming X ray.

18. **Critical Thinking** Imagine that the collision of two billiard balls models the interaction of a photon and an electron during the Compton effect. Suppose the electron is replaced by a much more massive proton. Would this proton gain as much energy from the collision as the electron does? Would the photon lose as much energy as it does when it collides with the electron?

The answer to both questions is no. A tennis ball can transfer more kinetic energy to a softball than it can to a bowling ball.

Practice Problems

27.2 Matter Waves pages 735–737

page 736

19. A 7.0-kg bowling ball rolls with a velocity of 8.5 m/s.

a. What is the de Broglie wavelength of the bowling ball?

$$\lambda = \frac{h}{mv} = \frac{6.63\times10^{-34}\ \text{J·s}}{(7.0\ \text{kg})(8.5\ \text{m/s})}$$

$$= 1.1\times10^{-35}\ \text{m}$$

b. Why does the bowling ball exhibit no observable wave behavior?

The wavelength is too small to show observable effects.

20. What is the de Broglie wavelength and speed of an electron accelerated by a potential difference of 250 V?

$$\frac{1}{2}mv^2 = qV, \text{ so}$$

$$v = \sqrt{\frac{2qV}{m}} = \sqrt{\frac{(2)(1.60\times10^{-19}\ \text{C})(250\ \text{J/C})}{9.11\times10^{-31}\ \text{kg}}}$$

$$= 9.4\times10^{6}\ \text{m/s}$$

$$\lambda = \frac{h}{mv}$$

$$= \frac{6.63\times10^{-34}\ \text{J·s}}{(9.11\times10^{-31}\ \text{kg})(9.4\times10^{6}\ \text{m/s})}$$

$$= 7.7\times10^{-11}\ \text{m}$$

21. What voltage is needed to accelerate an electron so it has a 0.125-nm wavelength?

$$\lambda = \frac{h}{p}, \text{ so } p = \frac{h}{\lambda}$$

$$KE = \frac{1}{2}mv^2 = \frac{p^2}{2m} = \frac{\left(\frac{h}{\lambda}\right)^2}{2m}$$

$$= \frac{\left(\frac{6.63\times10^{-34}\ \text{J·s}}{0.125\times10^{-9}\ \text{m}}\right)^2}{(2)(9.11\times10^{-31}\ \text{kg})}$$

$$= (1.544\times10^{-17}\ \text{J})\left(\frac{1\ \text{eV}}{1.60\times10^{-19}\ \text{J}}\right)$$

= 96.5 eV, so it would have to be accelerated through 96.5 V.

22. The electron in Example Problem 3 has a de Broglie wavelength of 0.14 nm. What is the kinetic energy, in eV, of a proton ($m = 1.67\times10^{-27}$ kg) with the same wavelength?

The de Broglie wavelength is $\lambda = \frac{h}{mv}$

so the velocity is $v = \frac{h}{m\lambda}$

The kinetic energy, then, is

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{h}{m\lambda}\right)^2 = \frac{h^2}{2m\lambda^2}$$

$$= \frac{(6.63\times10^{-34}\ \text{J·s})^2}{(2)(1.67\times10^{-27}\ \text{kg})(0.14\times10^{-9}\ \text{m})^2}\left(\frac{1\ \text{eV}}{1.60\times10^{-19}\ \text{J}}\right)$$

$$= 4.2\times10^{-2}\ \text{eV}$$

Section Review

27.2 Matter Waves pages 735–737

page 737

23. **Wavelike Properties** Describe the experiment that confirmed that particles have wavelike properties.

When a beam of electrons was aimed at a crystal, the crystal acted like a diffraction grating, causing the electrons to form a diffraction pattern. The diffraction of the electrons (particles) is similar to the diffraction of light (waves) through a grating.

24. **Wave Nature** Explain why the wave nature of matter is not obvious.

The wavelengths of most objects are much too small to be detected.

25. **De Broglie Wavelength** What is the de Broglie wavelength of an electron accelerated through a potential difference of 125 V?

$$v = \sqrt{\frac{-2qV}{m}}$$

$$= \sqrt{\frac{-2(-1.60\times10^{-19}\text{ C})(125\text{ V})}{9.11\times10^{-31}\text{ kg}}}$$

$$= 6.63\times10^{6}\text{ m/s}$$

$$p = mv = (9.11\times10^{-31}\text{ kg})(6.63\times10^{6}\text{ m/s})$$

$$= 6.04\times10^{-24}\text{ kg·m/s}$$

$$\lambda = \frac{h}{p} = \frac{6.63\times10^{-34}\text{ J·s}}{6.04\times10^{-24}\text{ kg·m/s}}$$

$$= 1.10\times10^{-10}\text{ m}$$

$$= 0.110\text{ nm}$$

26. **Wavelengths of Matter and Radiation** When an electron collides with a massive particle, the electron's velocity and wavelength decrease. How is it possible to increase the wavelength of a photon?

If the photon undergoes Compton scattering with a fixed target, the wavelength of the photon will increase. Note, however, that the photon's speed is not changed. The photon still travels at *c*.

27. **Heisenberg Uncertainty Principle** When light or a beam of atoms passes through a double slit, an interference pattern forms. Both results occur even when atoms or photons pass through the slits one at a time. How does the Heisenberg uncertainty principle explain this?

The Heisenberg uncertainty principle states that you cannot simultaneously know the precise position and momentum of a particle. Thus, if you know the precise position of a photon or an atom as it passes through the slit, you cannot know its precise momentum. Because of the unknown momentum, you cannot be sure which of the slits the beam passed through, resulting in the distribution of photons or atoms seen in the interference pattern.

28. **Critical Thinking** Physicists recently made a diffraction grating of standing waves of light. Atoms passing through the grating produce an interference pattern. If the spacing of the slits in the grating were $\frac{1}{2}\lambda$ (about 250 nm), what was the approximate de Broglie wavelength of the atoms?

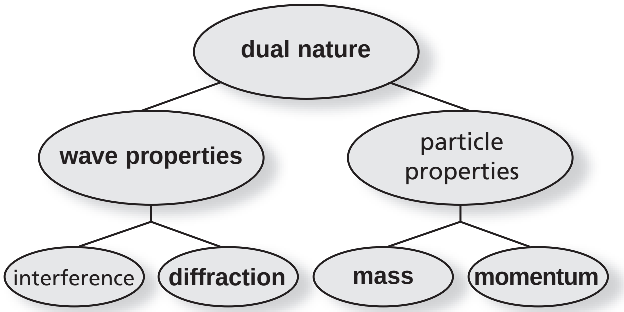
For diffraction gratings, $\lambda = d\sin\theta$, where *d* is the spacing of the slits, and θ is the angular separation between consecutive peaks. The de Broglie wavelength, then, is $\lambda = (250\text{ nm})\sin\theta$. If we assume $\sin\theta$ is around 0.1, then the de Broglie wavelength is a few tens of nanometers.

Chapter Assessment

Concept Mapping

page 742

29. Complete the following concept map using these terms: *dual nature, mass, wave properties, momentum, diffraction.*



Mastering Concepts

page 742

30. **Incandescent Light** An incandescent lightbulb is controlled by a dimmer. What happens to the color of the light given off by the bulb as the dimmer control is turned down? (27.1)

The light becomes redder.

31. Explain the concept of quantized energy. (27.1)

Quantized energy means that energy can exist only in multiples of some minimum value.

32. What is quantized in Max Planck's interpretation of the radiation of incandescent bodies? (27.1)

The vibrational energy of the incandescent atoms is quantized.

33. What is a quantum of light called? (27.1)

a photon

34. Light above the threshold frequency shines on the metal cathode in a photocell. How does Einstein's photoelectric effect theory explain the fact that as the light intensity increases, the current of photoelectrons increases? (27.1)

Each photon ejects a photoelectron. Light with greater intensity contains more photons per second; thus, it causes the ejection of more photoelectrons per second.

35. Explain how Einstein's theory accounts for the fact that light below the threshold frequency of a metal produces no photoelectrons, regardless of the intensity of the light. (27.1)

Photons below the threshold frequency do not have sufficient energy to eject an electron. If the intensity of the light increases, the number of photons increases but their energy does not; the photons are still unable to eject an electron.

36. **Photographic Film** Because certain types of black-and-white film are not sensitive to red light, they can be developed in a darkroom that is illuminated by red light. Explain this on the basis of the photon theory of light. (27.1)

Red photons do not have enough energy to cause the chemical reaction that exposes film.

37. How does the Compton effect demonstrate that photons have momentum as well as energy? (27.1)

Elastic collisions transfer both momentum and energy. Only if photons have momentum can the equations be satisfied.

38. The momentum, p, of a particle of matter is given by $p = mv$. Can you calculate the momentum of a photon using the same equation? Explain. (27.2)

No, using the equation yields a photon momentum of zero because photons are massless. This result is incorrect because massless photons have nonzero momenta.

39. Explain how each of the following electron properties could be measured. (27.2)

a. charge

Balance the force of gravity against the force of an electric field on the charge.

b. mass

Balance the force of an electric field against that of a magnetic field to find m/q, then use the measured value of q.

c. wavelength

Scatter electrons off a crystal and measure the angles of diffraction.

40. Explain how each of the following photon properties could be measured. (27.2)

a. energy

Measure the *KE* of the electrons ejected from a metal for at least two different wavelengths, or measure the *KE* of the electrons ejected from a known metal at only one wavelength.

b. momentum

Measure the change in wavelength of X rays scattered by matter.

c. wavelength

Measure the angle of diffraction when light passes through two slits

or a diffraction grating, measure the width of a single-slit diffraction pattern, or measure the angle the light is bent when it passes through a prism.

Applying Concepts

page 742

41. Use the emission spectrum of an incandescent body at three different temperatures shown in Figure 27-1 on page 724 to answer the following questions.

a. At what frequency does the peak emission intensity occur for each of the three temperatures?

4000 K: ~2.5×10^{14} Hz, 5800 K: ~3.5×10^{14} Hz, 8000 K: ~4.6×10^{14} Hz

b. What can you conclude about the relationship between the frequency of peak radiation emission intensity and temperature for an incandescent body?

The frequency of the peak intensity increases with increasing temperature.

c. By what factor does the intensity of the red light given off change as the body's temperature increases from 4000 K to 8000 K?

The intensity in the red portion of the spectrum increases from approximately 0.5 to 9.2, an increase by a factor of slightly greater than 18.

42. Two iron bars are held in a fire. One glows dark red, while the other glows bright orange.

a. Which bar is hotter?

the rod glowing bright orange

b. Which bar is radiating more energy?

the rod glowing bright orange

43. Will high-frequency light eject a greater number of electrons from a photosensitive surface than low-frequency light, assuming that both frequencies are above the threshold frequency?

Not necessarily; the number of ejected electrons is proportional to the number of incident photons or the brightness of the light, not the frequency of the light.

44. Potassium emits photoelectrons when struck by blue light, whereas tungsten emits photoelectrons when struck by ultraviolet radiation.

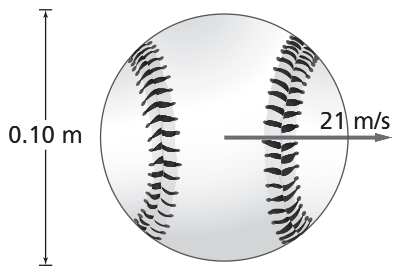
a. Which metal has a higher threshold frequency?

Blue light has a lower frequency and energy than UV light. Thus, tungsten has the higher threshold frequency.

b. Which metal has a larger work function?

tungsten

45. Compare the de Broglie wavelength of the baseball shown in **Figure 27-11** with the diameter of the baseball.



■ **Figure 27-11**

The diameter of the baseball is about 0.10 m, whereas the de Broglie wavelength is 10^{-34} m; the baseball is about 10^{33} times larger than the wavelength.

Mastering Problems

27.1 A Particle Model of Waves

page 742–743

Level 1

46. According to Planck's theory, how does the frequency of vibration of an atom change if it gives off 5.44×10^{-19} J while changing its value of n by 1?

$E = nhf$, so

$$f = \frac{E}{nh} = \frac{5.44\times10^{-19}\text{ J}}{(1)(6.63\times10^{-34}\text{ J·s})}$$

$$= 8.21\times10^{14}\text{ Hz}$$

47. What potential difference is needed to stop electrons with a maximum kinetic energy of 4.8×10^{-19} J?

$KE = -qV_0$, so

$$V_0 = \frac{KE}{-q} = \frac{4.8\times10^{-19}\ \text{C}}{-(-1.60\times10^{-19}\ \text{C})} = 3.0\ \text{V}$$

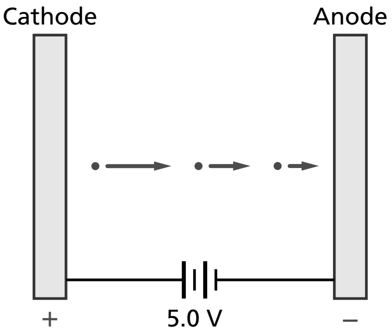
48. What is the momentum of a photon of violet light that has a wavelength of 4.0×10^2 nm?

$$p = \frac{h}{\lambda} = \frac{6.63\times10^{-34}\ \text{J·s}}{4.0\times10^{-7}\ \text{m}}$$

$$= 1.7\times10^{-27}\ \text{kg·m/s}$$

Level 2

49. The stopping potential of a certain metal is shown in **Figure 27-12.** What is the maximum kinetic energy of the photoelectrons in the following units?



■ **Figure 27-12**

a. electron volts

$$KE = -qV_0$$
$$= -(-1\ \text{elementary charge})(5.0\ \text{V})$$
$$= 5.0\ \text{eV}$$

b. joules

$$\left(\frac{5.0\ \text{eV}}{1}\right)\left(\frac{1.60\times10^{-19}\ \text{J}}{1\ \text{eV}}\right)$$
$$= 8.0\times10^{-19}\ \text{J}$$

50. The threshold frequency of a certain metal is 3.00×10^{14} Hz. What is the maximum kinetic energy of an ejected photoelectron if the metal is illuminated by light with a wavelength of 6.50×10^2 nm?

$$KE = hf - hf_0$$
$$= h\left(\frac{c}{\lambda} - f_0\right)$$
$$= (6.63\times10^{-34}\ \text{J·s})\left(\frac{3.00\times10^{8}\ \text{m/s}}{6.50\times10^{-7}\ \text{m}} - 3.00\times10^{14}\ \text{Hz}\right)$$
$$= 1.07\times10^{-19}\ \text{J}$$

51. The threshold frequency of sodium is 4.4×10^{14} Hz. How much work must be done to free an electron from the surface of sodium?

$$\text{Work} = hf_0$$
$$= (6.63\times10^{-34}\ \text{J/Hz})(4.4\times10^{14}\ \text{Hz})$$
$$= 2.9\times10^{-19}\ \text{J}$$

52. If light with a frequency of 1.00×10^{15} Hz falls on the sodium in the previous problem, what is the maximum kinetic energy of the photoelectrons?

$$KE = hf - hf_0$$
$$= h(f - f_0)$$
$$= (6.63\times10^{-34}\ \text{J/Hz})(1.00\times10^{15}\ \text{Hz} - 4.4\times10^{14}\ \text{Hz})$$
$$= 3.7\times10^{-19}\ \text{J}$$

Level 3

53. Light Meter A photographer's light meter uses a photocell to measure the light falling on the subject to be photographed. What should be the work function of the cathode if the photocell is to be sensitive to red light (λ = 680 nm) as well as to the other colors of light?

$$W = \frac{1240\ \text{eV·nm}}{\lambda_0} = \frac{1240\ \text{eV·nm}}{680\ \text{nm}}$$
$$= 1.8\ \text{eV}$$

54. Solar Energy A home uses about 4×10^{11} J of energy each year. In many parts of the United States, there are about 3000 h of sunlight each year.

a. How much energy from the Sun falls on one square meter each year?

Earth receives about 1000 J/m² each second, so

$$E = (1000\ \text{J/m}^2\text{·s})\left(\frac{3600\ \text{s}}{\text{h}}\right)\left(\frac{3000\ \text{h}}{\text{y}}\right)$$
$$= 1\times10^{10}\ \text{J/m}^2\ \text{per year}$$

b. If this solar energy can be converted to useful energy with an efficiency of 20 percent, how large an area of converters would produce the energy needed by the home?

$$\text{Area} = \frac{4\times10^{11}\ \text{J}}{(0.2)(1\times10^{10}\ \text{J/m}^2)}$$

$$= 2\times10^2\ \text{m}^2$$

27.2 Matter Waves

page 743

Level 1

55. What is the de Broglie wavelength of an electron moving at 3.0×10^6 m/s?

$$\lambda = \frac{h}{mv}$$

$$= \frac{6.63\times10^{-34}\ \text{J·s}}{(9.11\times10^{-31}\ \text{kg})(3.0\times10^6\ \text{m/s})}$$

$$= 2.4\times10^{-10}\ \text{m}$$

$$= 0.24\ \text{nm}$$

56. What velocity would an electron need to have a de Broglie wavelength of 3.0×10^{-10} m?

$$\lambda = \frac{h}{mv}$$

$$v = \frac{h}{m\lambda}$$

$$= \frac{6.63\times10^{-34}\ \text{J/Hz}}{(9.11\times10^{-31}\ \text{kg})(3.0\times10^{-10}\ \text{m})}$$

$$= 2.4\times10^6\ \text{m/s}$$

Level 2

57. A cathode-ray tube accelerates an electron from rest across a potential difference of 5.0×10^3 V.

a. What is the velocity of the electron?

$$\frac{1}{2}mv^2 = qV$$

$$v = \sqrt{\frac{qV}{\frac{1}{2}m}}$$

$$v = \sqrt{\frac{(1.60\times10^{-19}\ \text{C})(5.0\times10^3\ \text{V})}{\left(\frac{1}{2}\right)(9.11\times10^{-31}\ \text{kg})}}$$

$$= 4.2\times10^7\ \text{m/s}$$

b. What is the wavelength associated with the electron?

$$\lambda = \frac{h}{mv}$$

$$= \frac{6.63\times10^{-34}\ \text{J/Hz}}{(9.11\times10^{-31}\ \text{kg})(4.2\times10^7\ \text{m/s})}$$

$$= 1.7\times10^{-11}\ \text{m} = 0.017\ \text{nm}$$

58. A neutron is held in a trap with a kinetic energy of only 0.025 eV.

a. What is the velocity of the neutron?

$$KE = (0.025\ \text{eV})\left(\frac{1.60\times10^{-19}\ \text{J}}{\text{eV}}\right)$$

$$= 4.0\times10^{-21}\ \text{J}$$

$$= \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{(2)(4.0\times10^{-21}\ \text{J})}{1.67\times10^{-27}\ \text{kg}}}$$

$$= 2.2\times10^3\ \text{m/s}$$

b. Find the de Broglie wavelength of the neutron.

$$\lambda = \frac{h}{mv}$$

$$= \frac{6.63\times10^{-34}\ \text{J·s}}{(1.67\times10^{-27}\ \text{kg})(2.2\times10^3\ \text{m/s})}$$

$$= 1.8\times10^{-10}\ \text{m}$$

59. The kinetic energy of a hydrogen atom's electron is 13.65 eV.

a. Find the velocity of the electron.

$$KE = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2KE}{m}}$$

$$= \sqrt{\frac{(2)(13.65\ \text{eV})(1.60\times10^{-19}\ \text{J/eV})}{9.11\times10^{-31}\ \text{kg}}}$$

$$= 2.19\times10^6\ \text{m/s}$$

b. Calculate the electron's de Broglie wavelength.

$$\lambda = \frac{h}{mv}$$

$$= \frac{6.63\times10^{-34}\ \text{kg·m/s}}{(9.11\times10^{-31}\ \text{kg})(2.19\times10^6\ \text{m/s})}$$

$$= 0.332\ \text{nm}$$

c. Given that a hydrogen atom's radius is 0.519 nm, calculate the circumference of a hydrogen atom and compare it with the de Broglie wavelength for the atom's electron.

$$C = 2\pi r$$

$= (2\pi)(0.519\ \text{nm}) = 3.26\ \text{nm}$

The circumference is approximately equal to ten complete wavelengths.

Level 3

60. An electron has a de Broglie wavelength of 0.18 nm.

a. How large a potential difference did it experience if it started from rest?

The de Broglie wavelength is $\lambda = \frac{h}{mv}$,

which gives a velocity of $v = \frac{h}{m\lambda}$.

The kinetic energy, then, is

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{h}{m\lambda}\right)^2 = \frac{h^2}{2m\lambda^2}$$

In terms of voltage, the kinetic energy is $KE = qV$.

Combining these and solving for voltage,

$$V = \frac{h^2}{2mq\lambda^2} = \frac{(6.63\times10^{-34}\ \text{J·s})^2}{(2)(9.11\times10^{-31}\ \text{kg})(1.60\times10^{-19}\ \text{C})(0.18\times10^{-9}} = 47\ \text{V}$$

b. If a proton has a de Broglie wavelength of 0.18 nm, how large is the potential difference that it experienced if it started from rest?

Using the same derivation as before, the voltage is

$$V = \frac{h^2}{2mq\lambda^2} = \frac{(6.63\times10^{-34}\ \text{J·s})^2}{(2)(1.67\times10^{-27}\ \text{kg})(1.60\times10^{-19}\ \text{C})(0.18\times10^{-9}\ \text{m})^2} = 0.025\ \text{V}$$

Mixed Review

page 743–744

Level 1

61. What is the maximum kinetic energy of photoelectrons ejected from a metal that has a stopping potential of 3.8 V?

$KE = -qV_0 = -(-1\ \text{elementary charge})(3.8\ \text{V}) = 3.8\ \text{eV}$

62. The threshold frequency of a certain metal is 8.0×10^{14} Hz. What is the work function of the metal?

$$W = hf_0 = (6.63\times10^{-34}\ \text{J/Hz})(8.0\times10^{14}\ \text{Hz}) = 5.3\times10^{-19}\ \text{J}$$

63. If light with a frequency of 1.6×10^{15} Hz falls on the metal in the previous problem, what is the maximum kinetic energy of the photoelectrons?

$$KE = hf - hf_0$$
$$= (6.63\times10^{-34}\ \text{J/Hz})(1.6\times10^{15}\ \text{Hz}) - 5.3\times10^{-19}\ \text{J}$$
$$= 5.3\times10^{-19}\ \text{J}$$

64. Find the de Broglie wavelength of a deuteron (nucleus of ^{2}H isotope) of mass 3.3×10^{-27} kg that moves with a speed of 2.5×10^4 m/s.

$$\lambda = \frac{h}{mv}$$
$$= \frac{6.63\times10^{-34}\ \text{J·s}}{(3.3\times10^{-27}\ \text{kg})(2.5\times10^4\ \text{m/s})}$$
$$= 8.0\times10^{-12}\ \text{m}$$

Level 2

65. The work function of iron is 4.7 eV.

a. What is the threshold wavelength of iron?

$$W = \frac{hc}{\lambda_0} = \frac{1240\ \text{eV·nm}}{\lambda_0}$$
$$\lambda_0 = \frac{1240\ \text{eV·nm}}{W} = \frac{1240\ \text{eV·nm}}{4.7\ \text{eV}}$$
$$= 2.6\times10^2\ \text{nm}$$

b. Iron is exposed to radiation of wavelength 150 nm. What is the maximum kinetic energy of the ejected electrons in eV?

$$KE = \frac{hc}{\lambda} - \frac{hc}{\lambda_0} = \frac{1240\ \text{eV·nm}}{150\ \text{nm}} - 4.7\ \text{eV}$$
$$= 3.6\ \text{eV}$$

66. Barium has a work function of 2.48 eV. What is the longest wavelength of light that will cause electrons to be emitted from barium?

Work function = 2.48 eV = $hf_0 = \frac{hc}{\lambda_0}$**, so**

$$\lambda_0 = \frac{hc}{2.48\ \text{eV}}$$
$$= \frac{(6.63\times10^{-34}\ \text{J·s})(3.00\times10^8\ \text{m/s})}{(2.48\ \text{eV})\left(\frac{1.60\times10^{-19}\ \text{J}}{1\ \text{eV}}\right)}$$
$$= 5.01\times10^{-7}\ \text{m}$$
$$= 501\ \text{nm}$$

67. An electron has a de Broglie wavelength of 400.0 nm, the shortest wavelength of visible light.

a. Find the velocity of the electron.

$$\lambda = \frac{h}{mv}$$
$$v = \frac{h}{m\lambda}$$
$$= \frac{6.63\times10^{-34}\ \text{J/Hz}}{(9.11\times10^{-31}\ \text{kg})(400.0\times10^{-9}\ \text{m})}$$
$$= 1.82\times10^3\ \text{m/s}$$

b. Calculate the energy of the electron in eV.

$$KE = \frac{1}{2}mv^2$$
$$= \left(\frac{1}{2}\right)(9.11\times10^{-31}\ \text{kg})(1.82\times10^3\ \text{m/s})^2\left(\frac{\text{eV}}{1.60\times10^{-19}\ \text{J}}\right)$$
$$= 9.43\times10^{-6}\ \text{eV}$$

68. Electron Microscope An electron microscope is useful because the de Broglie wavelengths of electrons can be made smaller than the wavelength of visible light. What energy in eV has to be given to an electron for it to have a de Broglie wavelength of 20.0 nm?

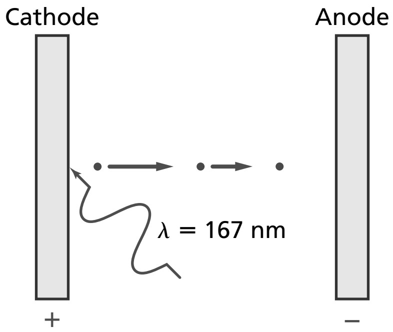
The de Broglie wavelength is $\lambda = \frac{h}{mv}$**, which gives a velocity of** $v = \frac{h}{m\lambda}$**.**

The kinetic energy, then, is

$$KE = \frac{1}{2}mv^2$$
$$= \frac{1}{2}m\left(\frac{h}{m\lambda}\right)^2$$
$$= \frac{h^2}{2m\lambda^2}$$
$$= \left(\frac{(6.63\times10^{-34}\ \text{J·s})^2}{(2)(9.11\times10^{-31}\ \text{kg})(20.0\times10^{-9}\ \text{m})^2}\right)\left(\frac{1\ \text{eV}}{1.60\times10^{-19}\ \text{J}}\right)$$
$$= 3.77\times10^{-3}\ \text{eV}$$

Level 3

69. Incident radiation falls on tin, as shown in **Figure 27-13.** The threshold frequency of tin is 1.2×10^{15} Hz.



■ **Figure 27-13**

a. What is the threshold wavelength of tin?

$$c = \lambda f$$

$$\lambda = \frac{c}{f} = \frac{3.00\times10^{8}\text{ m/s}}{1.2\times10^{15}\text{ Hz}} = 2.5\times10^{-7}\text{ m}$$

b. What is the work function of tin?

$$W = hf_0$$

$$= (6.63\times10^{-34}\text{ J/Hz})(1.2\times10^{15}\text{ Hz})$$

$$= 8.0\times10^{-19}\text{ J}$$

c. The incident electromagnetic radiation has a wavelength of 167 nm. What is the kinetic energy of the ejected electrons in eV?

$$KE_{max} = \frac{hc}{\lambda} - hf_0$$

$$= \frac{(6.63\times10^{-34}\text{ J/Hz})(3.00\times10^{8}\text{ m/s})}{167\times10^{-9}\text{ m}} - 8.0\times10^{-19}\text{ J}$$

$$= 3.9\times10^{-19}\text{ J}$$

$$(3.9\times10^{-19}\text{ J})\left(\frac{1\text{ eV}}{1.60\times10^{-19}\text{ J}}\right) = 2.4\text{ eV}$$

Thinking Critically

page 744

70. Apply Concepts A helium-neon laser emits photons with a wavelength of 632.8 nm.

a. Find the energy, in joules, of each photon emitted by the laser.

Each photon has energy

$$E = \frac{hc}{\lambda}$$

$$= \frac{(6.63\times10^{-34}\text{ J·s})(3.00\times10^{8}\text{ m/s})}{632.8\times10^{-9}\text{ m}}$$

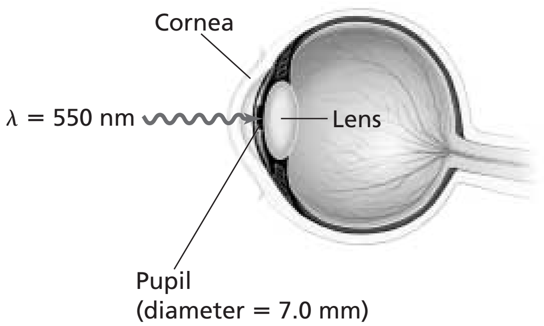
$$= 3.14\times10^{-19}\text{ J}$$

b. A typical small laser has a power of 0.5 mW (equivalent to 5×10^{-4} J/s). How many photons are emitted each second by the laser?

$$n = \frac{P}{E} = \frac{5\times10^{-4}\text{ J/s}}{3.14\times10^{-19}\text{ J/photon}}$$

$$= 2\times10^{15}\text{ photons/s}$$

71. Apply Concepts Just barely visible light with an intensity of 1.5×10^{-11} W/m^2 enters a person's eye, as shown in **Figure 27-14.**



■ **Figure 27-14**

a. If this light shines into the person's eye and passes through the person's pupil, what is the power, in watts, that enters the person's eye?

Power = (intensity)(area)

$$= (\text{intensity})(\pi r^2)$$

$$= (1.5\times10^{-11}\text{ W/m}^2)(\pi(3.5\times10^{-3}\text{ m})^2)$$

$$= 5.8\times10^{-16}\text{ W}$$

b. Use the given wavelength of the incident light and information provided in **Figure 27-14** to calculate the number of photons per second entering the eye.

Energy per photon

$$E = \frac{hc}{\lambda}$$

$$= \frac{(6.63\times10^{-34}\ \text{J·s})(3.00\times10^{8}\ \text{m/s})}{550\times10^{-9}\ \text{m}}$$

$$= 3.62\times10^{-19}\ \text{J}$$

$$n = \frac{P}{E} = \frac{5.8\times10^{-16}\ \text{J/s}}{3.62\times10^{-19}\ \text{J/photon}}$$

$$= 1600\ \text{photons/s}$$

72. Make and Use Graphs A student completed a photoelectric-effect experiment and recorded the stopping potential as a function of wavelength, as shown in **Table 27-1.** The photocell had a sodium cathode. Plot the data (stopping potential versus frequency) and use your calculator to draw the best-fit straight line (regression line). From the slope and intercept of the line, find the work function, the threshold wavelength, and the value of *h*/*q* from this experiment. Compare the value of *h*/*q* to the accepted value.

Table 27-1	
Stopping Potential v. Wavelength	
λ (nm)	**V_0 (eV)**
200	4.20
300	2.06
400	1.05
500	0.41
600	0.03

Convert wavelength to frequency and plot. Determine the best straight line through the data.

Slope $= 4.18\times10^{-15}$ **V/Hz**

$= 4.18\times10^{-15}$ **J/Hz·C**

The accepted value is

$$\frac{h}{e} = \frac{(6.63\times10^{-34}\ \text{J/Hz})}{(1.60\times10^{-19}\ \text{C})}$$

$$= 4.14\times10^{-15}\ \text{J/Hz·C}$$

From the graph, the threshold frequency is $f_0 = 4.99\times10^{14}$ Hz, which gives a threshold wavelength of $\lambda_0 = \frac{c}{f_0} = \frac{3.00\times10^{8}\ \text{m/s}}{4.99\times10^{14}\ \text{Hz}} = 601$ nm and a work function of

$$W = hf_0$$

$$= (6.63\times10^{-34}\ \text{J/Hz})(4.99\times10^{14}\ \text{Hz})$$

$$= 3.31\times10^{-19}\ \text{J}$$

Writing in Physics

page 744

73. Research the most massive particle for which interference effects have been seen. Describe the experiment and how the interference was created.

As of 2003, the largest is a buckyball, a C_{60} molecule. Nano-formed metallic grids were used as a diffraction grating.

Cumulative Review

page 744

74. The spring in a pogo stick is compressed 15 cm when a child who weighs 400.0 N stands on it. What is the spring constant of the spring? (Chapter 14)

$$F = kx$$

$$k = \frac{F}{x} = \frac{400\ \text{N}}{0.15\ \text{m}}$$

$$= 3\times10^{3}\ \text{N/m}$$

75. A marching band sounds flat as it plays on a very cold day. Why? (Chapter 15)

Answer: The pitch of a wind instrument depends on the speed of sound in the air within it. The colder the air, the lower the speed of sound and the flatter the pitch of the sound produced.

76. A charge of 8.0×10^{-7} C experiences a force of 9.0 N when placed 0.02 m from a second charge. What is the magnitude of the second charge? (Chapter 20)

$$F = K\frac{q_A q_B}{d^2}$$

$$q_B = \frac{Fd^2}{Kq_A}$$

$$= \frac{(9.0\ \text{N})(0.02\ \text{m})^2}{(9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)(8.0\times10^{-7}\ \text{C})}$$

$$= 5\times10^{-7}\ \text{C}$$

77. A homeowner buys a dozen identical 120-V light sets. Each light set has 24 bulbs connected in series, and the resistance of each bulb is 6.0 Ω. Calculate the total load in amperes if the homeowner operates all the sets from a single exterior outlet. (Chapter 23)

$$I_{total} = 12I_{set}$$

$$= (12)\left(\frac{V}{24R}\right)$$

$$= (12)\left(\frac{120\ \text{V}}{(24)(6.0\ \Omega)}\right)$$

$$= 1.0\times10^{1}\ \text{A}$$

78. The force on a 1.2-m wire is 1.1×10^{-3} N. The wire is perpendicular to Earth's magnetic field. How much current is in the wire? (Chapter 24)

$$F = BIL$$

$$I = \frac{F}{BL} = \frac{1.1\times10^{3}\ \text{N}}{(5\times10^{-5}\ \text{T})(1.2\ \text{m})} = 2\times10^{1}\ \text{A}$$

Challenge Problem

page 731

Suppose a nickel with a mass of 5.0 g vibrates up and down while it is connected to a spring. The maximum velocity of the nickel during the oscillations is 1.0 cm/s. Assume that the vibrating nickel models the quantum vibrations of the electrons within an atom, where the energy of the vibrations is given by the equation $E = nhf$.

Mass = 5.0 g
Maximum velocity = 1.0 cm/s

1. Find the maximum kinetic energy of the vibrating object.

$$KE = \frac{1}{2}mv^2$$

$$= \left(\frac{1}{2}\right)(5.0\times10^{-3}\ \text{kg})(1.0\times10^{-2}\ \text{m/s})^2$$

$$= 2.5\times10^{-7}\ \text{J}$$

2. The vibrating object emits energy in the form of light with a frequency of 5.0×10^{14} Hz. If the energy is emitted in a single step, find the energy lost by the object.

$$E = hf$$

$$= (6.63\times10^{-34}\ \text{J/Hz})(5.0\times10^{14}\ \text{Hz})$$

$$= 3.3\times10^{-19}\ \text{J}$$

3. Determine the number of equally sized energy-step reductions that the object would have to make in order to lose all of its energy.

$$\frac{2.5\times10^{-7}\ \text{J}}{3.3\times10^{-19}\ \text{J/step}} = 7.6\times10^{11}\ \text{steps}$$

CHAPTER

28 The Atom

Practice Problems

28.1 The Bohr Model of the Atom pages 747–759

page 757

1. Calculate the energies of the second, third, and fourth energy levels in the hydrogen atom.

$$E_n = \frac{-13.6\ \text{eV}}{n^2}$$

$$E_2 = \frac{-13.6\ \text{eV}}{(2)^2} = -3.40\ \text{eV}$$

$$E_3 = \frac{-13.6\ \text{eV}}{(3)^2} = -1.51\ \text{eV}$$

$$E_4 = \frac{-13.6\ \text{eV}}{(4)^2} = -0.850\ \text{eV}$$

2. Calculate the energy difference between E_3 and E_2 in the hydrogen atom.

$$\Delta E = E_3 - E_2 = (-13.6\ \text{eV})\left(\frac{1}{3^2} - \frac{1}{2^2}\right)$$

$$= (-13.6\ \text{eV})\left(\frac{1}{9} - \frac{1}{4}\right) = 1.89\ \text{eV}$$

3. Calculate the energy difference between E_4 and E_2 in the hydrogen atom.

$$\Delta E = E_4 - E_2 = (-13.6\ \text{eV})\left(\frac{1}{4^2} - \frac{1}{2^2}\right)$$

$$= (-13.6\ \text{eV})\left(\frac{1}{16} - \frac{1}{4}\right) = 2.55\ \text{eV}$$

4. The text shows the solution of the equation $r_n = \frac{h^2n^2}{4\pi^2Kmq^2}$ for $n = 1$, the innermost orbital radius of the hydrogen atom. Note that with the exception of n^2, all factors in the equation are constants. The value of r_1 is 5.3×10^{-11} m, or 0.053 nm. Use this information to calculate the radii of the second, third, and fourth allowable energy levels in the hydrogen atom.

$r_n = n^2k$, where $k = 5.3\times10^{-11}$ m

(We are using k for the combination of all the constants in the equation.)

$$r_2 = (2)^2(5.3\times10^{-11}\ \text{m})$$
$$= 2.1\times10^{-10}\ \text{m or } 0.21\ \text{nm}$$

$$r_3 = (3)^2(5.3\times10^{-11}\ \text{m})$$
$$= 4.8\times10^{-10}\ \text{m or } 0.48\ \text{nm}$$

$$r_4 = (4)^2(5.3\times10^{-11}\ \text{m})$$
$$= 8.5\times10^{-10}\ \text{m or } 0.85\ \text{nm}$$

5. The diameter of the hydrogen nucleus is 2.5×10^{-15} m, and the distance between the nucleus and the first electron is about 5×10^{-11} m. If you use a ball with a diameter of 7.5 cm to represent the nucleus, how far away will the electron be?

$$\frac{x}{0.075\ \text{m}} = \frac{5\times10^{-11}\ \text{m}}{2.5\times10^{-15}\ \text{m}}$$

$x = 2\times10^3$ m = 2 km, about 1 mile!

page 758

6. Find the wavelength of the light emitted in Practice Problems 2 and 3. Which lines in Figure 28-7 correspond to each transition?

$$\lambda_{3\text{ to }2} = \frac{hc}{\Delta E}$$

$$= \frac{(6.63\times10^{-34}\ \text{J·s})(3.00\times10^{8}\ \text{m/s})}{(1.89\ \text{eV})(1.60\times10^{-19}\ \text{J/eV})}$$

$$= 6.58\times10^{-7}\ \text{m} = 658\ \text{nm}$$

$$\lambda_{4\text{ to }2} = \frac{hc}{\Delta E}$$

$$= \frac{(6.63\times10^{-34}\ \text{J·s})(3.00\times10^{8}\ \text{m/s})}{(2.55\ \text{eV})(1.60\times10^{-19}\ \text{J/eV})}$$

$$= 4.88\times10^{-7}\ \text{m} = 488\ \text{nm}$$

7. For a particular transition, the energy of a mercury atom drops from 8.82 eV to 6.67 eV.

a. What is the energy of the photon emitted by the mercury atom?

$$\Delta E = 8.82\ \text{eV} - 6.67\ \text{eV} = 2.15\ \text{eV}$$

b. What is the wavelength of the photon emitted by the mercury atom?

$$\lambda = \frac{hc}{\Delta E}$$

$$= \frac{(6.63\times10^{-34}\ \text{J·s})(3.00\times10^{8}\ \text{m/s})}{(2.15\ \text{eV})(1.60\times10^{-19}\ \text{J/eV})}$$

$$= 5.78\times10^{-7}\ \text{m} = 578\ \text{nm}$$

8. The ground state of a helium ion is −54.4 eV. A transition to the ground state emits a 304-nm photon. What was the energy of the excited state?

$\lambda = \frac{hc}{\Delta E}$, so

$$\Delta E = \frac{hc}{\lambda} = \frac{1240\ \text{eV·nm}}{304\ \text{nm}} = 4.08\ \text{eV}$$

Therefore $E_{\text{excited}} = E_{\text{ground}} + \Delta E$

$$= -54.4\ \text{eV} + 4.08\ \text{eV}$$

$$= -50.3\ \text{eV}$$

Section Review

28.1 The Bohr Model of the Atom pages 747–759

page 759

9. Rutherford's Nuclear Model Summarize the structure of the atom according to Rutherford's nuclear model.

In Rutherford's nuclear model, all of an atom's positive charge and virtually all of its mass are concentrated in a tiny, centrally located nucleus around which negatively charged electrons orbit.

10. Spectra How do the emission spectra of incandescent solids and atomic gases differ? In what ways are they similar?

Incandescent solids produce spectra consisting of a continuous band of colors, whereas gases produce spectra made up of a set of discrete lines. All spectra are created by energy-level transitions in atoms.

11. Bohr Model Explain how energy is conserved when an atom absorbs a photon of light.

The initial sum of the energy of the electron in the atom plus the energy of the incident photon equals the final energy of the electron in the atom.

12. Orbit Radius A helium ion behaves like a hydrogen atom. The radius of the ion's lowest energy level is 0.0265 nm. According to Bohr's model, what is the radius of the second energy level?

The radius depends on n^2, so the second level would have a radius four times the first, or 0.106 nm.

13. Absorption Spectrum Explain how the absorption spectrum of a gas can be determined. Describe the reasons for the spectrum's appearance.

To obtain an absorption spectrum, white light is passed through a sample of gas and then a spectroscope. Because the gas absorbs specific wavelengths, the normally continuous spectrum of white light contains dark lines.

14. Bohr Model Hydrogen has been detected transitioning from the 101st to the 100th energy levels. What is the radiation's wavelength? Where in the electromagnetic spectrum is this emission?

$$\Delta E = E_{101} - E_{100}$$

$$= (-13.6\ \text{eV})\left(\frac{1}{101^2} - \frac{1}{100^2}\right)$$

$= 2.68\times10^{-5}$ eV, λ

$$= \frac{hc}{\Delta E} = \frac{1240\ \text{eV·nm}}{2.68\times10^{-5}\ \text{eV}}$$

$= 46.3\times10^{6}$ nm = 4.63 cm, the wavelengths indicates the radiation is a microwave

15. **Critical Thinking** The nucleus of the hydrogen atom has a radius of about 1.5×10^{-15} m. If you were to build a model of the hydrogen atom using a softball (r = 5 cm) to represent the nucleus, where would you locate an electron in the n = 1 Bohr orbit? Would it be in your classroom?

The scale is 5 cm = 1.5×10^{-15} m, or 1 cm = 3.0×10^{-16} m. The Bohr radius is 5.3×10^{-11} m. In our model this would be $(5.3\times10^{-11}/3.0\times10^{-16})$ 1 cm = 1.8×10^{5} cm, or 1.8 km. That would be far larger than most schools.

Section Review

28.2 The Quantum Model of the Atom pages 760–765

page 765

16. **Lasers** Which of the lasers in Table 28-1 emits the reddest light (visible light with the longest wavelength)? Which of the lasers emit blue light? Which of the lasers emit beams that are not visible to the human eye?

gallium aluminum arsenide laser in red; argon ion and indium gallium nitride in blue. Krypton-fluoride excimer, nitrogen, gallium arsenide, neodymium, and carbon dioxide are not visible to the human eye.

17. **Pumping Atoms** Explain whether green light could be used to pump a red laser. Why could red light not be used to pump a green laser?

Yes. Red photons have less energy than green ones. Red photons do not have enough energy to put the atoms in energy levels high enough to enable them to emit green photons.

18. **Bohr Model Limitations** Although it was able to accurately predict the behavior of hydrogen, in what ways did Bohr's atomic model have serious shortcomings?

The Bohr model could not predict the behavior of any other atom besides hydrogen. The model also could not explain why the laws of electromagnetism do not apply within the atom.

19. **Quantum Model** Explain why the Bohr model of the atom conflicts with the Heisenberg uncertainty principle, whereas the quantum model does not.

The uncertainty principle doesn't allow a particle to have a precisely known position, such as a Bohr orbit. The quantum model predicts only the probability that the radius of the electron orbit will have any given value.

20. **Lasers** Explain how a laser makes use of stimulated emission to produce coherent light.

When a photon strikes an atom in the excited state, it stimulates the excited atom to emit a photon of the same energy and in step with the incident photon. The incident photon remains unchanged and these two photons in turn strike other excited atoms, producing more and more in-step, coherent light.

21. **Laser Light** What are the four characteristics of laser light that make it useful?

concentrated, high power; directional; single wavelength; coherent light

22. **Critical Thinking** Suppose that an electron cloud were to get so small that the atom was almost the size of the nucleus. Use the Heisenberg uncertainty principle to explain why this would take a tremendous amount of energy.

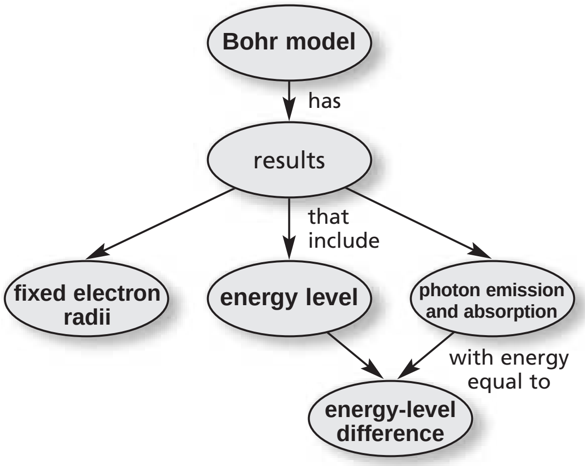
The smaller the electron cloud, the more precisely we know the position of the electrons. If a particle's position is well known, its momentum must be uncertain. The uncertainty of the momentum can be large only if momentum itself is large. Therefore, the kinetic energy of the electron also must be large, and it takes lots of energy to do this.

Chapter Assessment

Concept Mapping

page 770

23. Complete the following concept map using these terms: *energy levels, fixed electron radii, Bohr model, photon emission and absorption, energy-level difference.*



Mastering Concepts

page 770

24. Describe how Rutherford determined that the positive charge in an atom is concentrated in a tiny region, rather than spread throughout the atom. (28.1)

He directed a beam of charged α particles at a thin metal sheet and measured the number of particles deflected at various angles. The small but significant number depleted at wide angles indicates a concentrated nucleus.

25. How does the Bohr model explain why the absorption spectrum of hydrogen contains exactly the same frequencies as its emission spectrum? (28.1)

Bohr said the energy of an emitted photon or an absorbed photon is equal to the change in energy of the atom, which can have only specific values.

26. Review the planetary model of the atom. What are some of the problems with a planetary model of the atom? (28.1)

As the electrons undergo centripetal acceleration, they would lose energy and spiral into the nucleus. In addition, all atoms should radiate at all wavelengths, not discrete wavelengths.

27. Analyze and critique the Bohr model of the atom. What three assumptions did Bohr make in developing his model? (28.1)

stationary states (quantized energy levels), atom emits or absorbs radiation only when it changes states, angular momentum is quantized

28. **Gas-Discharge Tubes** Explain how line spectra from gas-discharge tubes are produced. (28.1)

Energy is supplied to the gas, which causes the electrons to excite and move to higher energy levels. The electrons then give off the difference in energy between energy levels as they drop back down to a less excited state. The energy differences between levels corresponds to spectral lines.

29. How does the Bohr model account for the spectra emitted by atoms? (28.1)

Photon wavelengths are determined by the difference in energies of allowed levels as electrons jump inward to stationary states.

30. Explain why line spectra produced by hydrogen gas-discharge tubes are different from those produced by helium gas-discharge tubes. (28.1)

Each element has a different configuration of electrons and energy levels.

31. **Lasers** A laboratory laser has a power of only 0.8 mW (8×10^{-4} W). Why does it seem more powerful than the light of a 100-W lamp? (28.2)

Light is concentrated into a narrow beam, rather than being spread over a wide area.

32. A device similar to a laser that emits microwave radiation is called a maser. What words likely make up this acronym? (28.2)

Microwave Amplification by Stimulated Emission of Radiation

33. What properties of laser light led to its use in light shows? (28.2)

Lasers are directional and single, pure colors.

Applying Concepts

page 770

34. As the complexity of energy levels changes from atom to atom, what do you think happens to the spectra that they produce?

Generally, the spectra become more complex.

35. Northern Lights The northern lights are caused by high-energy particles from the Sun striking atoms high in Earth's atmosphere. If you looked at these lights through a spectrometer, would you see a continuous or line spectrum? Explain.

Line spectrum; the light comes from gas made of specific elements.

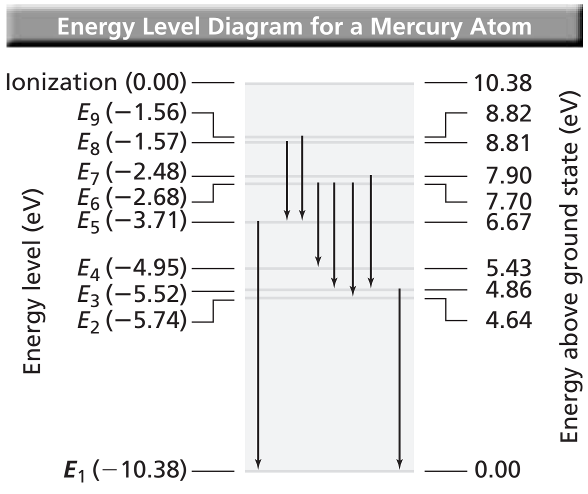
36. If white light were emitted from Earth's surface and observed by someone in space, would its spectrum appear to be continuous? Explain.

No, as white light passed through Earth's atmosphere, certain energies would be absorbed by the gases composing the atmosphere. Its spectrum, therefore, would have black lines on it.

37. Is money a good example of quantization? Is water? Explain.

Yes. Money comes in only certain discrete values. No, water seems to come in any possible quantity.

38. Refer to **Figure 28-21.** A photon with energy of 6.2 eV enters a mercury atom in the ground state. Will it be absorbed by the atom? Explain.



■ **Figure 28-21**

No, it takes 5.43 eV to raise the electron to the E_4 level and 6.67 eV to E_5. The atom can absorb only photons that have exactly the right energy.

39. A certain atom has four energy levels, with E_4 being the highest and E_1 being the lowest. If the atom can make transitions between any two levels, how many spectral lines can the atom emit? Which transition produces the photon with the highest energy?

Six lines are possible. $E_4 \rightarrow E_1$ has the largest photon energy.

40. A photon is emitted when an electron in an excited hydrogen atom drops through energy levels. What is the maximum energy that the photon can have? If this same amount of energy were given to the atom in the ground state, what would happen?

The maximum energy is 13.6 eV. This is also the ionization energy for hydrogen. The electron would have enough energy to leave the nucleus.

41. Compare the quantum mechanical theory of the atom with the Bohr model.

The Bohr model has fixed orbital radii. The present model gives a probability of finding an electron at a location. The Bohr model allows for calculation of only hydrogen atoms. The present model can be used for all elements.

42. Given a red, green, and blue laser, which produces photons with the highest energy?

Blue light has a higher frequency and therefore, higher energy.

Mastering Problems

28.1 The Bohr Model of the Atom

page 771

Level 1

43. A calcium atom drops from 5.16 eV above the ground state to 2.93 eV above the ground state. What is the wavelength of the photon emitted?

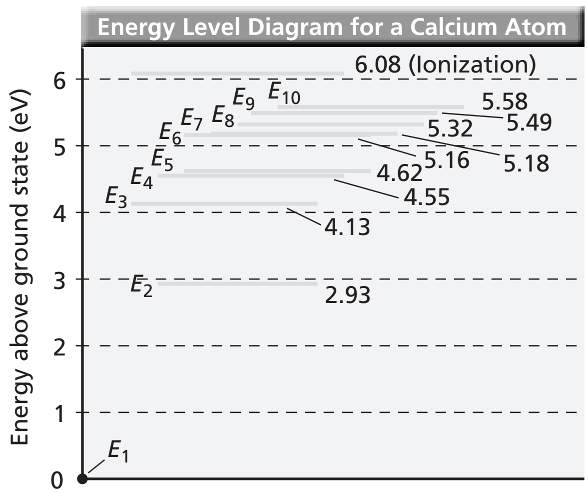
$$\Delta E = hf = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{\Delta E}$$

$$= \frac{1240\ \text{eV}\cdot\text{nm}}{5.16\ \text{eV} - 2.93\ \text{eV}}$$

$$= 556\ \text{nm}$$

44. A calcium atom in an excited state, E_2, has an energy level 2.93 eV above the ground state. A photon of energy 1.20 eV strikes the calcium atom and is absorbed by it. To what energy level is the calcium atom raised? Refer to **Figure 28-22.**



■ **Figure 28-22**

$$2.93\ \text{eV} + 1.20\ \text{eV} = 4.13\ \text{eV} = E_3$$

45. A calcium atom is in an excited state at the E_6 energy level. How much energy is released when the atom drops down to the E_2 energy level? Refer to Figure 28-22.

$$E_6 - E_2 = 5.16\ \text{eV} - 2.93\ \text{eV} = 2.23\ \text{eV}$$

46. A photon of orange light with a wavelength of 6.00×10^2 nm enters a calcium atom in the E_6 excited state and ionizes the atom. What kinetic energy will the electron have as it is ejected from the atom?

$$E = \frac{hc}{\lambda}$$

$$= \frac{(6.63\times10^{-34}\ \text{J/Hz})(3.00\times10^{8}\ \text{m/s})}{6.00\times10^{-7}\ \text{m}}$$

$$= 3.314\ \text{J} = 3.314\ \text{J}\left(\frac{1\ \text{eV}}{1.60\times10^{-19}\ \text{J}}\right)$$

$$= 2.07\ \text{eV}$$

Energy needed to ionize	**6.08 eV**
E_6	**−5.16 eV**
=	**0.92 eV**

Photon energy − ionization energy = kinetic energy

2.07 eV − 0.92 eV = 1.15 eV

Level 2

47. Calculate the energy associated with the E_7 and the E_2 energy levels of the hydrogen atom.

$$E_7 = -13.6\ \text{eV}\left(\frac{1}{n^2}\right)$$

$$= -13.6\ \text{eV}\left(\frac{1}{7^2}\right) = -0.278\ \text{eV}$$

$$E_2 = -13.6\ \text{eV}\left(\frac{1}{n^2}\right)$$

$$= -13.6\ \text{eV}\left(\frac{1}{2^2}\right) = -3.40\ \text{eV}$$

48. Calculate the difference in energy levels in the previous problem.

$$E_7 = -13.6\ \text{eV}\left(\frac{1}{n^2}\right)$$

$$= -13.6\ \text{eV}\left(\frac{1}{7^2}\right) = -0.278\ \text{eV}$$

$$E_2 = -13.6\text{ eV}\left(\frac{1}{n^2}\right)$$

$$= -13.6\text{ eV}\left(\frac{1}{2^2}\right) = -3.40\text{ eV}$$

$$E_7 - E_2 = -0.278\text{ eV} - (-3.40\text{ eV})$$

$$= 3.12\text{ eV}$$

Refer to Figure 28-21 for Problems 49 and 50.

49. A mercury atom is in an excited state at the E_6 energy level.

a. How much energy would be needed to ionize the atom?

$E_6 = 7.70$ eV

10.38 eV − 7.70 eV = 2.68 eV

b. How much energy would be released if the atom dropped down to the E_2 energy level instead?

$E_2 = 4.64$ eV

7.70 eV − 4.64 eV = 3.06 eV

50. A mercury atom in an excited state has an energy of −4.95 eV. It absorbs a photon that raises it to the next-higher energy level. What is the energy and the frequency of the photon?

$$E_5 - E_4 = -3.71\text{ eV} - (-4.95\text{ eV})$$

$$= 1.24\text{ eV}$$

$$E = hf$$

$$f = \frac{E}{h}$$

$$= \frac{1.24\text{ eV}\left(\frac{1.60\times10^{-19}\text{ J}}{\text{eV}}\right)}{6.63\times10^{-34}\text{ J·s}} = 2.99\times10^{14}\text{ Hz}$$

51. What energies are associated with a hydrogen atom's energy levels of E_2, E_3, E_4, E_5, and E_6?

$$E_2 = \frac{-13.6\text{ eV}}{n^2} = \frac{-13.6\text{ eV}}{(2)^2} = -3.40\text{ eV}$$

$$E_3 = \frac{-13.6\text{ eV}}{(3)^2} = -1.51\text{ eV}$$

$$E_4 = \frac{-13.6\text{ eV}}{(4)^2} = -0.850\text{ eV}$$

$$E_5 = \frac{-13.6\text{ eV}}{(5)^2} = -0.544\text{ eV}$$

$$E_6 = \frac{-13.6\text{ eV}}{(6)^2} = -0.378\text{ eV}$$

52. Using the values calculated in problem 51, calculate the following energy differences.

a. $E_6 - E_5$

(−0.378 eV) − (−0.544 eV) = 0.166 eV

b. $E_6 - E_3$

(−0.378 eV) − (−1.51 eV) = 1.13 eV

c. $E_4 - E_2$

(−0.850 eV) − (−3.40 eV) = 2.55 eV

d. $E_5 - E_2$

(−0.544 eV) − (−3.40 eV) = 2.86 eV

e. $E_5 - E_3$

(−0.544 eV) − (−1.51 eV) = 0.97 eV

53. Use the values from problem 52 to determine the frequencies of the photons emitted when an electron in a hydrogen atom makes the energy level changes listed.

a. $E = hf$, so $f = \frac{E}{h}$

$$hf = E_6 - E_5 = 0.166\text{ eV}$$

$$f = \frac{(0.166\text{ eV})(1.60\times10^{-19}\text{ J/eV})}{6.63\times10^{-34}\text{ J/Hz}}$$

$$= 4.01\times10^{13}\text{ Hz}$$

b. $hf = E_6 - E_3 = 1.13$ eV

$$f = \frac{(1.13\text{ eV})(1.60\times10^{-19}\text{ J/eV})}{6.63\times10^{-34}\text{ J/Hz}}$$

$$= 2.73\times10^{14}\text{ Hz}$$

c. $hf = E_4 - E_2 = 2.55$ eV

$$f = \frac{(2.55\text{ eV})(1.60\times10^{-19}\text{ J/eV})}{6.63\times10^{-34}\text{ J/Hz}}$$

$$= 6.15\times10^{14}\text{ Hz}$$

d. $hf = E_6 - E_3 = 2.86$ eV

$$f = \frac{(2.86\text{ eV})(1.60\times10^{-19}\text{ J/eV})}{6.63\times10^{-34}\text{ J/Hz}}$$

$$= 6.90\times10^{14}\text{ Hz}$$

e. $hf = E_6 - E_3 = 0.97$ eV

$$f = \frac{(0.97\text{ eV})(1.60\times10^{-19}\text{ J/eV})}{6.63\times10^{-34}\text{ J/Hz}}$$

$$= 2.3\times10^{14}\text{ Hz}$$

54. Determine the wavelengths of the photons having the frequencies that you calculated in problem 53.

a. $c = \lambda f$

$\lambda = \frac{c}{f} = \frac{3.00\times10^{8}\text{ m/s}}{4.01\times10^{13}\text{ Hz}}$

$= 7.48\times10^{-6}\text{ m} = 7480\text{ nm}$

b. $\lambda = \frac{c}{f} = \frac{3.00\times10^{8}\text{ m/s}}{2.73\times10^{14}\text{ Hz}}$

$= 1.10\times10^{-6}\text{ m} = 1.10\times10^{3}\text{ nm}$

c. $\lambda = \frac{c}{f} = \frac{3.00\times10^{8}\text{ m/s}}{6.15\times10^{14}\text{ Hz}}$

$= 4.88\times10^{-7}\text{ m} = 488\text{ nm}$

d. $\lambda = \frac{c}{f} = \frac{3.00\times10^{8}\text{ m/s}}{6.90\times10^{14}\text{ Hz}}$

$= 4.35\times10^{-6}\text{ m} = 435\text{ nm}$

e. $\lambda = \frac{c}{f} = \frac{3.00\times10^{8}\text{ m/s}}{2.3\times10^{14}\text{ Hz}}$

$= 1.3\times10^{-6}\text{ m} = 1.3\times10^{3}\text{ nm}$

Level 3

55. A hydrogen atom emits a photon with a wavelength of 94.3 nm when its falls to the ground state. From what energy level did the electron fall?

$c = \lambda f$

$\lambda = \frac{c}{\lambda} = \frac{3.00\times10^{8}\text{ m/s}}{9.43\times10^{-8}\text{ m}}$

$= 3.18\times10^{15}\text{ Hz}$

$E_n - E_1 = (6.626\times10^{-34}\text{ J/Hz})(3.18\times10^{15}\text{ Hz})$

$= 2.11\times10^{-18}\text{ J}$

$\Delta E = -2.11\times10^{-18}\text{ J}$

$E_n = E_1 - \Delta E$

$= -2.17\times10^{-18}\text{ J} - (-2.11\times10^{-18}\text{ J})$

$= -6\times10^{-20}\text{ J}$

$\frac{-2.17\times10^{-18}\text{ J}}{n^2} = -6\times10^{-20}\text{ J}$

$n^2 = 36$

$n = 6$

56. For a hydrogen atom in the $n = 3$ Bohr orbital, find the following.

a. the radius of the orbital

$r = \frac{h^2n^2}{4\pi^2Kmq^2}$

$= \frac{(6.63\times10^{-34}\text{ J·s})^2(3)^2}{4\pi^2(9.00\times10^{9}\text{ N·m}^2/\text{C}^2)(9.11\times10^{-31}\text{ kg})(1.60\times10^{-19}\text{ C})^2}$

$= 4.77\times10^{-10}\text{ m}$

b. the electric force acting between the proton and the electron

$$F = \frac{Kq^2}{r^2}$$

$$= \frac{(9.00\times10^{9}\ \text{N·m}^2/\text{C}^2)(1.60\times10^{-19}\ \text{C})^2}{(4.77\times10^{-10}\ \text{m})^2}$$

$$= 1.01\times10^{-9}\ \text{N}$$

c. the centripetal acceleration of the electron

$$F = ma$$

$$a = \frac{F}{m} = \frac{1.01\times10^{-9}\ \text{N}}{9.11\times10^{-31}\ \text{kg}}$$

$$= 1.11\times10^{21}\ \text{m/s}^2$$

d. the orbital speed of the electron (Compare this speed with the speed of light.)

$$a = \frac{v^2}{r}$$

$$v = \sqrt{ar}$$

$$= \sqrt{(1.11\times10^{21}\ \text{m/s}^2)(4.77\times10^{-10}\ \text{m})}$$

$$= 7.28\times10^{5}\ \text{m/s, or 0.24\% of } c$$

28.2 The Quantum Model of the Atom

page 771

Level 1

57. CD Players Gallium arsenide lasers are commonly used in CD players. If such a laser emits at 840 nm, what is the difference in eV between the two lasing energy levels?

$$c = \lambda f$$

$$f = \frac{c}{\lambda} = \frac{3.00\times10^{8}\ \text{m/s}}{840\times10^{-9}\ \text{m}}$$

$$= 3.57\times10^{14}\ \text{Hz}$$

$$E = hf$$

$$= \frac{(6.63\times10^{-34}\ \text{J/Hz})(3.57\times10^{14}\ \text{Hz})}{1.60\times10^{-19}\ \text{J/eV}}$$

$$= 1.5\ \text{eV}$$

58. A GaInNi laser lases between energy levels that are separated by 2.90 eV.

a. What wavelength of light does it emit?

$$\Delta E = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{\Delta E} = \frac{1240\ \text{eV·nm}}{2.90\ \text{eV}}$$

$$= 428\ \text{nm}$$

b. In what part of the spectrum is this light?

blue

Level 2

59. A carbon-dioxide laser emits very high-power infrared radiation. What is the energy difference in eV between the two lasing energy levels? Consult Table 28-1.

$$c = \lambda f$$

$$f = \frac{c}{\lambda} = \frac{3.00\times10^{8}\ \text{m/s}}{10{,}600\times10^{-9}\ \text{m}}$$

$$= 2.83\times10^{13}\ \text{Hz}$$

$$E = hf$$

$$= \frac{(6.63\times10^{-34}\ \text{J/Hz})(2.83\times10^{13}\ \text{Hz})}{1.60\times10^{-19}\ \text{J/eV}}$$

$$= 0.117\ \text{eV}$$

60. The power in a laser beam is equal to the energy of each photon times the number of photons per second that are emitted.

a. If you want a laser at 840 nm to have the same power as one at 427 nm, how many times more photons per second are needed?

Since $E = hf = \frac{hc}{\lambda}$, the ratio of energy in each photon is $\frac{427}{840} = 0.508$. Therefore, the ratio of number of photons per second is $\frac{1}{0.508} = 1.97$

b. Find the number of photons per second in a 5.0-mW 840-nm laser.

P = (photons/s)(E/photon) = nE so $n = P/E$.

Calculate the energy of the photon in joules.

$$E = \frac{hc}{\lambda}$$

$$= \frac{(1240\ \text{eV·nm})(1.60\times10^{-19}\ \text{J/eV})}{840\ \text{nm}}$$

$$= 2.4\times10^{-19}\ \text{J;}$$

$$\text{So, } n = \frac{5.0\times10^{-3}\ \text{J/s}}{2.4\times10^{-19}\ \text{J/photon}}$$

$$= 2.1\times10^{16}\ \text{photons/s}$$

Level 3

61. HeNe Lasers The HeNe lasers used in many classrooms can be made to lase at three wavelengths: 632.8 nm, 543.4 nm, and 1152.3 nm.

a. Find the difference in energy between the two states involved in the generation of each wavelength.

$\Delta E = \frac{hc}{\lambda}$, so $\Delta E = \frac{1240 \text{ eV·nm}}{\lambda}$;

substituting the three values of λ gives 1.96 eV, 2.28 eV, and 1.08 eV

b. Identify the color of each wavelength.

red, green, and infrared, respectively

Mixed Review

page 772

Level 1

62. A photon with an energy of 14.0 eV enters a hydrogen atom in the ground state and ionizes it. With what kinetic energy will the electron be ejected from the atom?

It takes 13.6 eV to ionize the atom, so 14.0 eV − 13.6 eV = 0.4 eV kinetic energy.

63. Calculate the radius of the orbital associated with the energy levels E_5 and E_6 of the hydrogen atom.

$$r_5 = \frac{h^2n^2}{4\pi^2Kmq^2} = \frac{(6.63\times10^{-34} \text{ J·s})^2(5)^2}{4\pi^2(9.00\times10^{9} \text{ N·m}^2/\text{C}^2)(9.11\times10^{-31} \text{ kg})(1.60\times10^{-19} \text{ C})^2}$$

$$= 1.33\times10^{-9} \text{ m}$$

$$r_6 = \frac{(6.63\times10^{-34} \text{ J·s})^2(6)^2}{4\pi^2(9.00\times10^{9} \text{ N·m}^2/\text{C}^2)(9.11\times10^{-31} \text{ kg})(1.60\times10^{-19} \text{ C})^2}$$

$$= 1.91\times10^{-9} \text{ m}$$

Level 2

64. A hydrogen atom is in the $n = 2$ level.

a. If a photon with a wavelength of 332 nm strikes the atom, show that the atom will be ionized.

$E_2 = \frac{-13.6 \text{ eV}}{n^2} = \frac{13.6 \text{ eV}}{(2)^2} = -3.40$ **eV, so 3.40 eV needed to ionize from this level.**

$$E = hf = \frac{hc}{\lambda}$$

$$= \frac{(6.63\times10^{-34} \text{ J/Hz})(3.00\times10^{8} \text{ m/s})}{332\times10^{-9} \text{ m}}$$

$$= 5.99\times10^{-19} \text{ J}$$

$$= 3.74 \text{ eV}$$

Yes, the atom is ionized.

b. When the atom is ionized, assume that the electron receives the excess energy from the ionization. What will be the kinetic energy of the electron in joules?

3.74 eV − 3.40 eV = 0.340 eV

$$= 5.4\times10^{-20}\ \text{J}$$

Level 3

65. A beam of electrons is directed onto a sample of atomic hydrogen gas. What minimum energy of the electrons is needed for the hydrogen atoms to emit the red light produced when the atom goes from the $n = 3$ to the $n = 2$ state?

There must be enough energy to transition a stable hydrogen atom to the $n = 3$ state.

$$\Delta E = E_3 - E_1$$

$$= (-13.6\ \text{eV})\left(\frac{1}{3^2} - \frac{1}{1^2}\right)$$

$$= (-13.6\ \text{eV})\left(\frac{-8}{9}\right)$$

$$= 12.1\ \text{eV}$$

66. The most precise spectroscopy experiments use "two-photon" techniques. Two photons with identical wavelengths are directed at the target atoms from opposite directions. Each photon has half the energy needed to excite the atoms from the ground state to the desired energy level. What laser wavelength would be needed to make a precise study of the energy difference between $n = 1$ and $n = 2$ in hydrogen?

$$\Delta E = E_2 - E_1$$

$$= (-13.6\ \text{eV})\left(\frac{1}{2^2} - \frac{1}{1^2}\right)$$

$$= (-13.6\ \text{eV})\left(-\frac{3}{4}\right)$$

$$= 10.2\ \text{eV}$$

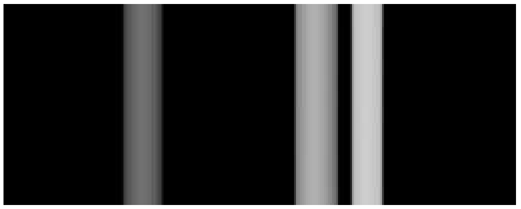
For each laser,

$$\lambda = \frac{hc}{\left(\frac{\Delta E}{2}\right)} = \frac{1240\ \text{eV·nm}}{\left(\frac{10.2\ \text{eV}}{2}\right)} = 243\ \text{nm}$$

Thinking Critically

page 772

67. Apply Concepts The result of projecting the spectrum of a high-pressure mercury vapor lamp onto a wall in a dark room is shown in **Figure 28-23.** What are the differences in energy levels for each of the three visible lines?



■ **Figure 28-23**

436 nm (2.84 eV) from E_6 to E_3 since $\frac{1240\ \text{eV·nm}}{436\ \text{nm}}$ = 284 eV; see Fig 28-21 to find energy levels.

546 nm (2.27 eV) from E_6 to E_4

579 nm (2.14 eV) from E_8 to E_5

68. Interpret Scientific Illustrations After the emission of the visible photons described in problem 67, the mercury atom continues to emit photons until it reaches the ground state. From an inspection of Figure 28-21, determine whether or not any of these photons would be visible. Explain.

No. The three highest energy lines leave the atom in states at least 4.64 eV above the ground state. A photon with this energy has a wavelength of 267 nm in the ultraviolet. The change from E_4 to E_2 involves an energy change of only 0.79 eV, resulting in light with a wavelength of 1570 nm in the infrared.

69. Anaylze and Conclude A positronium atom consists of an electron and its antimatter relative, the positron, bound together. Although the lifetime of this "atom" is very short—on the average it lives one-seventh of a microsecond—its energy levels can be measured. The Bohr model can be used to calculate energies with the mass of the electron replaced by one-half its mass. Describe how the radii of the orbits and the energy of each level would be affected.

What would be the wavelength of the E_2 to E_1 transition?

The radii would be twice as large because *m* appears in the denominator of the equation. The energies would be half as large because *m* appears in the numerator. Therefore, the wavelengths would be twice as large. Thus, the light emitted from E_2 to E_1 would be (2)(121 nm) = 242 nm.

Writing in Physics

page 772

70. Do research on the history of models of the atom. Briefly describe each model and identify its strengths and weaknesses.

Students should describe the "raisin pudding" model, a classical planetary model, the Bohr model, and the quantum model. The first explains how atoms can have electrons and mass, but fails to describe the results of Rutherford's experiments. The planetary explains electrons and Rutherford's results, but is unstable and would collapse in about 1 ns. Bohr's explains known spectra and fits Rutherford's nuclear model, but has unexplained assumptions and fails the uncertainty principle, as well as being unable to describe atoms with more than one electron. The quantum model can explain all known facts, but is hard to visualize and requires computers to solve the equations.

71. Green laser pointers emit light with a wavelength of 532 nm. Do research on the type of laser used in this type of pointer and describe its operation. Indicate whether the laser is pulsed or continuous.

It uses a pulsed Nd laser at 1064 nm. The IR is put into a "frequency doubling" crystal. Light with half that wavelength, or 532 nm, results.

Cumulative Review

page 772

72. The force on a test charge of $+3.00\times10^{-7}$ C is 0.027 N. What is the electric field strength at the position of the test charge? (Chapter 21)

$$E = \frac{F}{q'} = \frac{0.027\ \text{N}}{+3.00\times10^{-7}\ \text{C}} = 9.0\times10^{4}\ \text{N/C}$$

73. A technician needs a 4-Ω resistor but only has 1-Ω resistors of that value. Is there a way to combine what she has? Explain. (Chapter 23)

Yes. Put four 1Ω resistors in series.

$$R_T = R_1 + R_2 + R_3 + R_4$$

74. A 1.0-m–long wire is moved at right angles to Earth's magnetic field where the magnetic induction is 5.0×10^{-5} T at a speed of 4.0 m/s. What is the *EMF* induced in the wire? (Chapter 25)

$$EMF = BLv$$
$$= (5.0\times10^{-5}\ \text{T})(1.0\ \text{m})(4.0\ \text{m/s})$$
$$= 2.0\times10^{-4}\ \text{V} = 0.20\ \text{mV}$$

75. The electrons in a beam move at 2.8×10^{8} m/s in an electric field of 1.4×10^{4} N/C. What value must the magnetic field have if the electrons pass through the crossed fields undeflected? (Chapter 26)

$$v = \frac{E}{B}$$

$$B = \frac{E}{v} = \frac{1.4\times10^{4}\ \text{N/C}}{2.8\times10^{8}\ \text{m/s}}$$
$$= 5.0\times10^{-5}\ \text{T} = 5.0\times10^{1}\ \mu\text{T}$$

76. Consider the modifications that J. J. Thomson would need to make to his cathode-ray tube so that it could accelerate protons (rather than electrons), then answer the following questions. (Chapter 26)

a. To select particles of the same velocity, would the ratio *E*/*B* have to be changed? Explain.

No; $V = \frac{E}{B}$**, so ratio is same for a given V.**

b. For the deflection caused by the magnetic field alone to remain the same, would the B field have to be made smaller or larger? Explain.

For magnetic field only, $Bqv = \frac{mv^2}{r}$

and $r = \frac{mv}{qB}$ for a bigger mass, B must be bigger to keep v constant.

77. The stopping potential needed to return all the electrons ejected from a metal is 7.3 V. What is the maximum kinetic energy of the electrons in joules? (Chapter 27)

$$KE = (7.3\ \text{eV})\left(\frac{1.60\times10^{-19}\ \text{J}}{1\ \text{eV}}\right)$$

$$= 1.2\times10^{-18}\ \text{J}$$

Challenge Problem

page 759

Although the Bohr atomic model accurately explained the behavior of a hydrogen atom, it was unable to explain the behavior of any other atom. Verify the limitations of the Bohr model by analyzing an electron transition in a neon atom. Unlike a hydrogen atom, a neon atom has ten electrons. One of these electrons makes a transition between the $n = 5$ and the $n = 3$ energy states, emitting a photon in the process.

1. Assuming that the neon atom's electron can be treated as an electron in a hydrogen atom, what photon energy does the Bohr model predict?

$$\Delta E = E_i - E_f = (-13.6\ \text{eV})\left(\frac{1}{5^2} - \frac{1}{3^2}\right)$$

$$= 0.967\ \text{eV}$$

2. Assuming that the neon atom's electron can be treated as an electron in a hydrogen atom, what photon wavelength does the Bohr model predict?

$$\lambda = \frac{hc}{\Delta E} = \frac{1240\ \text{eV·nm}}{0.967\ \text{eV}} = 1280\ \text{nm}$$

3. The actual wavelength of the photon emitted during the transition is 632.8 nm. What is the percent error of the Bohr model's prediction of photon wavelength?

Percent error =

$$\left|\frac{\text{Accepted value} - \text{Predicted value}}{\text{Accepted value}}\right| \times 100$$

$$= \left|\frac{632.8\ \text{nm} - 1280\ \text{nm}}{6328\ \text{nm}}\right| \times 100 = 103\%$$

The calculated wavelength is roughly twice as large as the actual wavelength.

Solid-State Electronics

Practice Problems

29.1 Conduction in Solids pages 775–783

page 778

1. Zinc, with a density of 7.13 g/cm^3 and an atomic mass of 65.37 g/mol, has two free electrons per atom. How many free electrons are there in each cubic centimeter of zinc?

$$\text{free e}^-/\text{cm}^3 = \left(\frac{2 \text{ free e}^-}{\text{atom}}\right)\left(\frac{6.02\times10^{23} \text{ atoms}}{\text{mol}}\right)\left(\frac{1 \text{ mol}}{65.37 \text{ g}}\right)\left(\frac{7.13 \text{ g}}{\text{cm}^3}\right)$$

$$= 1.31\times10^{23} \text{ free e}^-/\text{cm}^3$$

2. Silver has 1 free electron per atom. Use Appendix D and determine the number of free electrons in 1 cm^3 of silver.

$$\text{free e}^-/\text{cm}^3 = \left(\frac{1 \text{ free e}^-}{\text{atom}}\right)\left(\frac{6.02\times10^{23} \text{ atoms}}{\text{mol}}\right)\left(\frac{1 \text{ mol}}{107.87 \text{ g}}\right)\left(\frac{10.49 \text{ g}}{\text{cm}^3}\right)$$

$$= 5.85\times10^{22} \text{ free e}^-/\text{cm}^3$$

3. Gold has 1 free electron per atom. Use Appendix D and determine the number of free electrons in 1 cm^3 of gold.

$$\text{free e}^-/\text{cm}^3 = \left(\frac{1 \text{ free e}^-}{\text{atom}}\right)\left(\frac{6.02\times10^{23} \text{ atoms}}{\text{mol}}\right)\left(\frac{1 \text{ mol}}{196.97 \text{ g}}\right)\left(\frac{19.32 \text{ g}}{\text{cm}^3}\right)$$

$$= 5.90\times10^{22} \text{ free e}^-/\text{cm}^3$$

4. Aluminum has 3 free electrons per atom. Use Appendix D and determine the number of free electrons in 1 cm^3 of aluminum.

$$\text{free e}^-/\text{cm}^3 = \left(\frac{3 \text{ e}^-}{\text{atom}}\right)\left(\frac{6.02\times10^{23} \text{ atoms}}{\text{mol}}\right)\left(\frac{1 \text{ mol}}{26.982 \text{ g}}\right)\left(\frac{2.70 \text{ g}}{\text{cm}^3}\right)$$

$$= 1.81\times10^{23} \text{ free e}^-/\text{cm}^3$$

5. The tip of the Washington Monument was made of 2835 g of aluminum because it was a rare and costly metal in the 1800s. Use problem 4 and determine the number of free electrons in the tip of the Washington Monument.

$$\text{free e}^- = (1.81\times10^{23} \text{ free e}^-/\text{cm}^3)\left(\frac{2835 \text{ g}}{2.70 \text{ g/cm}^3}\right)$$

$$= 1.90\times10^{26} \text{ free e}^- \text{ in the tip}$$

page 780

6. In pure germanium, which has a density of 5.23 g/cm^3 and an atomic mass of 72.6 g/mol, there are 2.25×10^{13} free electrons/cm^3 at room temperature. How many free electrons are there per atom?

$$\text{free e}^-\text{/atom} = \left(\frac{1\text{ mol}}{6.02\times10^{23}\text{ atoms}}\right)\left(\frac{72.6\text{ g}}{1\text{ mol}}\right)\left(\frac{\text{cm}^3}{5.23\text{ g}}\right)\left(\frac{2.25\times10^{13}\text{ free e}^-}{\text{cm}^3}\right)$$

$$= 5.19\times10^{-10}\text{ free e}^-\text{/atom}$$

7. At 200.0 K, silicon has 1.89×10^5 free electrons/cm^3. How many free electrons are there per atom at this temperature? What does this temperature represent on the Celsius scale?

$$\text{free e}^-\text{/atom} = \left(\frac{1\text{ mol}}{6.02\times10^{23}\text{ atoms}}\right)\left(\frac{28.09\text{ g}}{1\text{ mol}}\right)\left(\frac{\text{cm}^3}{2.33\text{ g}}\right)\left(\frac{1.89\times10^{5}\text{ free e}^-}{\text{cm}^3}\right)$$

$$= 3.78\times10^{-18}\text{ free e}^-\text{/atom}$$

$T_K = T_C + 273°$

$T_C = T_K - 273°$

$= 200.0° - 273°$

$= -73°C$

8. At 100.0 K, silicon has 9.23×10^{-10} free electrons/cm^3. How many free electrons are there per atom at this temperature? What does this temperature represent on the Celsius scale?

$$\text{free e}^-\text{/atom} = \left(\frac{1\text{ mol}}{6.02\times10^{23}\text{ atoms}}\right)\left(\frac{28.09\text{ g}}{1\text{ mol}}\right)\left(\frac{\text{cm}^3}{2.33\text{ g}}\right)\left(\frac{9.23\times10^{-10}\text{ free e}^-}{\text{cm}^3}\right)$$

$$= 1.85\times10^{-32}\text{ free e}^-\text{/atom}$$

$T_K = T_C + 273°$

$T_C = T_K - 273°$

$= 100.0° - 273°$

$= -173°C$

9. At 200.0 K, germanium has 1.16×10^{10} free electrons/cm^3. How many free electrons are there per atom at this temperature?

$$\text{free e}^-\text{/atom} = \left(\frac{1\text{ mol}}{6.02\times10^{23}\text{ atoms}}\right)\left(\frac{72.6\text{ g}}{1\text{ mol}}\right)\left(\frac{\text{cm}^3}{5.23\text{ g}}\right)\left(\frac{1.16\times10^{10}\text{ free e}^-}{\text{cm}^3}\right)$$

$$= 2.67\times10^{-13}\text{ free e}^-\text{/atom}$$

10. At 100.0 K, germanium has 3.47 free electrons/cm^3. How many free electrons are there per atom at this temperature?

$$\text{free e}^-\text{/atom} = \left(\frac{1\text{ mol}}{6.02\times10^{23}\text{ atoms}}\right)\left(\frac{72.6\text{ g}}{1\text{ mol}}\right)\left(\frac{\text{cm}^3}{5.23\text{ g}}\right)\left(\frac{3.47\text{ free e}^-}{\text{cm}^3}\right)$$

$$= 8.00\times10^{-23}\text{ free e}^-\text{/atom}$$

page 783

11. If you wanted to have 1×10^4 as many electrons from arsenic doping as thermally free electrons in silicon at room temperature, how many arsenic atoms should there be per silicon atom?

From Example Problem 3 you know that there are 4.99×10^{22} Si atoms/cm^3, 1.45×10^{10} free e$^-$/cm^3 in Si, and 1 free e$^-$/As atom.

e^- from As = (1×10^4)(free e^- from Si)

However, the ratio of atoms is needed, not electrons.

$$\text{As atoms} = \frac{e^- \text{ from As}}{\text{free } e^-/\text{atom As}} = \frac{(1\times10^4)(\text{free } e^- \text{ from Si})}{\text{free } e^-/\text{atom As}}$$

$$\text{free } e^- \text{ from Si} = (\text{Si atoms})\left(\frac{\text{free } e^-/\text{cm}^3 \text{ Si}}{\text{Si atoms/cm}^3}\right)$$

Substituting into the expression for As atoms yields

$$\text{As atoms} = \frac{(1\times10^4)(\text{Si atoms})\left(\frac{\text{free } e^-/\text{cm}^3 \text{ Si}}{\text{Si atoms/cm}^3}\right)}{\text{free } e^-/\text{atom As}}$$

$$\frac{\text{As atoms}}{\text{Si atoms}} = \frac{(1\times10^4)\left(\frac{\text{free } e^-/\text{cm}^3 \text{ Si}}{\text{Si atoms/cm}^3}\right)}{\text{free } e^-/\text{atom As}}$$

$$= \frac{(1\times10^4)\left(\frac{1.45\times10^{10}}{4.99\times10^{22}}\right)}{1}$$

$$= 2.91\times10^9$$

12. If you wanted to have 5×10^3 as many electrons from arsenic doping as thermally free electrons in the germanium semiconductor described in problem 6, how many arsenic atoms should there be per germanium atom?

Using the solution in problem 11 as a go by

$$\frac{\text{As atoms}}{\text{Ge atoms}} = \frac{(5\times10^3)\left(\frac{\text{free } e^-/\text{cm}^3 \text{ Ge}}{\text{Ge atoms/cm}^3}\right)}{\text{free } e^-/\text{atom As}}$$

From problem 6, free e^-/cm^3 Ge = 2.25×10^3

From Example Problem 3, free e^-/atom As = 1

$$\text{Ge atoms/cm}^3 = \left(\frac{6.02\times10^{23} \text{ atoms}}{1 \text{ mol}}\right)\left(\frac{1 \text{ mol}}{72.6 \text{ g}}\right)\left(\frac{5.23 \text{ g}}{\text{cm}^3}\right) = 4.34\times10^{22} \text{ atoms/cm}^3$$

$$\frac{\text{As atoms}}{\text{Ge atoms}} = \frac{(5\times10^3)\left(\frac{2.25\times10^{13}}{4.34\times10^{22}}\right)}{1}$$

$$= 2.59\times10^{-6}$$

13. Germanium at 400.0 K, has 1.13×10^{15} thermally liberated carriers/cm^3. If it is doped with 1 As atom per 1 million Ge atoms, what is the ratio of doped carriers to thermal carriers?

Use the solution to problem 12 as a starting point.

$$\frac{\text{As atoms}}{\text{Ge atoms}} = \frac{\left(\frac{\text{doped } e^-}{\text{Ge } e^-}\right)\left(\frac{\text{free } e^-/\text{cm}^3 \text{ Ge}}{\text{Ge atoms/cm}^3}\right)}{\text{free } e^-/\text{atom As}}$$

$$\frac{\text{doped } e^-}{\text{Ge } e^-} = \left(\frac{\text{As atoms}}{\text{Ge atoms}}\right)\left(\frac{\text{Ge atoms/cm}^3}{\text{free } e^-/\text{cm}^3 \text{ Ge}}\right)(\text{free } e^-/\text{atom As})$$

$$= \left(\frac{1}{1\times10^6}\right)\left(\frac{4.34\times10^{22}}{1.13\times10^{15}}\right)(1)$$

$$= 38.4$$

14. Silicon at 400.0 K, has 4.54×10^{12} thermally liberated carriers/cm^3. If it is doped with 1 As atom per 1 million Si, what is the ratio of doped carriers to thermal carriers?

Using the solution problem 13 as a go by

$$\frac{\text{doped e}^-}{\text{Si e}^-} = \left(\frac{\text{As atoms}}{\text{Si atoms}}\right)\left(\frac{\text{Si atoms/cm}^3}{\text{free e}^-\text{/cm}^3\text{ Si}}\right)(\text{free e}^-\text{/atom As})$$

$$= \left(\frac{1}{1\times10^6}\right)\left(\frac{4.99\times10^{22}}{4.54\times10^{12}}\right)(1)$$

$$= 1.10\times10^4$$

15. Based on problem 14, draw a conclusion about the behavior of germanium devices as compared to silicon devices at temperatures in excess of the boiling point of water.

Germanium devices do not work well at such temperatures because the ratio of doped carriers to thermal carriers is small enough that temperature has too much influence on conductivity. Silicon is much better.

Section Review

29.1 Conduction in Solids pages 775–783

page 783

16. Carrier Mobility In which type of material, a conductor, a semiconductor, or an insulator, are electrons most likely to remain with the same atom?

insulator

17. Semiconductors If the temperature increases, the number of free electrons in an intrinsic semiconductor increases. For example, raising the temperature by 8°C doubles the number of free electrons in silicon. Is it more likely that an intrinsic semiconductor or a doped semiconductor will have a conductivity that depends on temperature? Explain.

An intrinsic one because all its conduction is from thermally freed electrons, whereas the doped semiconductor depends on the charges from the dopants, which depend little on temperature.

18. Insulator or Conductor? Silicon dioxide is widely used in the manufacture of solid-state devices. Its energy-band diagram shows a gap of 9 eV between the valence band and the conduction band. Is it more useful as an insulator or a conductor?

insulator

19. Conductor or Insulator? Magnesium oxide has a forbidden gap of 8 eV. Is this material a conductor, an insulator, or a semiconductor?

insulator

20. **Intrinsic and Extrinsic Semiconductors** You are designing an integrated circuit using a single crystal of silicon. You want to have a region with relatively good insulating properties. Should you dope this region or leave it as an intrinsic semiconductor?

Leave it.

21. **Critical Thinking** Silicon produces a doubling of thermally liberated carriers for every 8°C increase in temperature, and germanium produces a doubling of thermally liberated carriers for every 13°C increase. It would seem that germanium would be superior for high-temperature applications, but the opposite is true. Explain.

Even though rate of change for thermal carrier production is greater for silicon, at any given temperature silicon shows far fewer thermally liberated carriers.

Practice Problems

29.2 Electronic Devices pages 784–789

page 786

22. What battery voltage would be needed to produce a current of 2.5 mA in the diode in Example Problem 4?

1.7 V

Using Fig. 29-10, the diode has

$V_d = 0.50\text{ V at }2.5\text{ mA}$

$V_b = IR + V_d$

$= (0.0025\text{ A})(470\ \Omega) + 0.50\text{ V}$

$= 1.7\text{ V}$

23. What battery voltage would be needed to produce a current of 2.5 mA if another identical diode were added in series with the diode in Example Problem 4?

$V_b = IR + V_d + V_d$

$= (0.0025\text{ A})(470\ \Omega) + 0.50\text{ V} + 0.50\text{ V}$

$= 2.2\text{ V}$

24. Describe how the diodes in the previous problem should be connected.

The anode of one connects to the cathode of the other and then the unconnected anode must be connected to the positive side of the circuit.

25. Describe what would happen in problem 23 if the diodes were connected in series but with improper polarity.

It would be impossible to obtain 2.5 mA of current with any reasonable power supply voltage because one of the diodes would be reverse-biased.

26. A germanium diode has a voltage drop of 0.40 V when 12 mA passes through it. If a 470-Ω resistor is used in series, what battery voltage is needed?

6.0 V

$V_b = IR + V_d$

$= (0.012\text{ A})(470\ \Omega) + 0.40\text{ V}$

$= 6.0\text{ V}$

Section Review

29.2 Electronic Devices pages 784–789

page 789

27. **Transistor Circuit** The emitter current in a transistor circuit is always equal to the sum of the base current and the collector current: $I_E = I_B + I_C$. If the current gain from the base to the collector is 95, what is the ratio of emitter current to base current?

$\text{Gain} = \frac{I_C}{I_B} = 95$

$I_E = I_B + I_C$

Divide both sides by I_B.

$\frac{I_E}{I_B} = 1 + \frac{I_C}{I_B} = 1 + 95 = 96$

96 to 1

28. Diode Voltage Drop If the diode characterized in Figure 29-10 is forward-biased by a battery and a series resistor so that there is more than 10 mA of current, the voltage drop is always about 0.70 V. Assume that the battery voltage is increased by 1 V.

a. By how much does the voltage across the diode or the voltage across the resistor increase?

Because the voltage across the diode is always 0.70 V, the voltage across the resistor increases by 1 V.

b. By how much does the current through the resistor increase?

The current increases by $I = \frac{1\ \text{V}}{R}$.

29. Diode Resistance Compare the resistance of a *pn*-junction diode when it is forward-biased and when it is reverse-biased.

It conducts much better when forward-biased, so its resistance is much smaller when forward-biased than when reverse-biased.

30. Diode Polarity In a light-emitting diode, which terminal should be connected to the *p*-end to make the diode light?

The LED must be forward-biased, so the positive terminal must be connected to the *p*-end.

31. Current Gain The base current in a transistor circuit measures 55 μA and the collector current measures 6.6 mA. What is the current gain from base to collector?

$$\text{Gain} = \frac{I_C}{I_B} = \frac{6.6\ \text{mA}}{0.055\ \text{mA}} = 120$$

32. Critical Thinking Could you replace an *npn*-transistor with two separate diodes connected by their *p*-terminals? Explain.

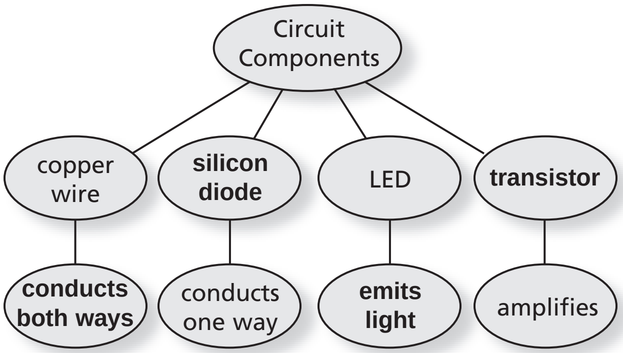
No, the *p*-region of an *npn*-transistor must be thin enough to allow electrons to pass through the base to the collector.

Chapter Assessment

Concept Mapping

page 794

33. Complete the concept map using the following terms: *transistor, silicon diode, emits light, conducts both ways.*



Mastering Concepts

page 794

34. How do the energy levels in a crystal of an element differ from the energy levels in a single atom of that element? (29.1)

The energy levels of a single atom have discrete and unique values. The energy levels in a crystal have a small range around the values found in a single atom.

35. Why does heating a semiconductor increase its conductivity? (29.1)

A higher temperature gives electrons additional energy, permitting more electrons to reach the conductive band.

36. What is the main current carrier in a *p*-type semiconductor? (29.1)

positively-charged holes

37. An ohmmeter is an instrument that places a potential difference across a device to be tested, measures the current, and displays the resistance of the device. If you connect an ohmmeter across a diode, will the current you measure depend on which end of the diode was connected to the positive terminal of the ohmmeter? Explain. (29.2)

Yes, one way you forward-bias the diode; the other way you reverse-bias it.

38. What is the significance of the arrowhead at the emitter in a transistor circuit symbol? (29.2)

The arrowhead shows the direction of the conventional current.

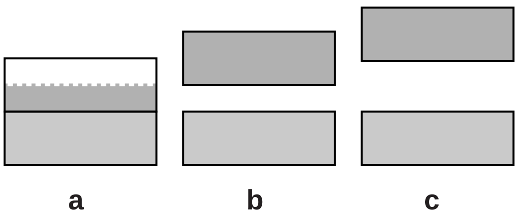
39. Describe the structure of a forward-biased diode, and explain how it works. (29.2)

A forward-biased diode has a *p*-type and an *n*-type semiconductor layer, connected to wires on either end through metal caps. The *p*-type layer is connected to the positive terminal of the battery. New holes are created in the *p*-type layer and those holes move toward the boundary between the two semiconductors. New electrons are added to the *n*-type layer, and those electrons move toward the boundary between the two semiconductors. As the holes and electrons combine, the circuit is completed and there is current. The current direction is from the *p*-type semiconductor to the *n*-type.

Applying Concepts

pages 794–795

40. For the energy-band diagrams shown in **Figure 29-16,** which one represents a material with an extremely high resistance?



■ **Figure 29-16**

41. For the energy-band diagrams shown in Figure 29-16, which have half-full conduction bands?

a

42. For the energy-band diagrams shown in Figure 29-16, which ones represent semiconductors?

b

43. The resistance of graphite decreases as temperature rises. Does graphite conduct electricity more like copper or more like silicon does?

more like Si

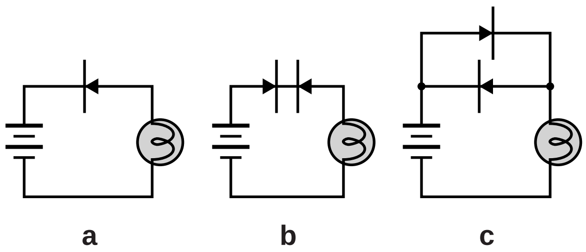
44. Which of the following materials would make a better insulator: one with a forbidden gap 8-eV wide, one with a forbidden gap 3-eV wide, or one with no forbidden gap?

one with an 8-eV gap

45. Consider atoms of the three materials in problem 44. From which material would it be most difficult to remove an electron?

one with an 8-eV gap

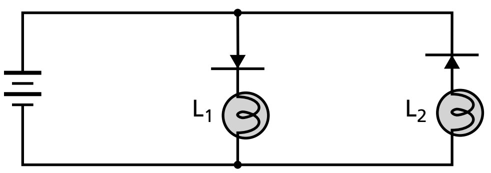
46. State whether the bulb in each of the circuits of **Figure 29-17** (**a, b,** and **c**) is lighted.



■ **Figure 29-17**

circuit a: no, circuit b: no, circuit c: yes

47. In the circuit shown in **Figure 29-18,** state whether lamp L_1, lamp L_2, both, or neither is lighted.



■ **Figure 29-18**

L_1 is on, L_2 is off.

48. Use the periodic table to determine which of the following elements could be added to germanium to make a *p*-type semiconductor: B, C, N, P, Si, Al, Ge, Ga, As, In, Sn, or Sb.

B, Al, Ga, In

49. Does an ohmmeter show a higher resistance when a *pn*-junction diode is forward-biased or reverse-biased?

The diode will have a lower resistance when it is forward-biased.

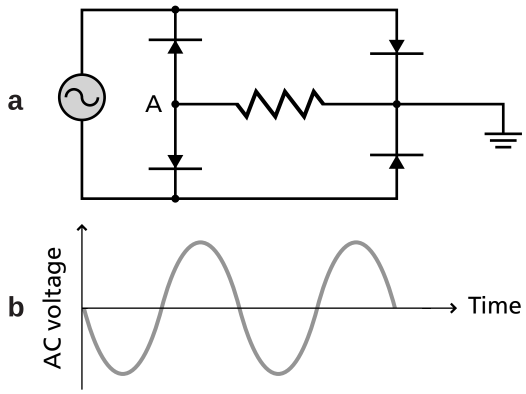
50. If the ohmmeter in problem 49 shows the lower resistance, is the ohmmeter lead on the arrow side of the diode at a higher or lower potential than the lead connected to the other side?

higher potential, more positive

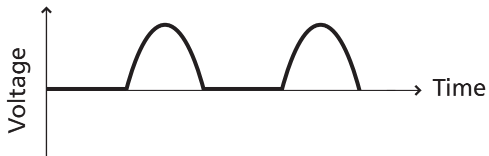
51. If you dope pure germanium with gallium alone, do you produce a resistor, a diode, or a transistor?

You make a resistor because there is no junction.

52. Draw the time-versus-amplitude waveform for point A in **Figure 29-19a** assuming an input AC waveform as shown in **Figure 29-19b.**



■ **Figure 29-19**



Output Voltage

Point A is negative with respect to ground and the graph shows that the alternating polarity of the input waveform has been rectified to a negative polarity.

Mastering Problems

29.1 Conduction in Solids

page 795

Level 1

53. How many free electrons exist in a cubic centimeter of sodium? Its density is 0.971 g/cm^3, its atomic mass is 22.99 g/mol, and there is 1 free electron per atom.

$$\text{free e}^-/\text{cm}^3 = \left(\frac{1\ \text{e}^-}{\text{atom}}\right)\left(\frac{6.02\times10^{23}\ \text{atoms}}{\text{mol}}\right)\left(\frac{0.971\ \text{g}}{\text{cm}^3}\right)\left(\frac{\text{mol}}{22.99\ \text{g}}\right)$$

$$= 2.54\times10^{22}\ \text{free e}^-/\text{cm}^3$$

Level 2

54. At a temperature of 0°C, thermal energy frees 1.55×10^9 e$^-$/cm^3 in pure silicon. The density of silicon is 2.33 g/cm^3, and the atomic mass of silicon is 28.09 g/mol. What is the fraction of atoms that have free electrons?

$$\frac{\left(\frac{6.02\times10^{23}\ \text{atoms}}{\text{mol}}\right)\left(\frac{2.33\ \text{g}}{\text{cm}^3}\right)\left(\frac{\text{mol}}{28.09\ \text{g}}\right)}{1.55\times10^{9}\ \text{e}^-/\text{cm}^3}$$

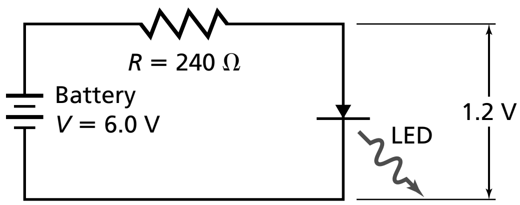
$$= 3.22\times10^{13}\ \text{atom/e}^-$$

29.2 Electronic Devices

page 795

Level 1

55. **LED** The potential drop across a glowing LED is about 1.2 V. In **Figure 29-20,** the potential drop across the resistor is the difference between the battery voltage and the LED's potential drop. What is the current through each of the following?



■ **Figure 29-20**

a. the LED

$$V_b = IR + V_d$$

$$I = \frac{V_b - V_d}{R}$$

$$= \frac{6.0\ V - 1.2\ V}{240\ \Omega}$$

$$= 2.0\times10^{1}\ mA$$

b. the resistor

2.0×10^{1} mA

56. Jon wants to raise the current through the LED in problem 55 up to 3.0×10^{1} mA so that it glows brighter. Assume that the potential drop across the LED is still 1.2 V. What resistor should be used?

$$R = \frac{V_b - V_d}{I} = \frac{6.0\ V - 1.2\ V}{3.0\times10^{1}\ mA} = 160\ \Omega$$

Level 2

57. Diode A silicon diode with *I*/*V* characteristics, as shown in Figure 29-10, is connected to a battery through a 270-Ω resistor. The battery forward-biases the diode, and the diode current is 15 mA. What is the battery voltage?

$$V_b = IR + V_d$$

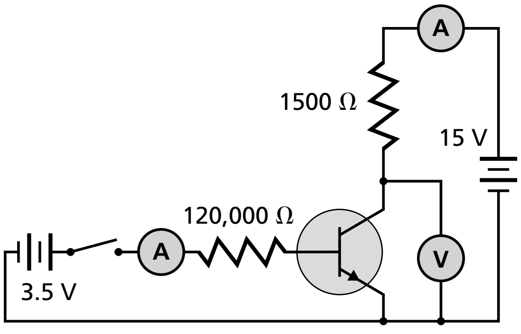
$$V_d = 0.70\ V\ \text{(from figure)}$$

$$V_b = (15\ mA)(270\ \Omega) + 0.70\ V$$

$$= 4.8\ V$$

Level 3

58. Assume that the switch shown in **Figure 29-21** is off.



■ **Figure 29-21**

a. Determine the base current.

by inspection, the base circuit is off, so it is zero

b. Determine the collector current.

by definition: when the base current is zero, so is the collector current

c. Determine the voltmeter reading.

15 V

With no current flow, the drop across the collector resistor is zero and there is a 15-V drop across the transistor.

59. Assume that the switch shown in Figure 29-21 is on, and that there is a 0.70-V drop across the base-emitter junction and a current gain from base to collector of 220.

a. Determine the base current.

$$I = \frac{V}{R}$$

$$= \frac{3.5\ V - 0.70\ V}{120{,}000\ \Omega}$$

$$= 2.3\times10^{-5}\ A$$

b. Determine the collector current.

$$\frac{I_C}{I_B} = 220$$

$$I_C = 220 I_B$$

$$= (220)(2.3\times10^{-5}\ A)$$

$$= 5.1\times10^{-3}\ A$$

c. Determine the voltmeter reading.

Find the drop across the 1500 Ω resistor:

$$V_{resistor} = IR$$

$$= (5.1\times10^{-3}\ A)(1500\ \Omega)$$

$$= 7.7\ V$$

The meter is connected across the transistor,

$$V_{battery} = V_{resistor} + V_{transistor}$$

$$V_{meter} = V_{transistor}$$

$$= V_{battery} - V_{resistor}$$

$$= 15\ V - 7.7\ V$$

$$= 7.3\ V$$

Mixed Review

pages 795–796

Level 1

60. The forbidden gap in silicon is 1.1 eV. Electromagnetic waves striking the silicon cause electrons to move from the valence band to the conduction band. What is the longest wavelength of radiation that could excite an electron in this way? Recall that $E = 1240\ \text{eV}\cdot\text{nm}/\lambda$.

$$\lambda = \frac{1240\ \text{eV}\cdot\text{nm}}{1.1\ \text{eV}}$$

= 1100 nm in the near infrared

Level 2

61. Si Diode A particular silicon diode at 0°C shows a current of 1.0 nA when it is reverse-biased. What current can be expected if the temperature increases to 104°C? Assume that the reverse-bias voltage remains constant. (The thermal carrier production of silicon doubles for every 8°C increase in temperature.)

$$\text{Number of 8°C increases} = \frac{104°\text{C}}{8°\text{C}} = 13$$

The current will double 13 times

$$\text{Current at 104°C} = (1\ \text{nA})(2^{13}) = 8.2\ \mu\text{A}$$

62. Ge Diode A particular germanium diode at 0°C shows a current of 1.5 μA when it is reverse-biased. What current can be expected if the temperature increases to 104°C? Assume that the reverse-biasing voltage remains constant. (The thermal charge-carrier production of germanium doubles for every 13°C increase in temperature.)

$$\text{Number of 13°C increases} = \frac{104°\text{C}}{13°\text{C}} = 8$$

The current will double 8 times.

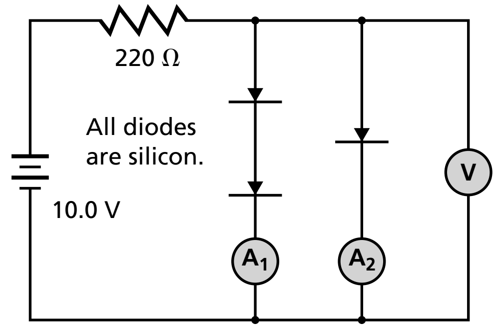
$$\text{Current at 104°C} = (1.5\ \mu\text{A})(2^{8}) = 380\ \mu\text{A}$$

Level 3

63. LED A light-emitting diode (LED) produces green light with a wavelength of 550 nm when an electron moves from the conduction band to the valence band. Find the width of the forbidden gap in eV in this diode.

$$E = \frac{1240\ \text{eV}\cdot\text{nm}}{550\ \text{nm}} = 2.25\ \text{eV}$$

64. Refer to **Figure 29-22.**



■ **Figure 29-22**

a. Determine the voltmeter reading.

0.70 V

by inspection and the approximation that a silicon diode will drop 0.70 V when it is forward biased

b. Determine the reading of A_1.

0 A

by inspection; 0.70 V is not enough to turn on two diodes in series.

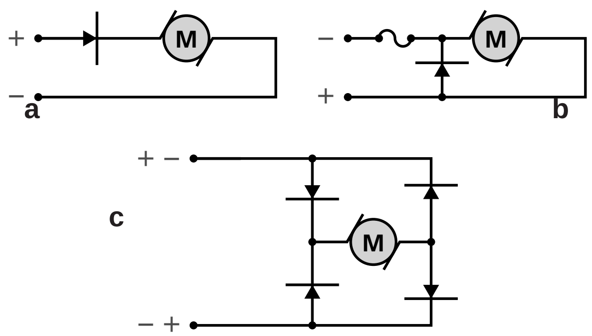
c. Determine the reading of A_2.

$$I = \frac{V}{R} = \frac{10.0\ \text{V} - 0.70\ \text{V}}{220\ \Omega} = 42\ \text{mA}$$

Thinking Critically

page 796

65. Apply Concepts A certain motor, in **Figure 29-23,** runs in one direction with a given polarity applied and reverses direction with the opposite polarity.



■ **Figure 29-23**

a. Which circuit (**a, b,** or **c**) will allow the motor to run in only one direction?

a

b. Which circuit will cause a fuse to blow if the incorrect polarity is applied?

b

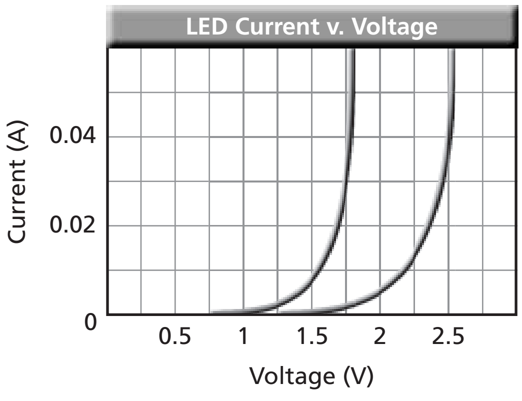
c. Which circuit produces the correct direction of rotation regardless of the applied polarity?

c

d. Discuss the advantages and disadvantages of all three circuits.

The circuit at a has the advantage of simplicity. It has the disadvantage of dropping 0.70 V, which can be important in low-voltage circuits. The circuit at b has the advantage of not wasting 0.70 V. It has the disadvantage of having to replace fuses. The circuit at c has the advantage of always working, regardless of polarity. It has the disadvantage of wasting 1.4 V.

66. Apply Concepts The *I*/*V* characteristics of two LEDs that glow with different colors are shown in **Figure 29-24.** Each is to be connected through a resistor to a 9.0-V battery. If each is to be run at a current of 0.040 A, what resistors should be chosen for each?



■ **Figure 29-24**

$$V_b = IR + V_D$$

$$R = \frac{V_b - V_D}{I}$$

$$R_1 = \frac{9.0\ \text{V} - 1.75\ \text{V}}{0.040\ \text{A}} = 180\ \Omega$$

$$R_2 = \frac{9.0\ \text{V} - 2.5\ \text{V}}{0.040\ \text{A}} = 160\ \Omega$$

67. Apply Concepts Suppose that the two LEDs in problem 66 are now connected in series. If the same battery is to be used and a current of 0.035 A is desired, what resistor should be used?

$$R = \frac{V_b - (V_{D1} + V_{D2})}{I}$$

$$= \frac{9.0\ \text{V} - (1.75\ \text{V} + 2.5\ \text{V})}{0.035\ \text{A}} = 140\ \Omega$$

Writing in Physics

page 796

68. Research the Pauli exclusion principle and the life of Wolfgang Pauli. Highlight his outstanding contributions to science. Describe the application of the exclusion principle to the band theory of conduction, especially in semiconductors.

Student answers will vary. Students could discuss his contributions to quantum mechanics, the Pauli matrices, his suggestion of a neutral, massless particle in beta decay (the neutrino), and his proof of the spin-statistics theorem.

69. Write a one-page paper discussing the Fermi energy level as it applies to energy-band diagrams for semiconductors. Include at least one drawing.

Student answers will vary, but should indicate that the Fermi energy is the energy of the highest occupied state at absolute zero. It applies when there are many electrons in a system, and thus, the electrons are forced into higher energy levels due to the Pauli exclusion principle.

Cumulative Review

page 796

70. An alpha particle, a doubly ionized (2+) helium atom, has a mass of 6.7×10^{-27} kg and is accelerated by a voltage of 1.0 kV. If a uniform magnetic field of 6.5×10^{-2} T is maintained on the alpha particle, what will be the particle's radius of curvature? (Chapter 26)

$$r = \frac{1}{B}\sqrt{\frac{2Vm}{q}}$$

$$= \frac{1}{(6.5\times10^{-2}\text{ T})}\sqrt{\frac{(2)(1.0\times10^{3}\text{ V})(6.7\times10^{-27}\text{ kg})}{(2)(1.60\times10^{-19}\text{ C})}}$$

$$= 0.010\text{ m}$$

71. What is the potential difference needed to stop photoelectrons that have a maximum kinetic energy of 8.0×10^{-19} J? (Chapter 27)

$$KE = 8.0\times10^{-19}\text{ J}\left(\frac{1\text{ eV}}{1.60\times10^{-19}\text{ J}}\right)$$

$$= 5.0\text{ eV, so } 5.0\text{ V}$$

72. Calculate the radius of the orbital associated with the energy level E_4 of the hydrogen atom. (Chapter 28)

$$r = \frac{h^2n^2}{4\pi^2 Kmq^2}$$

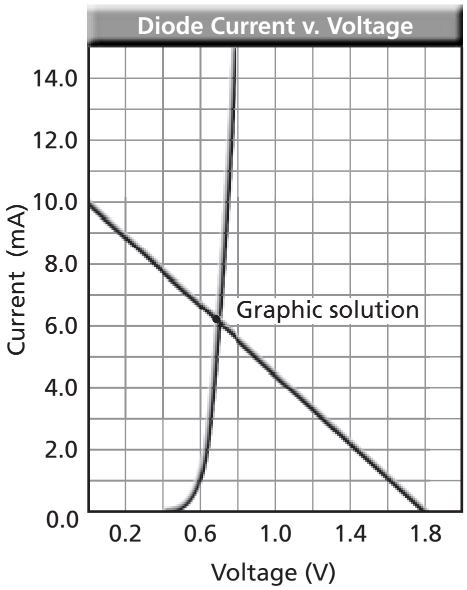
$$= \frac{(6.627\times10^{-34}\text{ J·s})^2(4)^2}{4\pi^2(8.99\times10^{9}\text{ N·m}^2/\text{C}^2)(9.11\times10^{-31}\text{ kg})(1.60\times10^{-19}\text{ C})^2}$$

$$= 8.49\times10^{-10}\text{ m} = 0.849\text{ nm}$$

Challenge Problem

page 786

Approximations often are used in diode circuits because diode resistance is not constant. For diode circuits, the first approximation ignores the forward voltage drop across the diode. The second approximation takes into account a typical value for the diode voltage drop. A third approximation uses additional information about the diode, often in the form of a graph, as shown in the illustration to the right. The curve is the characteristic current-volatage curve for the diode. The straight line shows current-voltage conditions for all possible diode voltage drops for a 180-Ω resistor, a 1.8-V battery, and a diode, from a zero diode voltage drop and 10.0 mA at one end, to a 1.8-V drop, 0.0 mA at the other end. Use the diode circuit in Example Problem 4 with V_b = 1.8 V, but with R = 180 Ω:



1. Determine the diode current using the first approximation.

$$I = \frac{V}{R} = \frac{1.8\text{ V}}{180\ \Omega} = 1.0\times10^{1}\text{ mA}$$

2. Determine the diode current using the second approximation and assuming a 0.70-V diode drop.

$$I = \frac{V}{R} = \frac{1.8\text{ V} - 0.70\text{ V}}{180\ \Omega} = 6.1\text{ mA}$$

3. Determine the diode current using the third approximation by using the accompanying diode graph.

The straight line represents all the possible conditions for a 180-Ω resistor and a 1.8-V battery (from a diode voltage drop of 0.0 V at 10.0 mA on one end to a 1.8-V drop at 0.0 mA on the other end). The solution is the intersection of both lines and occurs at I = 6.3 mA.

4. Estimate the error for all three approximations, ignoring the battery and resistor. Discuss the impact of greater battery voltages on the errors.

For the first approximation, the error is (10.0 mA − 6.1 mA)/6.1 mA, or 64 percent (when the actual diode drop is 0.70 V). This error decreases for greater battery voltages. For the second approximation, the error source is any deviation from 0.70 V as the actual diode drop. It cannot be exactly determined, but it's much less than 64 percent. This error also decreases with higher battery voltages. For the third approximation, the error is due to graphic resolution and is not affected by the battery voltage.

CHAPTER

30 Nuclear Physics

Practice Problems

30.1 The Nucleus pages 799–805

page 801

1. Three isotopes of uranium have mass numbers of 234, 235, and 238. The atomic number of uranium is 92. How many neutrons are in the nuclei of each of these isotopes?

   $A - Z$ = neutrons

   234 − 92 = 142 neutrons

   235 − 92 = 143 neutrons

   238 − 92 = 146 neutrons

2. An isotope of oxygen has a mass number of 15. How many neutrons are in the nucleus of this isotope?

   $A - Z$ = 15 − 8 = 7 neutrons

3. How many neutrons are in the mercury isotope $^{200}_{80}Hg$?

   $A - Z$ = 200 − 80 = 120 neutrons

4. Write the symbols for the three isotopes of hydrogen that have zero, one, and two neutrons in the nucleus.

   $^{1}_{1}H$, $^{2}_{1}H$, $^{3}_{1}H$

page 805

Use these values to solve the following problems: mass of hydrogen = 1.007825 u, mass of neutron = 1.008665 u, 1 u = 931.49 MeV.

5. The carbon isotope $^{12}_{6}C$ has a mass of 12.0000 u.

   a. Calculate its mass defect.

   Mass defect = (isotope mass) − (mass of protons and electrons) − (mass of neutrons)

   = 12.000000 u − (6)(1.007825 u) − (6)(1.008665 u)

   = −0.098940 u

   b. Calculate its binding energy in MeV.

   Binding energy = (mass defect)(binding energy of 1 u)

   = (−0.098940 u)(931.49 MeV/u)

   = −92.161 MeV

6. The isotope of hydrogen that contains one proton and one neutron is called deuterium. The mass of the atom is 2.014102 u.

a. What is its mass defect?

Mass defect = (isotope mass) − (mass of proton and electron) − (mass of neutron)

= 2.014102 u − 1.007825 u − 1.008665 u

= − 0.002388 u

b. What is the binding energy of deuterium in MeV?

Binding energy = (mass defect)(binding energy of 1 u)

= (−0.002388 u)(931.49 MeV/u)

= −2.2244 MeV

7. A nitrogen isotope, $^{15}_{7}N$, has seven protons and eight neutrons. It has a mass of 15.010109 u.

a. Calculate the mass defect of this nucleus.

Mass defect = (isotope mass) − (mass of protons and electrons) − (mass of neutrons)

= 15.010109 u − (7)(1.007825 u) − (8)(1.008665 u)

= − 0.113986 u

b. Calculate the binding energy of the nucleus.

Binding energy = (mass defect)(binding energy of 1 u)

= (−0.113986 u)(931.49 MeV/u)

= −106.18 MeV

8. An oxygen isotope, $^{16}_{8}O$, has a nuclear mass of 15.994915 u.

a. What is the mass defect of this isotope?

Mass defect = (isotope mass) − (mass of protons and electrons) − (mass of neutrons)

= 15.994915 u − (8)(1.007825 u) − (8)(1.008665 u)

= − 0.137005 u

b. What is the binding energy of its nucleus?

Binding energy = (mass defect)(binding energy of 1 u)

= (−0.137005 u)(931.49 MeV/u)

= −127.62 MeV

Section Review

30.1 The Nucleus pages 799–805

page 805

9. Nuclei Consider these two pairs of nuclei: $^{12}_{6}C$ and $^{13}_{6}C$ and $^{11}_{5}B$ and $^{11}_{6}C$. In which way are the two alike? In which way are they different?

The first pair has the same number of protons, but a different number of nucleons. The second pair has the same number of nucleons, but a different number of protons.

10. **Binding Energy** When tritium, $^{3}_{1}H$, decays, it emits a beta particle and becomes $^{3}_{2}He$. Which nucleus would you expect to have a more negative binding energy?

The tritium nucleus, because tritium emits a particle with mass and kinetic energy in its decay.

11. **Strong Nuclear Force** The range of the strong nuclear force is so short that only nucleons that are adjacent to each other are affected by the force. Use this fact to explain why, in large nuclei, the repulsive electromagnetic force can overcome the strong attractive force and make the nucleus unstable.

The electric force is long range, so that all protons repel each other, even in large nuclei. The strong force is short range, so that only neighboring protons attract. The repulsive force grows, with increasing nuclear size, faster than the strong force.

12. **Mass Defect** Which of the two nuclei in problem 10 has the larger mass defect?

the tritium nucleus

13. **Mass Defect and Binding Energy** The radioactive carbon isotope $^{14}_{6}C$ has a mass of 14.003074 u.

a. What is the mass defect of this isotope?

Mass defect = (isotope mass) − (mass of protons and electrons) − (mass of neutrons)

= 14.003074 u − (6)(1.007825 u) − (8)(1.008665 u)

= −0.113169 u

b. What is the binding energy of its nucleus?

Binding energy = (mass defect)(binding energy of 1 u)

= (−0.113196 u)(931.49 MeV/u)

= −105.44 MeV

14. **Critical Thinking** In old stars, not only are helium and carbon produced by joining more tightly bound nuclei, but so are oxygen ($Z = 8$) and silicon ($Z = 14$). What is the atomic number of the heaviest nucleus that could be formed in this way? Explain.

26, iron, because its binding energy is largest.

Practice Problems

30.2 Nuclear Decay and Reactions pages 806–814

page 808

15. Write the nuclear equation for the transmutation of a radioactive uranium isotope, $^{234}_{92}U$, into a thorium isotope, $^{230}_{90}Th$, by the emission of an α particle.

$$^{234}_{92}U \rightarrow {}^{230}_{90}Th + {}^{4}_{2}He$$

16. Write the nuclear equation for the transmutation of a radioactive thorium isotope, ${}^{230}_{90}Th$, into a radioactive radium isotope, ${}^{226}_{88}Ra$, by the emission of an α particle.

$${}^{230}_{90}Th \rightarrow {}^{226}_{88}Ra + {}^{4}_{2}He$$

17. Write the nuclear equation for the transmutation of a radioactive radium isotope, ${}^{226}_{88}Ra$, into a radon isotope, ${}^{222}_{86}Rn$, by α decay.

$${}^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$$

18. A radioactive lead isotope, ${}^{214}_{82}Pb$, can change to a radioactive bismuth isotope, ${}^{214}_{83}Bi$, by the emission of a β particle and an antineutrino. Write the nuclear equation.

$${}^{214}_{82}Pb \rightarrow {}^{214}_{83}Bi + {}^{0}_{-1}e + {}^{0}_{0}\bar{\nu}$$

19. A radioactive carbon isotope, ${}^{14}_{6}C$, undergoes β decay to become the nitrogen isotope ${}^{14}_{7}N$. Write the nuclear equation.

$${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e + {}^{0}_{0}\bar{\nu}$$

page 809

20. Use the periodic table on page 916 to complete the following.

a. ${}^{14}_{6}C \rightarrow ? + {}^{0}_{-1}e + {}^{0}_{0}\bar{\nu}$

$${}^{14}_{6}C \rightarrow {}^{A}_{Z}X + {}^{0}_{-1}e + {}^{0}_{0}\bar{\nu}$$

where $Z = 6 - (-1) - 0 = 7$

$A = 14 - 0 - 0 = 14$

For $Z = 7$, the element must be nitrogen. Thus, the isotope is ${}^{14}_{7}N$.

b. ${}^{55}_{24}Cr \rightarrow ? + {}^{0}_{-1}e + {}^{0}_{0}\bar{\nu}$

$${}^{55}_{24}Cr \rightarrow ? + {}^{0}_{-1}e + {}^{0}_{0}\bar{\nu}$$

$${}^{55}_{24}Cr \rightarrow {}^{A}_{Z}X + {}^{0}_{-1}e + {}^{0}_{0}\bar{\nu}$$

where $Z = 24 - (-1) - 0 = 25$

$A = 55 - 0 - 0 = 55$

For $Z = 25$, the element must be manganese. Thus, the isotope is ${}^{55}_{25}Mn$.

21. Write the nuclear equation for the transmutation of a seaborgium isotope, ${}^{263}_{106}Sg$, into a rutherfordium isotope, ${}^{259}_{104}Rf$, by the emission of an alpha particle.

$${}^{263}_{106}Sg \rightarrow {}^{259}_{104}Rf + {}^{4}_{2}He$$

22. A proton collides with the nitrogen isotope ${}^{15}_{7}N$, forming a new isotope and an alpha particle. What is the isotope? Write the nuclear equation.

$${}^{15}_{7}N + {}^{1}_{1}H \rightarrow {}^{A}_{Z}X + {}^{4}_{2}He$$

where $Z = 7 + 1 - 2 = 6$

$A = 15 + 1 - 4 = 12$

For $Z = 6$, the element must be carbon. Thus, the equation is ${}^{15}_{7}N + {}^{1}_{1}H \rightarrow {}^{12}_{6}C + {}^{4}_{2}He$.

23. Write the nuclear equations for the beta decay of the following isotopes.

a. ${}^{210}_{80}Pb$

$${}^{210}_{80}Pb \rightarrow {}^{A}_{Z}X + {}^{0}_{-1}e + {}^{0}_{0}\bar{\nu}$$

where $Z = 80 - (-1) - 0 = 81$

$A = 210 - 0 - 0 = 210.$

For $Z = 81$, the element must be thallium. Thus, the equation is ${}^{210}_{80}Pb \rightarrow {}^{210}_{81}Tl + {}^{0}_{-1}e + {}^{0}_{0}\bar{\nu}$.

b. ${}^{210}_{83}Bi$

$${}^{210}_{83}Bi \rightarrow {}^{A}_{Z}X + {}^{0}_{-1}e + {}^{0}_{0}\bar{\nu}$$

where $Z = 83 - (-1) - 0 = 84$

$A = 210 - 0 - 0 = 210$

For $Z = 84$, the element must be polonium. Thus, the equation is ${}^{210}_{83}Bi \rightarrow {}^{210}_{84}Po + {}^{0}_{-1}e + {}^{0}_{0}\bar{\nu}$.

c. ${}^{234}_{90}Th$

$${}^{234}_{90}Th \rightarrow {}^{A}_{Z}X + {}^{0}_{-1}e + {}^{0}_{0}\bar{\nu}$$

where $Z = 90 - (-1) - 0 = 91$

$A = 234 - 0 - 0 = 234$

For $Z = 91$, the element must be protactinium. Thus, the equation is ${}^{234}_{90}Th \rightarrow {}^{234}_{91}Pa + {}^{0}_{-1}e + {}^{0}_{0}\bar{\nu}$.

d. $^{239}_{93}\text{Np}$

$^{239}_{93}\text{Np} \rightarrow {}^{A}_{Z}\text{X} + {}^{0}_{-1}\text{e} + {}^{0}_{0}\bar{\nu}$

where $Z = 93 - (-1) - 0 = 94$

$A = 239 - 0 - 0 = 239$

For $Z = 94$, the element must be plutonium. Thus, the equation is

$^{239}_{93}\text{Np} \rightarrow {}^{239}_{94}\text{Pu} + {}^{0}_{-1}\text{e} + {}^{0}_{0}\bar{\nu}$.

page 810

Refer to Figure 30-4 and Table 30-2 to solve the following problems.

24. A sample of 1.0 g of tritium, $^{3}_{1}\text{H}$, is produced. What will be the mass of the tritium remaining after 24.6 years?

24.6 years = (2)(12.3 years), which is 2 half-lives.

$$\text{remaining} = \text{original}\left(\frac{1}{2}\right)^t$$

$$= (1.0\text{ g})\left(\frac{1}{2}\right)^2$$

$$= 0.25\text{ g}$$

25. The isotope $^{238}_{93}\text{Np}$ has a half-life of 2.0 days. If 4.0 g of neptunium is produced on Monday, what will be the mass of neptunium remaining on Tuesday of the next week?

8.0 days = (4)(2.0 days), which is 4 half-lives remaining

$$= (\text{original})\left(\frac{1}{2}\right)^t$$

$$= (4.0\text{ g})\left(\frac{1}{2}\right)^4$$

$$= 0.25\text{ g}$$

26. A sample of polonium-210 is purchased for a physics class on September 1. Its activity is 2×10^6 Bq. The sample is used in an experiment on June 1. What activity can be expected?

The half-life of $^{210}_{84}\text{Po}$ is 138 days. There are 273 days or about 2 half-lives between September 1 and June 1. So the activity

$$= \left(2\times10^6\ \frac{\text{decays}}{\text{s}}\right)\left(\frac{1}{2}\right)^2$$

$$= 5\times10^5\text{ Bq}$$

27. Tritium, $^{3}_{1}\text{H}$, once was used in some watches to produce a fluorescent glow so that the watches could be read in the dark. If the brightness of the glow is proportional to the activity of the tritium, what would be the brightness of such a watch, in comparison to its original brightness, when the watch is six years old?

Six years is about half of tritium's half-life of 12.3 years. Thus, the brightness is $\left(\frac{1}{2}\right)^{\frac{1}{2}}$, or about $\frac{7}{10}$ of the original brightness.

Section Review

30.2 Nuclear Decay and Reactions pages 806–814

page 814

28. Beta Decay How can an electron be expelled from a nucleus in beta decay if the nucleus has no electrons?

In the nucleus a neutron changes into a proton and emits an electron and an antineutrino.

29. Nuclear Reactions The polonium isotope $^{210}_{84}\text{Po}$ undergoes alpha decay. Write the equation for the reaction.

$^{210}_{84}\text{Po} \rightarrow {}^{A}_{Z}\text{X} + {}^{4}_{2}\text{He}$

where $Z = 84 - 2 = 82$

$A = 210 - 4 = 206$

For $Z = 82$, the element must be lead. Thus, the equation is

$^{210}_{84}\text{Po} \rightarrow {}^{206}_{82}\text{Pb} + {}^{4}_{2}\text{He}$.

30. Half-Life Use Figure 30-4 and Table 30-2 to estimate in how many days a sample of $^{131}_{53}\text{I}$ would have three-eighths its original activity.

From the graph, 3/8 are left at about 1.4 half lives. From the table, the half-life is 8.07 days, so it would take about 11 days.

31. **Nuclear Reactor** Lead often is used as a radiation shield. Why is it not a good choice for a moderator in a nuclear reactor?

Lead is used as a radiation shield because it absorbs radiation, including neutrons. A moderator should only slow the neutrons so they can be absorbed by the fissile material.

32. **Fusion** One fusion reaction involves two deuterium nuclei, ${}^{2}_{1}H$. A deuterium molecule contains two deuterium atoms. Why doesn't this molecule undergo fusion?

The nuclei in the molecule must be moving very fast to undergo fusion.

33. **Energy** Calculate the energy released in the first fusion reaction in the Sun, ${}^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{2}_{1}H + {}^{0}_{+1}e + {}^{0}_{0}\nu$.

The energy released is

$$E = ((\text{initial mass}) - (\text{final mass}))(931.49\ \text{MeV/u})$$

$$= (2(\text{mass of protium}) - (\text{mass of deuterium}) - (\text{mass of positron}))(931.49\ \text{MeV/u})$$

$$= \left(2(1.007825\ \text{u}) - 2.014102\ \text{u} - (9.11\times10^{-31}\ \text{kg})\left(\frac{1\ \text{u}}{1.6605\times10^{-27}\ \text{kg}}\right)\right)(931.49\ \text{MeV/u})$$

$$= 0.931\ \text{MeV}$$

34. **Critical Thinking** Alpha emitters are used in smoke detectors. An emitter is mounted on one plate of a capacitor, and the α particles strike the other plate. As a result, there is a potential difference across the plates. Explain and predict which plate has the more positive potential.

The plate being stuck by the α particles has the more positive potential because the positively charged α particles move positive charge from the emitter plate to the struck plate.

Practice Problems

30.3 The Building Blocks of Matter pages 815–823

page 821

35. The mass of a proton is 1.67×10^{-27} kg.

a. Find the energy equivalent of the proton's mass in joules.

$$E = mc^2$$
$$= (1.67\times10^{-27}\ \text{kg})(3.00\times10^{8}\ \text{m/s})^2$$
$$= 1.50\times10^{-10}\ \text{J}$$

b. Convert this value to eV.

$$E = \frac{1.50\times10^{-10}\ \text{J}}{1.60217\times10^{-19}\ \text{J/eV}}$$
$$= 9.36\times10^{8}\ \text{eV}$$

c. Find the smallest total γ-ray energy that could result in a proton-antiproton pair.

The minimum energy is

$(2)(9.36\times10^{8}\text{ eV}) = 1.87\times10^{9}\text{ eV}$

36. A positron and an electron can annihilate and form three gammas. Two gammas are detected. One has an energy of 225 keV, the other 357 keV. What is the energy of the third gamma?

As shown in this section, the energy equivalent of the positron and electron is 1.02 MeV. Thus, the energy of the third gamma is 1.02 MeV − 0.225 MeV − 0.357 MeV = 0.438 MeV.

37. The mass of a neutron is 1.008665 u.

a. Find the energy equivalent of the neutron's mass in MeV.

$$E = (\text{neutron mass in u})(931.49\text{ MeV/u})$$
$$= (1.008665\text{ u})(931.49\text{ MeV/u})$$
$$= 939.56\text{ MeV}$$

b. Find the smallest total γ-ray energy that could result in the production of a neutron-antineutron pair.

The smallest possible γ-ray energy would be twice the neutron energy.

$$E_{\text{total}} = 2E_{\text{n}} = (2)(939.56\text{ MeV})$$
$$= 1879.1\text{ MeV}$$

38. The mass of a muon is 0.1135 u. It decays into an electron and two neutrinos. What is the energy released in this decay?

$$\text{Energy released} = (\text{mass of muon} - \text{mass of electron})(931.49\text{ MeV/u})$$
$$= \left(0.1135\text{ u} - (9.109\times10^{-31}\text{ kg})\left(\frac{1\text{ u}}{1.6605\times10^{-27}\text{ kg}}\right)\right)(931.49\text{ MeV/u})$$
$$= 105.2\text{ MeV}$$

Section Review

30.3 The Building Blocks of Matter pages 815–823

page 823

39. Nucleus Bombardment Why would a proton require more energy than a neutron when used to bombard a nucleus?

The proton and nucleus both have positive charge, so they repel each other. Therefore, the proton must have enough kinetic energy to overcome the potential energy caused by the repulsion. The uncharged neutron does not experience this repulsive force.

40. Particle Accelerator Protons in the Fermi Laboratory accelerator, Figure 30-11, move counterclockwise. In what direction is the magnetic field of the bending magnets?

down, into Earth

41. Pair Production Figure 30-18 shows the production of two electron/positron pairs. Why does the bottom set of tracks curve less than the top pair of tracks?

The electron/positron pair at the bottom has more kinetic energy, and therefore, a greater velocity.

42. The Standard Model Research the limitations of the Standard Model and possible replacements.

Answers include: The Standard Model has several parameters that can be obtained only from experiment. The Higgs particle that would set the energy scale has not been found. It is not really a theory that explains, and so is not complete. Supersymmetry and string theory are two possible replacements.

43. Critical Thinking Consider the following equations.

$u \rightarrow d + W^+$ and $W^+ \rightarrow e^+ + \nu$

How could they be used to explain the radioactive decay of a nucleon that results in the emission of a positron and a neutrino? Write the equation involving nucleons rather than quarks.

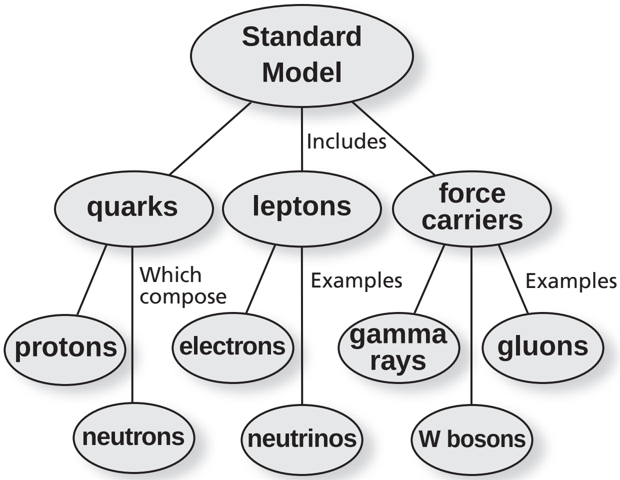
A nucleon containing a u quark could decay by this process to a nucleon with one less u and one more d quark. A proton is uud and a neutron is uud, so the following equation would work:
$^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{+1}e + {}^{0}_{0}\nu$

Chapter Assessment

Concept Mapping

page 828

44. Organize the following terms into the concept map: *Standard Model, quarks, gamma rays, force carriers, protons, neutrons, leptons, W bosons, neutrinos, electrons, gluons.*



Mastering Concepts

page 828

45. What force inside a nucleus acts to push the nucleus apart? What force inside the nucleus acts to hold the nucleus together? (30.1)

The repulsive electric force between the positive protons acts to push the nucleus apart. The strong nuclear force acts to hold the nucleus together.

46. Define the mass defect of a nucleus. To what is it related? (30.1)

The mass defect is the difference between the sum of the masses of the individual particles of the nucleus and the mass of the nucleus. It is related to binding energy through $E = mc^2$.

47. Which are generally more unstable, small or large nuclei? (30.1)

Large nuclei are generally more unstable. The greater number of protons makes the repulsive electric force overcome the attractive strong force.

48. Which isotope has the greater number of protons, uranium-235 or uranium-238? (30.1)

They both have the same number of protons, but different numbers of neutrons.

49. Define the term *transmutation* as used in nuclear physics and give an example. (30.2)

Transmutation is the change of one element into another by means of a nuclear reaction caused by radioactive decay or nuclear bombardment. For example, uranium-238 decays into thorium-234 and an α particle.

50. **Radiation** What are the common names for an α particle, β particle, and γ radiation? (30.2)

An a particle is a helium nucleus, a β particle is an electron, and γ radiation is a high-energy photon.

51. What two quantities must always be conserved in any nuclear equation? (30.2)

the atomic number, to conserve charge; the mass number, to conserve the number of nucleons

52. **Nuclear Power** What sequence of events must occur for a chain reaction to take place? (30.2)

Many neutrons must be released by a fissioned nucleus and absorbed by neighboring nuclei, causing them to undergo fission.

53. **Nuclear Power** What role does a moderator play in a fission reactor? (30.2)

The moderator slows the fast neutrons, increasing their probability of being absorbed.

54. Fission and fusion are opposite processes. How can each release energy? (30.2)

When a large atom, such as uranium, undergoes fission, the mass of the products is less than that of the original nucleus. An amount of energy equivalent to the difference in mass is released. However, when small nuclei fuse into a larger nucleus, the mass of the more tightly bound, large nucleus is less, and the extra mass appears as energy.

55. **High-Energy Physics** Why would a linear accelerator not work with a neutron? (30.3)

It accelerates particles using electric force, and the neutron has no charge.

56. **Forces** In which of the four interactions (strong, weak, electromagnetic, and gravitational) do the following particles take part? (30.3)

a. electron

electromagnetic, weak, gravitational

b. proton

strong, electromagnetic, gravitational

c. neutrino

weak

57. What happens to the atomic number and mass number of a nucleus that emits a positron? (30.3)

The atomic number decreases by 1, and there is no change in the mass number.

$Z \rightarrow Z - 1$; $A \rightarrow A$

58. **Antimatter** What would happen if a meteorite made of antiprotons, antineutrons, and positrons landed on Earth? (30.3)

It would annihilate with an equivalent amount of matter, producing an extremely large amount of energy.

Applying Concepts

page 828

59. **Fission** A Web site claims that scientists have been able to cause iron nuclei to undergo fission. Is the claim likely to be true? Explain.

It is not true. Iron is the most tightly bound element, and thus the most stable nucleus. It cannot decay by either fission or fusion.

60. Use the graph of binding energy per nucleon in Figure 30-2 to determine whether the reaction ${}_{1}^{2}H + {}_{1}^{1}H \rightarrow {}_{2}^{3}He$ is energetically possible.

The initial binding energy is less than the final binding energy and, therefore, the reaction is energetically possible.

61. Isotopes Explain the difference between naturally and artificially produced radioactive isotopes.

A natural radioactive material is one that is found to exist normally in ores and that experiences radioactive decay. Artificially, radioactive material experiences radioactive decay only after being subjected to bombardment by particles.

62. Nuclear Reactor In a nuclear reactor, water that passes through the core of the reactor flows through one loop, while the water that produces steam for the turbines flows through a second loop. Why are there two loops?

The water that passes through the core is at high pressure, so it doesn't boil. A second loop carries water at lower pressure, producing steam.

63. The fission of a uranium nucleus and the fusion of four hydrogen nuclei to produce a helium nucleus both produce energy.

a. Which produces more energy?

As shown in Section 30-2, the energy produced by the fission of one uranium nucleus is 200 MeV. The energy produced by the fusion of four hydrogen nuclei is 24 MeV.

b. Does the fission of a kilogram of uranium nuclei or the fusion of a kilogram of hydrogen produce more energy?

The mass number of fissionable uranium is 238. The mass number of hydrogen is 1. For an equal mass of the elements, you would have 238 times more hydrogen nuclei than uranium nuclei. The fission of each uranium nucleus would produce 200 MeV of energy. The fusion of 238 nuclei of hydrogen to produce helium nuclei would produce $\left(\frac{238}{4}\right)$(25 MeV), or about 1500 MeV of energy.

c. Why are your answers to parts **a** and **b** different?

Although the fission of one uranium nucleus produces more energy than the fusion of four hydrogen nuclei to produce helium, there are more than 200 times as many hydrogen nuclei in 1kg as there are uranium nuclei.

Mastering Problems

30.1 The Nucleus

pages 828–829

Level 1

64. What particles, and how many of each, make up an atom of ${}_{47}^{109}Ag$?

47 electrons, 47 protons, 62 neutrons

65. What is the isotopic symbol (the one used in nuclear equations) of a zinc atom composed of 30 protons and 34 neutrons?

$^{64}_{30}\mathrm{Zn}$

66. The sulfur isotope $^{32}_{16}\mathrm{S}$ has a nuclear mass of 31.97207 u.

a. What is the mass defect of this isotope?

mass defect = (isotope mass) − (mass of protons and electrons) − (mass of neutrons)

= 31.97207 u − (16)(1.007825 u) − (16)(1.008665 u)

= −0.29177 u

b. What is the binding energy of its nucleus?

Binding energy = (mass defect)(binding energy of 1 u)

= (−0.29177 u)(931.5 MeV/u)

= −271.78 MeV

c. What is the binding energy per nucleon?

Binding energy per nucleon is

$$\frac{-271.8\ \mathrm{MeV}}{32\ \mathrm{nucleons}} = -8.494\ \mathrm{MeV/nucleon}$$

Level 2

67. A nitrogen isotope, $^{12}_{7}\mathrm{N}$, has a nuclear mass of 12.0188 u.

a. What is the binding energy per nucleon?

Binding energy = (mass of defect)(binding energy for 1 u)

((isotope mass) − (mass of protons and electrons) − (mass of neutrons))(binding energy for 1 u)

= ((12.0188 u) − (7)(1.007825 u) − (5)(1.008665 u))(931.49 MeV/u)

= −73.867 MeV

The binding energy per nucleon is $\frac{-73.867\ \mathrm{MeV}}{12\ \mathrm{nucleons}} = -6.1556\ \mathrm{MeV/nucleon}$

b. Does it require more energy to separate a nucleon from a $^{14}_{7}\mathrm{N}$ nucleus or from a $^{12}_{7}\mathrm{N}$ nucleus? $^{14}_{7}\mathrm{N}$ has a mass of 14.00307 u.

For $^{14}_{7}\mathrm{N}$, the binding energy is

Binding energy = (mass defect)(binding energy for 1 u)

= ((isotope mass) − (mass of protons and electrons) − (mass of neutrons))(binding energy for 1 u)

= ((14.00307 u − (7)(1.007825 u) − (7)(1.008665 u))(931.49 MeV/u)

= −104.66 MeV

The binding energy per nucleon is $\frac{-104.66\ \mathrm{MeV}}{14\ \mathrm{nucleons}} = -7.4757\ \mathrm{MeV/nucleon}$

Thus, removing a nucleon from $^{14}_{7}\mathrm{N}$ requires more energy.

68. The two positively charged protons in a helium nucleus are separated by about 2.0×10^{-15} m. Use Coulomb's law to find the electric force of repulsion between the two protons. The result will give you an indication of the strength of the strong nuclear force.

$$F = K\frac{q_Aq_B}{d^2}$$

$$= (9.0\times10^9\ \text{N·m}^2/\text{C}^2)\frac{(1.60\times10^{-19}\ \text{C})(1.60\times10^{-19}\ \text{C})}{2.0\times10^{-15}\ \text{m}} = 58\ \text{N}$$

69. The binding energy for ^4_2He is -28.3 MeV. Calculate the mass of a helium isotope in atomic mass units.

mass of the isotope = (mass defect) + (mass of protons and electrons) + (mass of neutrons)

$$= \left(\frac{\text{binding energy}}{\text{binding energy of 1 u}}\right) + \text{(mass of protons and electrons)} + \text{(mass of neutrons)}$$

$$= \left(\frac{-28.3\ \text{MeV}}{931.49\ \text{MeV/u}}\right) + (2)(1.007825\ \text{u}) + (2)(1.008665\ \text{u})$$

$$= 4.00\ \text{u}$$

30.2 Nuclear Decay and Reactions

page 829

Level 1

70. Write the complete nuclear equation for the alpha decay of $^{222}_{86}\text{Rn}$.

$^{222}_{86}\text{Rn} \rightarrow {}^{A}_{Z}\text{X} + {}^{4}_{2}\text{He}$

where $A = 222\text{-}4 = 218$

$Z = 86\text{-}2 = 84$

For $Z = 84$, the element must be polonium. Thus, the equation is

$^{222}_{86}\text{Rn} \rightarrow {}^{218}_{84}\text{Po} + {}^{4}_{2}\text{He}$

71. Write the complete nuclear equation for the beta decay of $^{89}_{36}\text{Kr}$.

$^{89}_{36}\text{Kr} = {}^{A}_{Z}\text{X} + {}^{0}_{-1}\text{e} + {}^{0}_{0}\bar{\nu}$

where $Z = 36 - (-1) - 0 = 37$

$A = 89 - 0 - 0 = 89$

For $Z = 37$, the element must be rubidium. Thus, the equation is

$^{89}_{36}\text{Kr} = {}^{89}_{37}\text{Rb 1} + {}^{0}_{-1}\text{e} + {}^{0}_{0}\bar{\nu}$

72. Complete each nuclear reaction.

a. $^{225}_{89}\text{Ac} \rightarrow {}^{4}_{2}\text{He} +$ _____

$^{225}_{89}\text{Ac} \rightarrow {}^{4}_{2}\text{He} + {}^{221}_{87}\text{Fr}$

b. $^{227}_{88}\text{Ra} \rightarrow {}^{0}_{-1}\text{e} +$ _____ $+$ _____

$^{227}_{88}\text{Ra} \rightarrow {}^{0}_{-1}\text{e} + {}^{227}_{89}\text{Ac} + {}^{0}_{0}\bar{\nu}$

c. ${}^{65}_{29}\text{Cu} + {}^{1}_{0}\text{n} \rightarrow$ _____ $\rightarrow {}^{1}_{1}\text{p} +$ _____

$\mathbf{{}^{65}_{29}Cu + {}^{1}_{0}n \rightarrow {}^{66}_{29}Cu \rightarrow {}^{1}_{1}p + {}^{65}_{28}Ni}$

d. ${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{96}_{40}\text{Zr} + 3({}^{1}_{0}\text{n}) +$ _____

$\mathbf{{}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{96}_{40}Zr + 3\left({}^{1}_{0}n\right) + {}^{136}_{52}Te}$

73. An isotope has a half-life of 3.0 days. What percent of the original material will be left after

a. 6.0 days?

$\frac{6.0\text{ d}}{3.0\text{ d}} = 2.0$ **half-lives**

percent remaining $= \left(\frac{1}{2}\right)^t \times 100$

$= \left(\frac{1}{2}\right)^{2.0} \times 100$

$= 25\%$

b. 9.0 days?

$\frac{9.0\text{ d}}{3.0\text{ d}} = 3.0$ **half-lives**

percent remaining $= \left(\frac{1}{2}\right)^t \times 100$

$= \left(\frac{1}{2}\right)^{3.0} \times 100$

$= 13\%$

c. 12 days?

$\frac{12\text{ d}}{3.0\text{ d}} = 4$ **half-lives**

percent remaining $= \left(\frac{1}{2}\right)^t \times 100$

$= \left(\frac{1}{2}\right)^{4.0} \times 100$

$= 6.3\%$

74. In an accident in a research laboratory, a radioactive isotope with a half-life of three days is spilled. As a result, the radiation is eight times the maximum permissible amount. How long must workers wait before they can enter the room?

For the activity to fall to $\frac{1}{8}$ its present amount, you must wait three half-lives, or 9 days.

75. When a boron isotope, ${}^{11}_{5}\text{B}$, is bombarded with protons, it absorbs a proton and emits a neutron.

a. What element is formed?

carbon

b. Write the nuclear equation for this reaction.

$\mathbf{{}^{11}_{5}B + {}^{1}_{1}p \rightarrow {}^{A}_{6}C + {}^{1}_{0}n}$

where $A = 11 + 1 - 1 = 11$

Thus, the equation is

$\mathbf{{}^{11}_{5}B + {}^{1}_{1}p \rightarrow {}^{11}_{6}C + {}^{1}_{0}n}$

c. The isotope formed is radioactive and decays by emitting a positron. Write the complete nuclear equation for this reaction.

$\mathbf{{}^{11}_{6}C \rightarrow {}^{A}_{Z}X + {}^{0}_{+1}e + {}^{0}_{0}\bar{\nu}}$

where $Z = 6 - 1 - 0 = 5$

$A = 11 - 0 - 0 = 11$

For $Z = 5$, the element must be boron. Thus, the equation is

$\mathbf{{}^{11}_{6}C \rightarrow {}^{11}_{5}B + {}^{0}_{+1}e + {}^{0}_{0}\bar{\nu}}$

76. The first atomic bomb released an energy equivalent of 2.0×10^{1} kilotons of TNT. One kiloton of TNT is equivalent to 5.0×10^{12} J. Uranium-235 releases 3.21×10^{-11} J/atom. What was the mass of the uranium-235 that underwent fission to produce the energy of the bomb?

$E = (2.0\times10^{1}\text{ kton})(5.0\times10^{12}\text{ J/kton})$

$\left(\frac{1\text{ atom}}{3.21\times10^{-11}\text{ J}}\right)\left(\frac{1\text{ mol}}{6.02\times10^{23}\text{ atom}}\right)$

$\left(\frac{0.235\text{ kg}}{\text{mol}}\right)$

$= 1.2\text{ kg}$

77. During a fusion reaction, two deuterons, ${}^{2}_{1}\text{H}$, combine to form a helium isotope, ${}^{3}_{2}\text{He}$. What other particle is produced?

$\mathbf{{}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + {}^{A}_{Z}X}$

where $Z = 1 + 1 - 2 = 0$

$A = 2 + 2 - 3 = 1$

Thus, the particle must be ${}^{1}_{0}$n, a neutron.

Level 2

78. $^{209}_{84}$Po has a half-life of 103 years. How long would it take for a 100-g sample to decay so that only 3.1 g of Po-209 was left?

remaining = original $\left(\frac{1}{2}\right)^t$

Let *R* = remaining mass and *I* = original mass

$$R = I\left(\frac{1}{2}\right)^t = \frac{I}{2^t}$$

$$2^t = \frac{I}{R}$$

$$\log(2^t) = \log\left(\frac{I}{R}\right)$$

$$t \log 2 = \log\left(\frac{I}{R}\right)$$

$$t = \frac{\log\left(\frac{I}{R}\right)}{\log 2}$$

$$= \frac{\log\left(\frac{100\ \text{g}}{3.1\ \text{g}}\right)}{\log 2}$$

$$= 5 \text{ half-lives}$$

Therefore, the sample would take about 500 years to decay.

30.3 The Building Blocks of Matter

page 829

Level 1

79. What would be the charge of a particle composed of three up quarks?

Each u quark has a charge of $+\frac{2}{3}$**.**

$\text{uuu} = 3\left(+\frac{2}{3}\right) = +2$ **elementary charges**

80. The charge of an antiquark is opposite that of a quark. A pion is composed of an up quark and an anti-down quark, $u\bar{d}$. What would be the charge of this pion?

$u + \bar{d} = +\frac{2}{3} + \left(-\left(\frac{1}{3}\right)\right) = +1$ **elementary charge**

81. Pions are composed of a quark and an antiquark. Find the charge of a pion made up of the following.

a. $u\bar{u}$

$d + \bar{u} = +\frac{2}{3} + \left(-\left(+\frac{2}{3}\right)\right) = 0$ **charge**

b. $d\bar{u}$

$d + \bar{u} = -\frac{1}{3} + \left(-\left(+\frac{2}{3}\right)\right) = -1$ **charge**

c. $d\bar{d}$

$u + \bar{d} = -\frac{1}{3} + \left(-\left(-\frac{1}{3}\right)\right) = 0$ **charge**

82. Baryons are particles that are made of three quarks. Find the charge on each of the following baryons.

a. neutron: ddu

$d + d + u = 2\left(-\frac{1}{3}\right) + \left(\frac{2}{3}\right) = 0$

b. antiproton: $\bar{u}\bar{u}\bar{d}$

$$\bar{u} + \bar{u} + \bar{d} = -\left(\frac{2}{3}\right) + -\left(\frac{2}{3}\right) + -\left(-\frac{1}{3}\right)$$
$$= -1$$

Level 2

83. The synchrotron at the Fermi Laboratory has a diameter of 2.0 km. Protons circling in it move at approximately the speed of light in a vacuum.

a. How long does it take a proton to complete one revolution?

$$v = \frac{d}{t}$$

where *d* is the circumference of the synchrotron,

$$\text{so } t = \frac{d}{v} = \frac{\pi(2.0\times10^3\ \text{m})}{3.0\times10^8\ \text{m/s}}$$
$$= 2.1\times10^{-5}\ \text{s}$$

b. The protons enter the ring at an energy of 8.0 GeV. They gain 2.5 MeV each revolution. How many revolutions must they travel before they reach 400.0 GeV of energy?

$$\frac{400.0\times10^9\ \text{eV} - 8.00\times10^9\ \text{eV}}{2.5\times10^6\ \text{eV/rev}}$$
$$= 1.6\times10^5\ \text{rev}$$

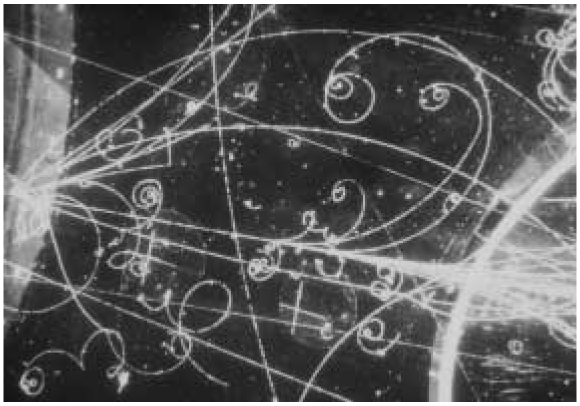
c. How long does it take the protons to be accelerated to 400.0 GeV?

$$t = (1.6\times10^5\ \text{rev})(2.1\times10^{-5}\ \text{s/rev})$$
$$= 3.4\ \text{s}$$

d. How far do the protons travel during this acceleration?

$$d = vt = (3.00\times10^8\ \text{m/s})(3.4\ \text{s})$$
$$= 1.0\times10^9\ \text{m, or about 1 million km}$$

84. **Figure 30-21** shows tracks in a bubble chamber. What are some reasons one track might curve more than another?



■ **Figure 30-21**

The paths of faster-moving particles would curve less.

Mixed Review

page 830

Level 1

85. Each of the following nuclei can absorb an α particle. Assume that no secondary particles are emitted by the nucleus. Complete each equation.

a. $^{14}_{7}\text{N} + ^{4}_{2}\text{He} \rightarrow$ _____

$^{14}_{7}\text{N} + ^{4}_{2}\text{He} \rightarrow ^{A}_{Z}\text{X}$

where $Z = 7 + 2 = 9$

$A = 14 + 4 = 18$

For $Z = 9$**, the element must be fluorine. Thus, the equation is**

$^{14}_{7}\text{N} + ^{4}_{2}\text{He} \rightarrow ^{18}_{9}\text{F}$

b. $^{27}_{13}\text{Al} + ^{4}_{2}\text{He} \rightarrow$ _____

$^{27}_{13}\text{Al} + ^{4}_{2}\text{He} \rightarrow ^{A}_{Z}\text{X}$

where $Z = 13 + 2 = 15$

$A = 27 + 4 = 31$

For $Z = 15$**, the element must be phosphorus. Thus, the equation is**

$^{27}_{13}\text{Al} + ^{4}_{2}\text{He} \rightarrow ^{31}_{15}\text{P}$

86. $^{211}_{86}\text{Rn}$ has a half-life of 15 h. What fraction of a sample would be left after 60 h?

$\frac{60\text{ h}}{15\text{ h}} = 4$ **half-lives, so** $\left(\frac{1}{2}\right)^4 = \frac{1}{16}$ **is left.**

Level 2

87. One of the simplest fusion reactions involves the production of deuterium, $^{2}_{1}\text{H}$(2.014102 u), from a neutron and a proton. Write the complete fusion reaction and find the amount of energy released.

The equation for the reaction is

$^{1}_{0}\text{n} + ^{1}_{0}\text{p} \rightarrow ^{2}_{1}\text{H}$

The energy released is

$E = ((\text{initial mass}) - (\text{final mass}))(931.49\text{ MeV/u})$

$= ((\text{mass of neutron}) + (\text{mass of proton}) - (\text{mass of deuterium}))(931.49\text{ MeV/u})$

$= ((1.008665\text{ u}) + (1.007276\text{ u}) - (2.014102\text{ u}))(931.49\text{ MeV/u})$

$= 1.7130\text{ MeV}$

88. A $^{232}_{92}\text{U}$ nucleus, mass = 232.0372 u, decays to $^{228}_{90}\text{Th}$, mass = 228.0287 u, by emitting an α particle, mass = 4.0026 u, with a kinetic energy of 5.3 MeV. What must be the kinetic energy of the recoiling thorium nucleus?

The total kinetic energy of the decay products is

$KE_{\text{total}} = KE_{\text{thorium}} + KE_{\alpha}$

Thus,

$KE_{\text{thorium}} = KE_{\text{total}} - KE_{\alpha}$

$= (\text{mass defect})(931.49\text{ MeV/u}) - KE_{\alpha}$

$= ((\text{mass of } ^{232}_{92}\text{U}) - (\text{mass of } ^{228}_{90}\text{Th}) - (\text{mass of } ^{4}_{2}\text{He}))(931.49\text{ MeV/u}) - KE_{\alpha}$

$= ((232.0372\text{ u}) - (228.0287\text{ u}) - (4.0026\text{ u}))(931.49\text{ MeV/u}) - 5.3\text{ MeV}$

$= 0.2\text{ MeV}$

Thinking Critically

page 830

89. Infer Gamma rays carry momentum. The momentum of a gamma ray of energy *E* is equal to *E*/*c*, where *c* is the speed of light. When an electron-positron pair decays into two gamma rays, both momentum and energy must be conserved. The sum of the energies of the gamma rays is 1.02 MeV. If the positron and electron are initially at rest, what must be the magnitude and direction of the momentum of the two gamma rays?

Because the initial momentum is zero, this must be the final momentum. Thus, the two gamma rays must have equal and opposite momentum. The magnitude of the momenta is

$$p_\gamma = \left(\frac{1}{2}\right)\left(\frac{E}{c}\right)$$

$$= \frac{(1.02\times10^{6}\ \text{eV})(1.60\times10^{-19}\ \text{J/eV})}{(2)(3.00\times10^{8}\ \text{m/s})}$$

$$= 2.72\times10^{-22}\ \text{kg·m/s}$$

They move in opposite directions.

90. Infer An electron-positron pair, initially at rest, also can decay into three gamma rays. If all three gamma rays have equal energies, what must be their relative directions? Make a sketch.

The question becomes the following: how can three particles, each with the same momentum, have zero total momentum? The three gamma rays leave with angles of 120° between them on a plane.

91. Estimate One fusion reaction in the Sun releases about 25 MeV of energy. Estimate the number of such reactions that occur each second from the luminosity of the Sun, which is the rate at which it releases energy, 4×10^{26} W.

1 eV = 1.6022×10^{-19} J, so

$$25\ \text{MeV} = (25\times10^{6}\ \text{eV/reaction})(1.6022\times10^{-19}\ \text{J/eV})$$

$$= 4.0\times10^{-12}\ \text{J/reaction}$$

The total power is 4×10^{26} J/s, so the number of reactions occurring each second is

$$\frac{4\times10^{26}\ \text{J/s}}{4.0\times10^{-12}\ \text{J/reaction}} = 10^{38}\ \text{reactions/s}$$

92. Interpret Data An isotope undergoing radioactive decay is monitored by a radiation detector. The number of counts in each five-minute interval is recorded. The results are shown in **Table 30-3.** The sample is then removed and the radiation detector records 20 counts resulting from cosmic rays in 5 min. Find the half-life of the isotope. Note that you should first subtract the 20-count background reading from each result. Then plot the counts as a function of time. From your graph, determine the half-life.

Table 30-3

Radioactive Decay Measurements

Time (min)	Counts (per 5 min)
0	987
5	375
10	150
15	70
20	40
25	25
30	18

about 4 min

Writing in Physics

page 830

93. Research the present understanding of dark matter in the universe. Why is it needed by cosmologists? Of what might it be made?

About 25 percent of the universe is dark matter. It is needed to explain galactic rotation and the expansion of the universe. According to one theory, dark matter is not made of ordinary matter that is covered by the Standard Model. It may interact with ordinary matter only through gravity and weak nuclear forces.

94. Research the hunt for the top quark. Why did physicists hypothesize its existence?

Theorists had predicted the existence of different flavors of quarks. They realized quarks occur in pairs. The up and down quark pair and the charmed and strange pair had been found by experiments. When the bottom quark was found in 1977, they felt it must have a partner. The short lifetime and high mass of the top quark made it difficult to find. It finally was found at a Fermilab experiment in 1995.

Cumulative Review

page 830

95. An electron with a velocity of 1.7×10^6 m/s is at right angles to a 0.91-T magnetic field. What is the force on the electron produced by the magnetic field? (Chapter 24)

$$F = Bqv$$
$$= (0.91\text{ T})(1.60\times10^{-19}\text{ C})(1.7\times10^{6}\text{ m/s})$$
$$= 2.5\times10^{-13}\text{ N}$$

96. An *EMF* of 2.0 mV is induced in a wire that is 0.10 m long when it is moving perpendicularly across a uniform magnetic field at a velocity of 4.0 m/s. What is the magnetic induction of the field? (Chapter 25)

$$EMF = BLv$$
$$B = \frac{EMF}{Lv} = \frac{2.0\times10^{-3}\text{ V}}{(0.10\text{ m})(4.0\text{ m/s})}$$
$$= 5.0\times10^{-3}\text{ T} = 5.0\text{ mT}$$

97. An electron has a de Broglie wavelength of 400.0 nm, the shortest wavelength of visible light. (Chapter 27)

a. Find the velocity of the electron.

$$\lambda = \frac{h}{mv}$$
$$v = \frac{h}{m\lambda}$$
$$= \frac{6.63\times10^{-34}\text{ J/Hz}}{(9.11\times10^{-31}\text{ kg})(400.0\times10^{-9}\text{ m})}$$
$$= 1.82\times10^{3}\text{ m/s}$$

b. Calculate the energy of the electron in eV.

$$KE = \frac{1}{2}mv^2$$
$$= \left(\frac{1}{2}\right)(9.11\times10^{-31}\text{ kg})(1.82\times10^{3}\text{ m/s})^2\left(\frac{1\text{ eV}}{1.60\times10^{-19}\text{ J}}\right)$$
$$= 9.43\times10^{-6}\text{ eV}$$

98. A photon with an energy of 14.0 eV enters a hydrogen atom in the ground state and ionizes it. With what kinetic energy will the electron be ejected from the atom? (Chapter 28)

KE = (photon energy) + (energy of electron in the ground state)

$$= 14.0\text{ eV} + (-13.6\text{ eV})$$
$$= 0.4\text{ eV}$$

99. A silicon diode ($V = 0.70$ V) that is conducting 137 mA is in series with a resistor and a 6.67-V power source. (Chapter 29)

a. What is the voltage drop across the resistor?

$$V_R = V_{source} - V_{diode}$$
$$= 6.67\text{ V} - 0.70\text{ V}$$
$$= 5.97\text{ V}$$

b. What is the value of the resistor?

$$R = \frac{V}{I} = \frac{5.97\text{ V}}{137\text{ mA}} = 43.6\ \Omega$$

Challenge Problem

page 821

$^{238}_{92}U$ decays by α emission and two successive β emissions back into uranium again.

1. Show the three nuclear decay equations.

For the α emission, $^{238}_{92}U \rightarrow ^{A}_{Z}X + ^{4}_{2}He$

where $Z = 92 - 2 = 90$

$A = 238 - 4 = 234$

For $Z = 90$, the element must be thorium. Thus, the equation is

$^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He$

For the first β emission, $^{234}_{90}Th \rightarrow ^{A}_{Z}X + ^{0}_{-1}e + ^{0}_{0}\bar{\nu}$

where $Z = 90 - (-1) - 0 = 91$

$A = 234 - 0 - 0 = 234$

For $Z = 91$, the element must be protactinium. Thus, the equation is

$^{234}_{90}Th \rightarrow ^{234}_{91}Pa + ^{0}_{-1}e + ^{0}_{0}\bar{\nu}$

For the second β emission, $^{234}_{91}Pa \rightarrow ^{A}_{Z}X + ^{0}_{-1}e + ^{0}_{0}\bar{\nu}$

where $Z = 91 - (-1) - 0 = 92$

$A = 234 - 0 - 0 = 234$

For $Z = 92$, the element must be uranium. Thus, the equation is

$^{234}_{91}Pa \rightarrow ^{234}_{92}U + ^{0}_{-1}e + ^{0}_{0}\bar{\nu}$

2. Predict the atomic mass number of the uranium formed.

$A = 234$

Appendix B

Additional Problems

Appendix B

Chapter 1

page 858

1. The density, ρ, of an object is given by the ratio of the object's mass, *m*, and volume, *V*, according to the equation $\rho = m/V$. What is the density of a cube that is 1.2 cm on each side and has a mass of 25.6 g?

$$\rho = \frac{m}{V} = \frac{25.6\text{ g}}{(1.2\text{ cm})^3} = 15\text{ g/cm}^3$$

2. An object that is moving in a straight line with speed *v* covers a distance, $d = vt$, in time *t*. Rewrite the equation to find *t* in terms of *d* and *v*. How long does it take a plane that is traveling at 350 km/h to travel 1750 km?

$$t = \frac{d}{v} = \frac{1750\text{ km}}{350\text{ km/h}} = 5.0\text{ h}$$

3. Convert 523 kg to milligrams.

$$523\text{ kg} = (523\text{ kg})\left(\frac{1000\text{ g}}{1\text{ kg}}\right)\left(\frac{1000\text{ mg}}{1\text{ g}}\right)$$
$$= 5.23\times10^{8}\text{ mg}$$

4. The liquid measure milliliter, mL, is the same as 1 cm^3. How many milliliters of liquid can be held in a 2.5-m^3 container?

$$2.5\text{ m}^3 = (2.5\text{ m}^3)\left(\frac{100\text{ cm}}{1\text{ m}}\right)^3\left(\frac{1\text{ mL}}{1\text{ cm}^3}\right)$$
$$= 2.5\times10^{6}\text{ mL}$$

5. Part of the label from a vitamin container is shown below. The abbreviation "mcg" stands for micrograms. Convert the values to milligrams.

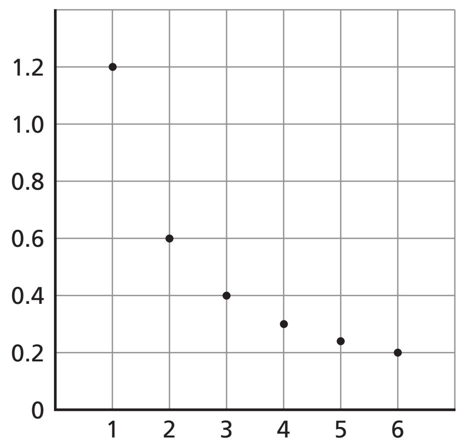
Each Tablet Contains	%DV
Folic Acid 400 mcg	100%
Vitamin B12 6 mcg	100%
Biotin 30 mcg	10%

folic acid:
(400 mcg)(0.001 mg/mcg) = 0.4 mg

vitamin B12:
(6 mcg)(0.001 mg/mcg) = 0.006 mg

biotin:
(30 mcg)(0.001 mg/mcg) = 0.03 mg

6. What type of relationship is shown in the scatter plot? Write an equation to model the data.



inverse relationship; $y = \frac{1.2}{x}$

7. How many significant digits are there in each of the following measurements?

a. 100 m

1

b. 0.0023 m/s

2

c. 100.1 m

4

d. 2.0023

5

8. The buoyant (upward) force exerted by water on a submerged object is given by the formula $F = \rho Vg$, where ρ is the density of water (1.0×10^3 kg/m^3), V is the volume of the object in m^3, and g is the acceleration due to gravity (9.80 m/s^2). The force is in newtons. Rewrite the equation to find V in terms of F. Use this to find the volume of a submerged barrel if the buoyant force on it is 9200 N.

$$V = \frac{F}{\rho g}$$

$$= \frac{9200\text{ N}}{(1.0\times10^3\text{ kg/m}^3)(9.80\text{ m/s}^2)} = 0.94\text{ m}^3$$

9. What is 2.3 kg + 0.23 g?

2.3 kg + 0.23 g = 2.3×10^3 g + 0.23 g
= 2.3×10^3 g = 2.3 kg

10. Solve the following problems.

a. 15.5 cm × 12.1 cm

188 cm^2

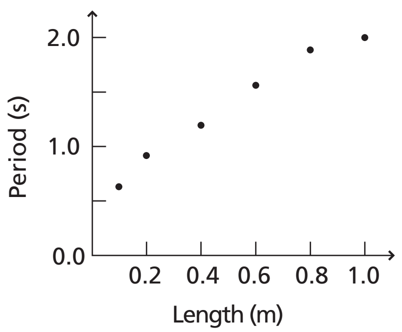
b. $\frac{14.678\text{ m}}{3.2\text{ m/s}}$

4.6 s

11. An experiment was performed to determine the period of a pendulum as a function of the length of its string. The data in the table below were measured.

Length (m)	Period (s)
0.1	0.6
0.2	0.9
0.4	1.3
0.6	1.6
0.8	1.8
1.0	2.0

a. Plot period, T, versus length, l.

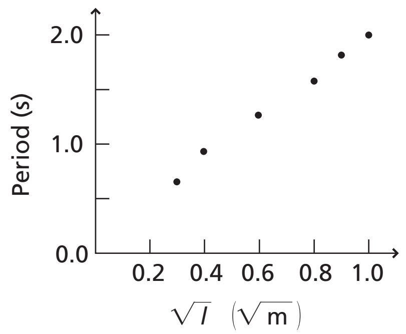


b. Are the data linear?

no

c. Plot the period versus the square root of the length.

$\sqrt{l}$	T
0.3	0.6
0.4	0.9
0.6	1.3
0.8	1.6
0.9	1.8
1.0	2.0



d. What is the relationship between the period and the square root of the length?

The graph is linear, so the period is proportional to the square root of the length of the string.

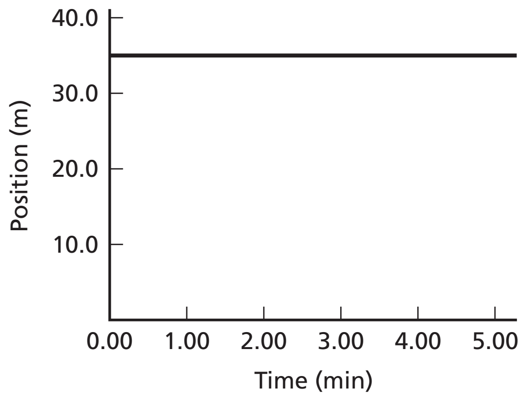
12. Based on the previous problem, what should be the period of a pendulum whose length is 0.7 m?

around 1.7 s

Chapter 2

pages 859–860

1. A position-time graph for a bicycle is shown in the figure below.



a. What is the position of the bicycle at 1.00 min?

35.0 m

b. What is the position of the bicycle at 3.50 min?

35.0 m

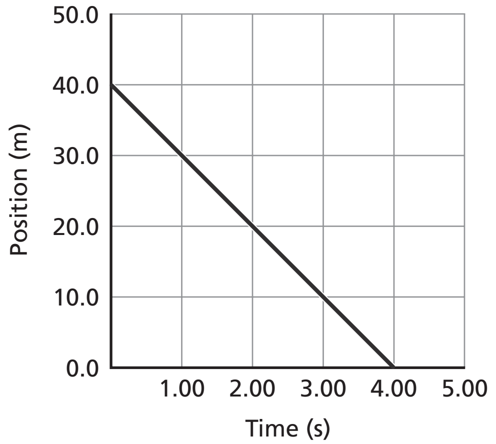
c. What is the displacement of the bicycle between the times 1.00 min and 5.00 min?

0.00 m

d. Describe the motion of the bicycle.

The bicycle is not moving.

2. The position of an automobile is plotted as a function of time in the accompanying figure.



a. What is the position of the car at 0.00 s?

40.0 m

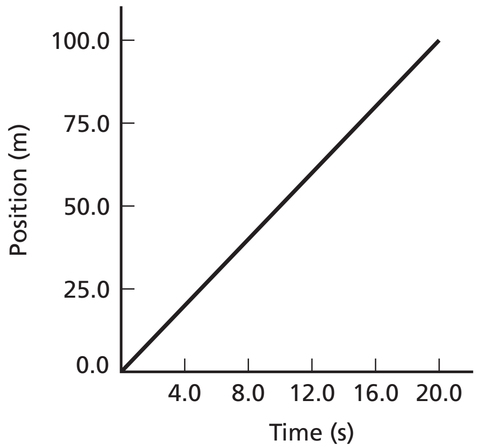
b. What is the position of the automobile after 2.00 s has elapsed?

20.0 m

c. How far did the automobile travel between the times 1.00 s and 3.00 s?

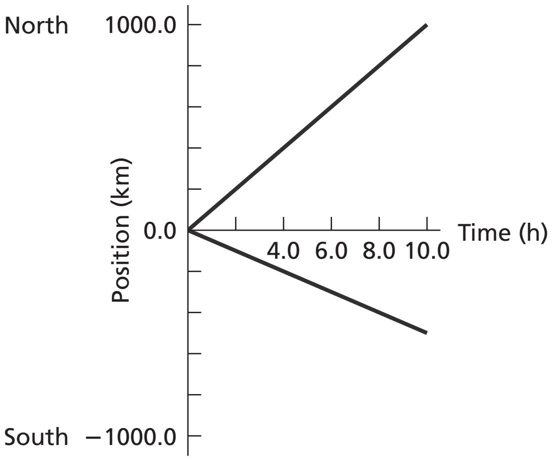
distance traveled = 30.0 m − 10.0 m
= 20.0 m

3. A jogger runs at a constant rate of 10.0 m every 2.0 s. The jogger starts at the origin, and runs in the positive direction for 3600.0 s. The figure below is a position-time graph showing the position of the jogger from time $t = 0.0$ s to time $t = 20.0$ s. Where is the runner at time $t = 5.0$ s? $t = 15.0$ s?



At t = 5.0 s the jogger is at 25.0 m.
At t = 15.0 s the jogger is at 75.0 m.

4. Two trains simultaneously leave the same train station at noon. One train travels north and the other travels south. The position-time graph for both trains is shown in the accompanying figure.



a. What is the position of the train traveling north at 6.0 h?

600.0 km

b. What is the position of the train traveling south at 6.0 h?

300.0 km

c. What is the distance between the trains at 6.0 h? What is the distance at 10.0 h?

900.0 km, 1500.0 km

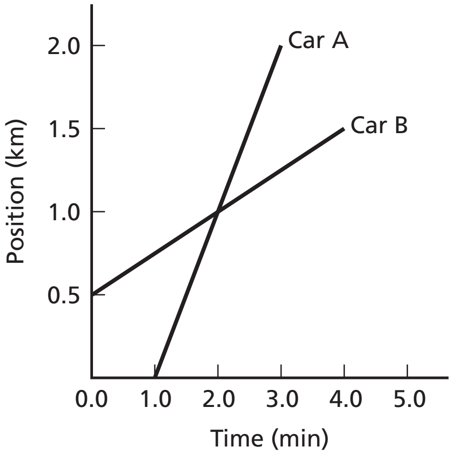
d. At what time are the trains 600.0 km apart?

4.0 h

e. Which train is moving more quickly?

northbound train

5. Two cars head out in the same direction. Car A starts 1.0 min before car B. The position-time graphs for both cars are shown in the accompanying figure.



a. How far apart are the two cars when car B starts out at $t = 1.0$ min?

0.75 km

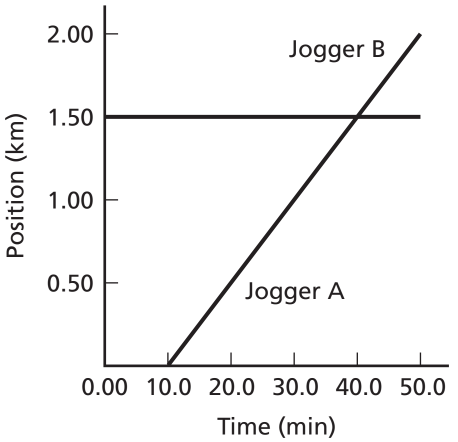
b. At what time do the cars meet?

2.0 min

c. How far apart are the cars at time $t = 3.0$ min?

0.75 km

6. The position-time graph for two joggers, A and B, is shown in the accompanying figure.



a. How far apart are the two runners at 10.0 min?

1.50 km

b. At what time are they 1.00 km apart?

20.0 min

c. How far apart are they at 50.0 min?

0.50 km

d. At what time do they meet?

40.0 min

e. What distance does jogger B cover between 30.0 min and 50.0 min?

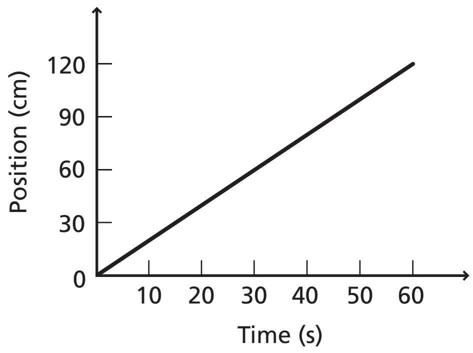
0.00 km

f. What distance does jogger A cover between 30.0 min and 50.0 min?

1.00 km

7. A child's toy train moves at a constant speed of 2.0 cm/s.

a. Draw the position-time graph showing the position of the toy for 1.0 min.

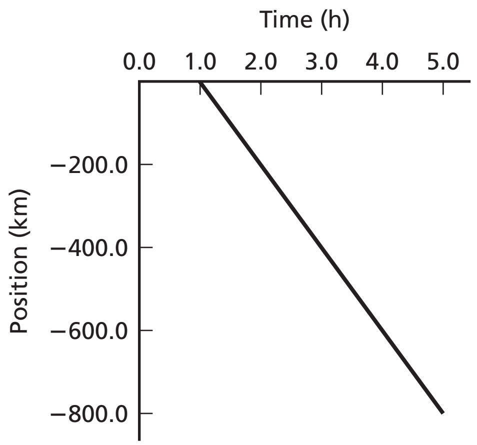


b. What is the slope of the line representing the motion of the toy?

$$\textbf{slope} = \frac{\text{rise}}{\text{run}} = \frac{120\ \text{cm}}{60\ \text{s}}$$

= 2.0 cm/s, the same as the train's speed

8. The position of an airplane as a function of time is shown in the figure below.



a. What is the average velocity of the airplane?

velocity = slope of line

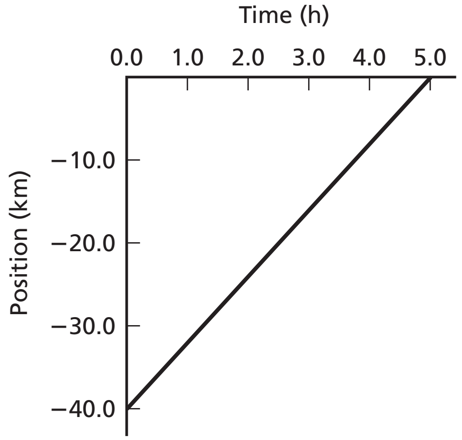
$$= \frac{-800.0\ \text{km} - 0.0\ \text{km}}{5.0\ \text{h} - 1.0\ \text{h}}$$

$$= -2.0\times10^{2}\ \text{km/h}$$

b. What is the average speed of the airplane?

speed = absolute value of the velocity
$= 2.0\times10^{2}$ **km/h**

9. The position-time graph for a hot-air balloon that is in flight is shown in the accompanying figure.



a. What is the average velocity of the balloon?

velocity = slope

$$= \frac{0.00\ \text{km} - (-40.0\ \text{km})}{5.0\ \text{h} - 0.0\ \text{h}}$$

= 8.0 km/h

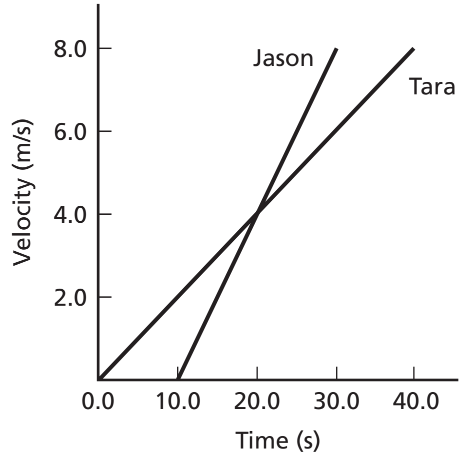
b. What is the average speed of the balloon?

speed = absolute value of slope
= 8.0 km/h

Chapter 3

pages 861–862

1. Jason and his sister, Tara, are riding bicycles. Jason tries to catch up to Tara, who has a 10.0-s head start.



a. What is Jason's acceligibility?

$$a_J = \frac{8.0\text{ m/s} - 0.0\text{ m/s}}{30.0\text{ s} - 10.0\text{ s}}$$

$$= 0.40\text{ m/s}^2$$

b. What is Tara's acceleration?

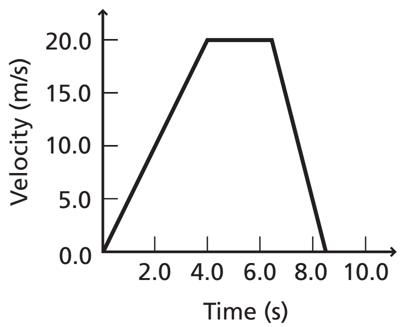
$$a_T = \frac{8.0\text{ m/s} - 0.0\text{ m/s}}{40.0\text{ s} - 0.0\text{ s}}$$

$$= 0.20\text{ m/s}^2$$

c. At what time do they have the same velocity?

20.0 s

2. A dragster starts from rest and accelerates for 4.0 s at a rate of 5.0 m/s^2. It then travels at a constant speed for 2.5 s. A parachute opens, stopping the vehicle at a constant rate in 2.0 s. Plot the *v-t* graph representing the entire motion of the dragster.



3. A car traveling at 21 m/s misses the turnoff on the road and collides into the safety guard rail. The car comes to a complete stop in 0.55 s.

a. What is the average acceleration of the car?

$$\bar{a} = \frac{v_f - v_i}{t_f - t_i} = \frac{0.00\text{ m/s} - 21\text{ m/s}}{0.55\text{ s}}$$

$$= -38\text{ m/s}^2$$

b. If the safety rail consisted of a section of rigid rail, the car would stop in 0.15 s. What would be the acceleration in this case?

$$\bar{a} = \frac{v_f - v_i}{t_f - t_i} = \frac{0.00\text{ m/s} - 21\text{ m/s}}{0.15\text{ s}}$$

$$= -1.4\times10^2\text{ m/s}^2$$

4. On the way to school, Jamal realizes that he left his physics homework at home. His car was initially heading north at 24.0 m/s. It takes him 35.5 s to turn his car around and head south at 15.0 m/s. If north is designated to be the positive direction, what is the average acceleration of the car during this 35.5-s interval?

$$\bar{a} = \frac{v_f - v_i}{t_f - t_i} = \frac{-15.0\text{ m/s} - 24.0\text{ m/s}}{35.5\text{ s}}$$

$$= 1.10\text{ m/s}^2$$

5. A cheetah can reach a top speed of 27.8 m/s in 5.2 s. What is the cheetah's average acceleration?

$$\bar{a} = \frac{v_f - v_i}{t_f - t_i} = \frac{27.8\text{ m/s} - 0.0\text{ m/s}}{5.2\text{ s}}$$

$$= 5.3\text{ m/s}^2$$

6. After being launched, a rocket attains a speed of 122 m/s before the fuel in the motor is completely used. If you assume that the acceleration of the rocket is constant at 32.2 m/s^2, how much time does it take for the fuel to be completely consumed?

$$\bar{a} = \frac{\Delta v}{\Delta t}$$

$$\Delta t = \frac{\Delta v}{\bar{a}} = \frac{122\text{ m/s} - 0.00\text{ m/s}}{32.2\text{ m/s}^2} = 3.79\text{ s}$$

7. An object in free fall has an acceleration of 9.80 m/s^2 assuming that there is no air resistance. What is the speed of an object dropped from the top of a tall cliff 3.50 s after it has been released, if you assume the effect of air resistance against the object is negligible?

$$\bar{a} = \frac{\Delta v}{\Delta t}$$

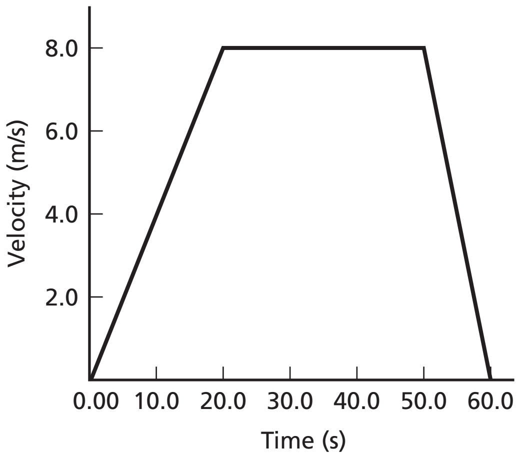
$$\Delta v = \bar{a}\Delta t = g\Delta t = (9.80\ \text{m/s}^2)(3.50\ \text{s})$$
$$= 34.3\ \text{m/s}$$

8. A train moving with a velocity of 51 m/s east undergoes an acceleration of −2.3 m/s^2 as it approaches a town. What is the velocity of the train 5.2 s after it has begun to decelerate?

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{\Delta t}$$

$$v_f = \bar{a}\Delta t + v_i$$
$$= (-2.3\ \text{m/s}^2)(5.2\ \text{s}) + 51\ \text{m/s}$$
$$= 39\ \text{m/s}$$

9. The *v-t* graph of a runner is shown in the accompanying figure.



The displacement is the area under the graph.

a. What is the displacement of the runner between $t = 0.00$ s and $t = 20.0$ s?

$$\Delta d = \left(\frac{1}{2}\right)(8.0\ \text{m/s})(20.0\ \text{s})$$
$$= 8.0\times10^1\ \text{m}$$

b. What is the displacement of the runner between $t = 20.0$ s and $t = 50.0$ s?

$$\Delta d = (8.0\ \text{m/s})(50.0\ \text{s} - 20.0\ \text{s})$$
$$= 240\ \text{m}$$

c. What is the displacement of the runner between $t = 50.0$ s and $t = 60.0$ s?

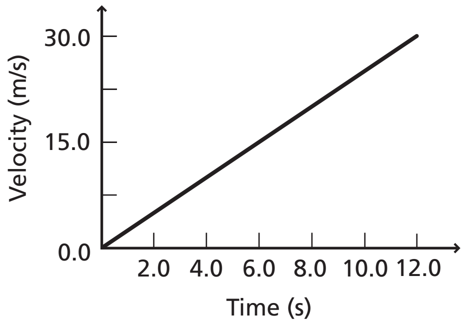
$$\Delta d = \left(\frac{1}{2}\right)(8.0\ \text{m/s})(60.0\ \text{s} - 50.0\ \text{s})$$
$$= 4.0\times10^1\ \text{m}$$

10. Draw the *v-t* graph of an automobile that accelerates uniformly from rest at $t = 0.00$ s and covers a distance of 180.0 m in 12.0 s.

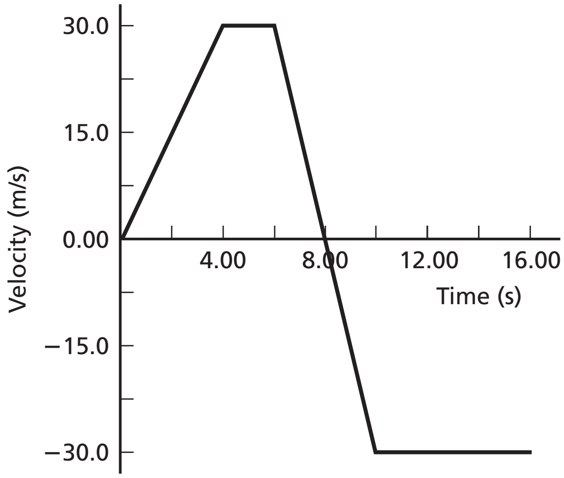
Since the car accelerates uniformly, the *v-t* graph is a straight line. Starting from the origin, the area is triangular.

Thus, $\Delta d = \frac{1}{2}v_{max}\Delta t$

$$v_{max} = \frac{2\Delta d}{\Delta t} = \frac{(2)(180.0\ \text{m})}{12.0\ \text{s}} = 30.0\ \text{m/s}$$



11. The *v-t* graph of a car is shown in the accompanying figure. What is the displacement of the car from $t = 0.00$ s to $t = 15.0$ s?



displacement = area under *v-t* graph

The total displacement is the sum of the displacements from 0.00 s to 4.00 s, 4.00 s to 6.00 s, 6.00 s to 8.00 s, 8.00 s to 10.0 s, and 10.0 s to 15.0 s:

$$\Delta d_{total} = \Delta d_1 + \Delta d_2 + \Delta d_3 + \Delta d_4 + \Delta d_5$$

$$= \left(\frac{1}{2}\right)(30.0\ m/s)(4.00\ s) + (30.0\ m/s)(2.00\ s) + \left(\frac{1}{2}\right)(30.0\ m/s)(2.00\ s) + \left(\frac{1}{2}\right)(-30.0\ m/s)(2.00\ s) + (-30.0\ m/s)(5.00\ s)$$

$$= -30.0\ m$$

12. Suppose a car rolls down a 52.0-m-long inclined parking lot and is stopped by a fence. If it took the car 11.25 s to roll down the hill, what was the acceleration of the car before striking the fence?

$$d_f = d_i + v_i t_f + \frac{1}{2} a t_f^2$$

v_i = 0.00 m/s since the car starts from rest

$$a = \frac{2(d_f - d_i)}{t_f^2} = \frac{(2)(52.0\ m)}{(11.25\ s)^2} = 0.823\ m/s^2$$

13. A sky diver in free fall reaches a speed of 65.2 m/s when she opens her parachute. The parachute quickly slows her down to 7.30 m/s at a constant rate of 29.4 m/s^2. During this period of acceleration, how far does she fall?

$$v_f^2 = v_i^2 + 2a(d_f - d_i)$$

$$d_f - d_i = \frac{v_f^2 - v_i^2}{2a}$$

$$= \frac{(-7.30\ m/s)^2 - (-65.2\ m/s)^2}{(2)(29.4\ m/s^2)}$$

$$= -71.4\ m$$

She has fallen 71.4 m during the acceleration period.

14. A child rolls a ball up a hill at 3.24 m/s. If the ball experiences an acceleration of 2.32 m/s^2, how long will it take for the ball to have a velocity of 1.23 m/s down the hill?

Let the positive direction be up the hill.

$$v_f = v_i + a t_f$$

$$t_f = \frac{v_f - v_i}{a} = \frac{-1.23\ m/s - 3.24\ m/s}{-2.32\ m/s^2}$$

$$= 1.93\ s$$

15. A cheetah can accelerate from rest to a speed of 27.8 m/s in 5.20 s. The cheetah can maintain this speed for 9.70 s before it quickly runs out of energy and stops. What distance does the cheetah cover during this 14.9-s run?

During the acceleration period:

$$v_f = v_i + a t_f$$

$$a = \frac{v_f - v_i}{t_f} = \frac{27.8\ m/s - 0.00\ m/s}{5.20\ s}$$

$$= 5.35\ m/s^2$$

With this acceleration the distance during acceleration can be determined.

$$v_f^2 = v_i^2 + 2a(d_f - d_i)$$

$$d_f - d_i = \frac{v_f^2 - v_i^2}{2a}$$

$$= \frac{(27.8\ m/s)^2 - (0.00\ m/s)^2}{(2)(5.35\ m/s^2)}$$

$$= 72.3\ m$$

During the constant speed period, a = 0.00 m/s^2.

$$d = vt = (27.8\ m/s)(9.70\ s)$$

$$= 2.70\times10^2\ m$$

The total distance is then the sum of the two.

$$\text{distance} = 2.70\times10^2\ m + 72.3\ m$$

$$= 342\ m$$

16. A cab driver in a hurry is sitting at a red light. When the light turns green she rapidly accelerates for 3.50 s at 6.80 m/s^2. The next light is still red. She then slams on the brakes, accelerating at a rate of −9.60 m/s^2 before coming to rest at the stop light. What was her total distance for this trip?

During the first part of the trip,

$$d_f = d_i + v_i t_f + \frac{1}{2} a t_f^2$$

$$d_f - d_i = \frac{1}{2} a t_f^2 = \left(\frac{1}{2}\right)(6.80\ m/s^2)(3.50\ s)^2$$

$$= 41.6\ m$$

For the second part, first determine the speed of the cab at the end of the first acceleration period.

$$v_f = v_i + at_f$$
$$= (0.00\text{ m/s}) + (6.80\text{ m/s}^2)(3.50\text{ s})$$
$$= 23.8\text{ m/s}$$

During the second acceleration period,

$$v_f^2 = v_i^2 + 2a(d_f - d_i)$$
$$d_f - d_i = \frac{v_f^2 - v_i^2}{2a}$$
$$= \frac{(0.00\text{ m/s}) - (23.8\text{ m/s})^2}{(2)(-9.60\text{ m/s}^2)}$$
$$= 29.5\text{ m}$$

The total distance traveled is then the sum of the two.

distance = 41.6 m + 29.5 m = 71.1 m

17. A cyclist rides at a constant speed of 12.0 m/s for 1.20 min and then coasts to a stop with uniform acceleration 21.2 s later. If the total distance traveled is 1321 m, then what is the acceleration while the bike coasts to a stop?

During the first part of the motion, the rider moves at constant speed, or $a = 0.00\text{ m/s}^2$.

The distance covered is then

$$d = vt = (12.0\text{ m/s})(72\text{ s}) = 864\text{ m.}$$

The distance covered during the coasting period is then 1321 − 864 = 457 m.

$$v_f^2 = v_i^2 + 2a(d_f - d_i)$$
$$a = \frac{v_f^2 - v_i^2}{2(d_f - d_i)} = \frac{(0.00\text{ m/s})^2 - (12.0\text{ m/s})^2}{(2)(457\text{ m})}$$
$$= -0.158\text{ m/s}^2$$

18. A hiker tosses a rock into a canyon. He hears it strike water 4.78 s later. How far down is the surface of the water?

Assume that downward is the positive direction.

$$d_f = d_i + v_i t_f + \frac{1}{2}at_f^2$$
$$= 0.00\text{ m} + (0.00\text{ m/s})(4.78\text{ s}) + \left(\frac{1}{2}\right)(9.80\text{ m/s}^2)(4.78\text{ s})^2$$
$$= 112\text{ m}$$

19. A rock is thrown upward with a speed of 26 m/s. How long after it is thrown will the rock have a velocity of 48 m/s toward the ground?

Take upward as the positive direction.

$$v_f = v_i + at_f \text{ where } a = -g$$
$$t_f = \frac{v_f - v_i}{-g} = \frac{-48\text{ m/s} - 26\text{ m/s}}{-9.80\text{ m/s}^2} = 7.6\text{ s}$$

20. The high-dive board at most pools is 3.00 m above the water. A diving instructor dives off the board and strikes the water 1.18 s later.

a. What was the initial velocity of the diver?

$$d_f = d_i + v_i t_f + \frac{1}{2}at_f^2 \text{ where } a = -g$$
$$v_i = \frac{(d_f - d_i) - \left(\frac{1}{2}\right)(-g)t_f^2}{t_f}$$
$$= \frac{(-3.00\text{ m}) - \left(\frac{1}{2}\right)(-9.80\text{ m/s}^2)(1.18\text{ s})^2}{1.18\text{ s}}$$
$$= 3.24\text{ m/s}$$

b. How high above the board did the diver rise?

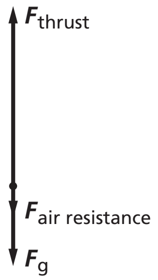
At the highest point, the speed is 0.00 m/s.

$$v_f^2 = v_i^2 + 2a(d_f - d_i) \text{ where } a = -g$$
$$d_f - d_i = \frac{v_f^2 - v_i^2}{2(-g)}$$
$$= \frac{(0.00\text{ m/s})^2 - (3.24\text{ m/s})^2}{(2)(-9.80\text{ m/s}^2)}$$
$$= 0.536\text{ m}$$

Chapter 4

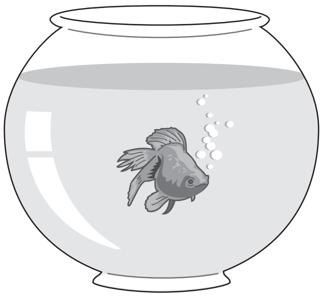
pages 862–864

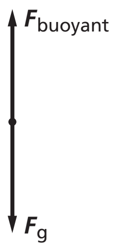
1. Draw a free-body diagram for the space shuttle just after it leaves the ground. Identify the forces acting on the shuttle. Make sure that you do not neglect air resistance. Also be sure that you indicate the direction of the acceleration, as well as the net force.



The net force and acceleration are both upward.

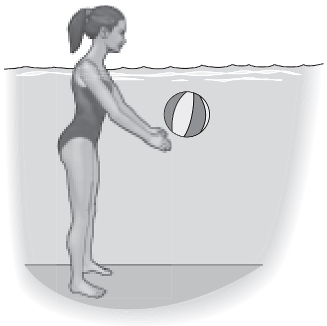
2. Draw a free-body diagram for a goldfish that is motionless in the middle of a fishbowl. Identify the forces acting on the fish. Indicate the direction of the net force on the fish and the direction of the acceleration of the fish.

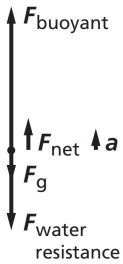




The net force and the acceleration are both zero.

3. Draw a free-body diagram for a submerged beach ball as it rises toward the surface just after being released. Identify the forces acting on the beach ball and indicate the direction of the net force and the acceleration.



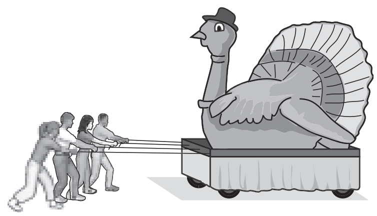


The net force and acceleration vectors are upward.

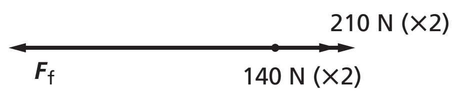
4. Muturi is rearranging some furniture. He pushes the dresser with a force of 143 N, and there is opposing frictional force of 112 N. What is the net force?

$\boldsymbol{F_{net} = 143\ N - 112\ N = 31\ N}$

5. One of the floats in a Thanksgiving Day parade requires four people pulling on ropes to maintain a constant speed of 3.0 km/h for the float. Two people pull with a force of 210 N each, and the other two pull with a force of 140 N each.



a. Draw a free-body diagram.



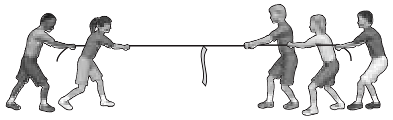
b. What is the force of friction between the float and the ground?

$$F_{net} = 210\text{ N} + 210\text{ N} + 140\text{ N} + 140\text{ N} - F_f$$

$$= 0 \text{ since speed is constant}$$

$$F_f = 7.0\times10^2\text{ N}$$

6. Five people are playing tug-of-war. Anders and Alyson pull to the right with 45 N and 35 N, respectively. Calid and Marisol pull to the left with 53 N and 38 N, respectively. With what force and in what direction does Benito pull if the game is tied?



Assign the coordinate system so that positive forces are to the right. Since the rope is not accelerating:

$$F_{net} = F_{Anders} - F_{Alyson} + F_{Calid} + F_{Marisol} + F_{Benito}$$

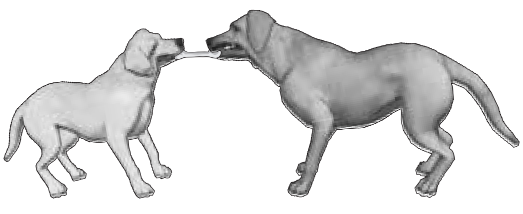
$$0\text{ N} = 45\text{ N} + 35\text{ N} - 53\text{ N} - 38\text{ N} + F_{Benito}$$

$$0\text{ N} = -11\text{ N} + F_{Benito}$$

$$F_{Benito} = 11\text{ N}$$

Benito pulls to the right.

7. Two dogs fight over a bone. The larger of the two pulls on the bone to the right with a force of 42 N. The smaller one pulls to the left with a force of 35 N.



a. Draw the free-body diagram for the bone.

b. What is the net force acting on the bone?

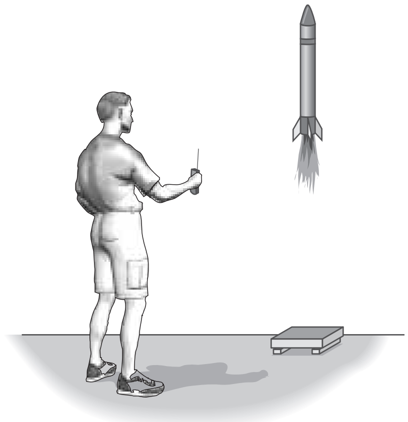
$$F_{net} = 42\text{ N} - 35\text{ N} = 7\text{ N to the right}$$

c. If the bone has a mass of 2.5 kg, what is its acceleration?

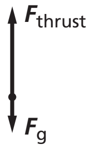
$$F_{net} = ma$$

$$a = \frac{F_{net}}{m} = \frac{7\text{ N}}{2.5\text{ kg}} = 3\text{ m/s}^2$$

8. A large model rocket engine can produce a thrust of 12.0 N upon ignition. This engine is part of a rocket with a total mass of 0.288 kg when launched.



a. Draw a free-body diagram of the rocket just after launch.



b. What is the net force that is acting on the model rocket just after it leaves the ground?

$$F_{net} = F_{thrust} + F_g$$

$$= 12.0\text{ N} + (0.288\text{ kg})(-9.80\text{ m/s}^2)$$

$$= 9.2\text{ N upward}$$

c. What is the initial acceleration of the rocket?

$$F_{net} = ma$$

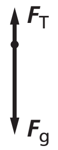
$$a = \frac{F_{net}}{m}$$

$$= \frac{1.20\text{ N} + (0.288\text{ kg})(-9.80\text{ m/s}^2)}{0.288\text{ kg}}$$

$$= 31.8\text{ m/s}^2$$

9. Erika is on an elevator and presses the button to go down. When the elevator first starts moving, it has an acceleration of 2.5 m/s^2 downward. Erika and the elevator have a combined mass of 1250 kg.

a. Draw a free-body diagram for the elevator.



b. What is the tension in the cable that provides the upward force on the elevator car?

$F_{net} = F_T + F_g = ma$

$F_T = ma - F_g$

$= (1250\ kg)(2.5\ m/s^2) - (1250\ kg)(9.80\ m/s^2)$

$= 9100\ N$ **upward**

10. Ngan has a weight of 314.5 N on Mars and a weight of 833.0 N on Earth.

a. What is Ngan's mass on Mars?

$F_{g,\ Earth} = mg_{Earth}$

$$m = \frac{F_{g,\ Earth}}{g_{Earth}} = \frac{833.0\ N}{9.80\ m/s^2} = 85.0\ kg$$

b. What is the acceleration due to gravity on Mars, g_{Mars}?

$F_{g,\ Mars} = mg_{Mars}$

$$g_{Mars} = \frac{F_{g,\ Mars}}{m} = \frac{314.5\ N}{85.0\ kg}$$

$= 3.70\ m/s^2$

11. Alex is on the wrestling team and has a mass of 85.3 kg. Being a whiz at physics, he realizes that he is over the 830.0-N cutoff for his weight class. If he can convince the trainers to measure his weight in the elevator, what must be the acceleration of the elevator so that he just makes his weight class?

$F_{net} = F_{g,\ apparent} + F_g = ma$

$$a = \frac{F_{g,\ apparent} + F_g}{m}$$

$$= \frac{830.0\ kg + (85.3\ kg)(-9.80\ m/s^2)}{85.3\ kg}$$

$= -0.0696\ m/s^2$

$a = 0.0696\ m/s^2$ **down**

12. During a space launch, an astronaut typically undergoes an acceleration of 3 *g*s, which means he experiences an acceleration that is three times that of gravity alone. What would be the apparent weight of a 205-kg astronaut that experiences a 3-*g* liftoff?

Let up be the negative direction.

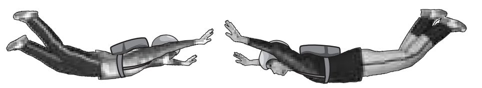
$F_{net} = F_{g,\ apparent} + F_g = ma$

$F_{g,\ apparent} = F_g - ma$

$= (205\ kg)(9.80\ m/s^2) - (205\ kg)(3)(-9.80\ m/s^2)$

$= 8040\ N$

13. Alfonso and Sarah like to go sky diving together. Alfonso has a mass of 88 kg, and Sarah has a mass of 66 kg. While in free fall together, Alfonso pushes Sarah horizontally with a force of 12.3 N.



a. What is Alfonso's horizontal acceleration?

$F_{on\ Sarah} = m_{Sarah}a_{Sarah}$

$$a_{Sarah} = \frac{F_{on\ Sarah}}{m_{Sarah}}$$

$$= \frac{12.3\ N}{66\ kg} = 0.19\ m/s^2$$

b. What is Sarah's horizontal acceleration?

$F_{on\ Alphonso} = F_{on\ Sarah}$

$= m_{Alphonso}a_{Alphonso}$

$$a_{Alphonso} = \frac{F_{on\ Alphonso}}{m_{Alphonso}} = \frac{12.3\ N}{88\ kg}$$

$= 0.14\ m/s^2$

14. A 7.25-g bullet is fired from a gun. The muzzle velocity of the bullet is 223 m/s. Assume that the bullet accelerates at a constant rate along the barrel of the gun before it emerges with constant speed. The barrel of the gun is 0.203 m long. What average force does the bullet exert on the gun?

by Newton's third law

$F_{on\ bullet} = F_{on\ gun}$

$F_{\text{on bullet}} = m_{\text{bullet}}a_{\text{bullet}}$

$v_f^2 = v_i^2 + 2a_{\text{bullet}}(d_f - d_i)$

$a_{\text{bullet}} = \frac{(223\ \text{m/s})^2}{(2)(0.203\ \text{m})} = 1.22\times10^5\ \text{m/s}^2$

$F_{\text{on bullet}} = m_{\text{bullet}}a_{\text{bullet}}$

$= (0.00725\ \text{kg})(1.22\times10^5\ \text{m/s}^2)$

$= 888\ \text{N}$

so, 888 N on the gun

15. A 15.2-kg police battering ram exerts an average force of 125 N on a 10.0-kg door.

a. What is the average acceleration of the door?

By Newton's third law,

$F_{\text{door}} = F_{\text{ram}}$

$F_{\text{door}} = m_{\text{door}}a_{\text{door}}$

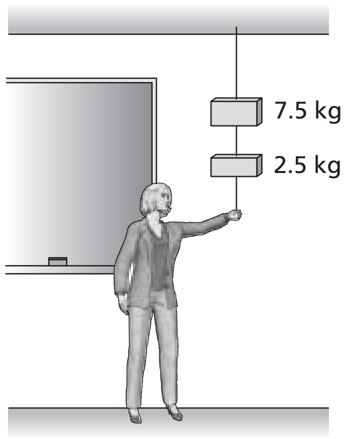
$a_{\text{door}} = \frac{F_{\text{door}}}{m_{\text{door}}} = \frac{125\ \text{N}}{10.0\ \text{kg}} = 12.5\ \text{m/s}^2$

b. What is the average acceleration of the battering ram?

$F_{\text{ram}} = m_{\text{ram}}a_{\text{ram}}$

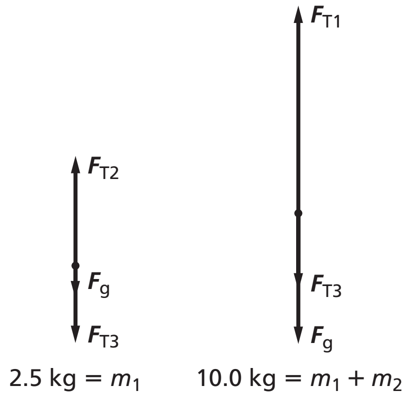
$a_{\text{ram}} = \frac{F_{\text{ram}}}{m_{\text{ram}}} = \frac{125\ \text{N}}{15.2\ \text{kg}} = 8.22\ \text{m/s}^2$

16. As a demonstration, a physics teacher attaches a 7.5-kg object to the ceiling by a nearly massless string. This object then supports a 2.5-kg object below it by another piece of string. Finally, another piece of string hangs off the bottom of the lower object to be pulled with ever increasing force until the string breaks somewhere. The string will break when the tension reaches 156 N.



a. Which length of string will break first?

A free-body diagram can be drawn for the 2.5-kg mass, m_1, and the two masses taken together, $m_1 + m_2$. Let F_{T1} be the tension in the top string, and F_{T2} the tension in the middle string, and F_{T3} the tension applied by the physics teacher.



$F_{T2} - F_{T3} - F_g = 0$

$F_{T2} = (2.5\ \text{kg})(9.80\ \text{m/s}^2) + F_{T3}$

$= 24.5\ \text{N} + F_{T3}$

$F_{T1} - F_{T3} - F_g = 0$

$F_{T1} = (10.0\ \text{kg})(9.80\ \text{m/s}^2) + F_{T3}$

$= 98.0\ \text{N} + F_{T3}$

Regardless of the applied force $F_{T1} > F_{T2} > F_{T3}$. Therefore, the upper string will break first.

b. What is the maximum downward force the physics teacher can apply before the string breaks?

The string breaks when F_{T1} = 156 N.

$F_{T1} = 98.0 \text{ N} + F_{T3}$

$F_{T3} = F_{T1} - 98.0 \text{ N} = 156 \text{ N} - 98.0 \text{ N}$

$= 58 \text{ N}$

17. A 10.0-kg object is held up by a string that will break when the tension exceeds 1.00×10^2 N. At what upward acceleration will the string break?

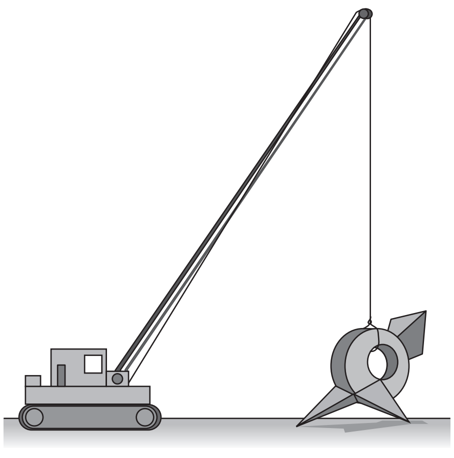
$F_{net} = F_T + F_g = ma$

$a = \frac{F_T + F_g}{m}$

$= \frac{1.00\times10^2 \text{ N} + (10.0 \text{ kg})(-9.80 \text{ m/s}^2)}{10.0 \text{ kg}}$

$= 0.200 \text{ m/s}^2$

18. A large sculpture is lowered into place by a crane. The sculpture has a mass of 2225 kg. When the sculpture makes contact with the ground, the crane slowly releases the tension in the cable as workers make final adjustments to the sculpture's position on the ground.



a. Draw a free-body diagram of the sculpture when it is in contact with the ground, and there is still tension in the cable while the workers make the final adjustments.

b. What is the normal force on the sculpture when the tension in the cable is 19,250 N?

What is the normal force on the sculpture when the tension in the cable is 19,250 N?

$F_{net} = F_T + F_N + F_g = 0$

$F_N = -F_g - F_T$

$= (2225 \text{ kg})(-9.80 \text{ m/s}^2) - 19{,}250 \text{ N}$

$= 2560 \text{ N}$

2560 N upward

Chapter 5

pages 865–867

1. A soccer ball is kicked from a 22-m-tall platform. It lands 15 m from the base of the platform. What is the net displacement of the ball?

Since the two distances are perpendicular, use the Pythagorean theorem.

$R^2 = A^2 + B^2$

$R = \sqrt{A^2 + B^2} = \sqrt{(22\ \text{m})^2 + (15\ \text{m})^2}$

$= 27\ \text{m}$

2. If the net displacement is 32 m for the same situation, as described in problem 1, how far from the platform base must the ball land?

$R^2 = A^2 + B^2$

$B = \sqrt{R^2 - A^2} = \sqrt{(32\ \text{m})^2 - (22\ \text{m})^2}$

$= 23\ \text{m}$

3. For any single force vector, there is only one angle for which its *x*- and *y*-components are equal in size.

a. What is that angle?

$R \sin\theta = R\cos\theta$

$\frac{\sin\theta}{\cos\theta} = \frac{R}{R}$

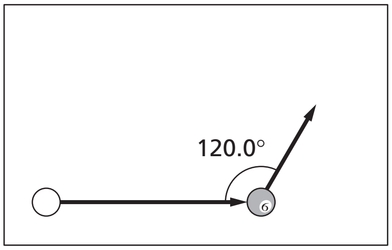
$\theta = \tan^{-1}\left(\frac{R}{R}\right) = \tan^{-1}(1) = 45°$

b. How many times bigger is a vector at this particular angle than either of its components?

$\frac{R}{R\sin\theta} = \frac{1}{\sin\theta} = \frac{1}{\sin 45°}$

$= 1.4$ **times bigger**

4. A cue ball on a billiards table travels at 1.0 m/s for 2.0 s. After striking another ball, it travels at 0.80 m/s for 2.5 s at an angle of 60.0° from its original path.



a. How far does the cue ball travel before and after it strikes the other ball?

In first leg it goes

$x_{before} = v_{before}t_{before}$

$= (1.0\ \text{m/s})(2.0\ \text{s})$

$= 2.0\ \text{m}$

and in second leg

$x_{after} = v_{after}t_{after}$

$= (0.80\ \text{m/s})(2.5\ \text{s})$

$= 2.0\ \text{m}$

b. What is the net displacement of the cue ball for the entire 4.5-s time interval?

Note that the angle between the two legs is 120.0°, not 60.0°.

Using the law of cosines

$R^2 = x^2 + y^2 - 2xy(\cos \theta)$

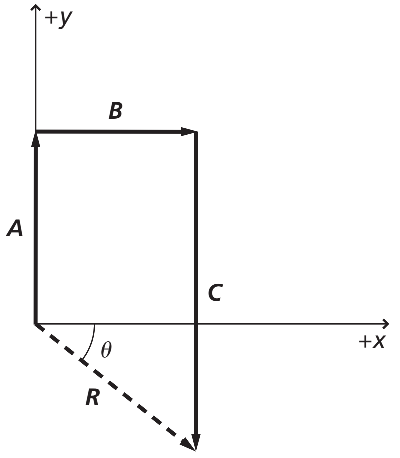
$R = \sqrt{x^2 + y^2 - 2xy(\cos \theta)}$

$= \sqrt{(2.0\ \text{m})^2 + (2.0\ \text{m})^2 - (2)(2.0\ \text{m})(2.0\ \text{m})(\cos 120.0°)}$

$= 3.5\ \text{m}$

5. The table below represents a set of force vectors. These vectors begin at the origin of a coordinate system, and end at the coordinates given in the table.

Vector #	*x*-value (N)	*y*-value (N)
A	0.0	6.0
B	5.0	0.0
C	0.0	−10.0



a. What is the magnitude of the resultant of the sum of these three vectors?

$R_x = A_x + B_x + C_x$

$= 0.0\ \text{N} + 5.0\ \text{N} + 0.0\ \text{N} = 5.0\ \text{N}$

$R_y = A_y + B_y + C_y$

$= 6.0\ \text{N} + 0.0\ \text{N} + (-10.0\ \text{N}) = -4.0\ \text{N}$

$R = \sqrt{R_x{}^2 + R_y{}^2}$

$= \sqrt{(5.0\ \text{N})^2 + (-4.0\ \text{N})^2} = 6.4\ \text{N}$

b. What is the size of the angle, *θ*, that the resultant makes with the horizontal?

$\theta = \tan^{-1}\left(\frac{R_y}{R_x}\right) = \tan^{-1}\left(\frac{-4.0\ \text{N}}{5.0\ \text{N}}\right)$

$= -39°$

c. Into which quadrant does the resultant point?

Because the *x*-component is positive and the *y*-component is negative, the resultant points into quadrant 4.

6. A 9.0-kg crate sits on a level, rough floor. A 61-N force is needed just to start it moving. What is the size of the coefficient of maximum static friction?

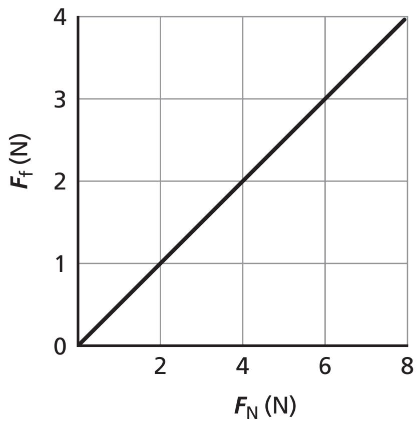
if there is no motion, $F_{\text{applied}} = F_f = \mu_s F_N$;

therefore,

$\mu_s = \frac{F_{\text{applied}}}{F_N} = \frac{F_{\text{applied}}}{mg}$

$= \frac{61\ \text{N}}{(9.0\ \text{kg})(9.80\ \text{m/s}^2)} = 0.69$

7. Given the graph below, answer the following questions.



a. What is the value of μ_k for this system?

μ_k is the slope of the line.

$$\frac{4\text{ N} - 0\text{ N}}{8\text{ N} - 0\text{ N}} = 0.5$$

b. If the frictional force is 1.5 N, what is F_N?

From the graph, $F_N = 3$ N

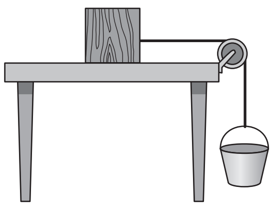
c. Does tripling F_N triple $F_{applied}$?

Yes, they are directly proportional.

d. Do $F_{applied}$ and F_N act in the same direction? Explain why or why not.

No, the friction force acts horizontally and opposite to applied force, while the normal force acts perpendicular to the fixed surface.

8. A wooden block sits on a level lab table. A string draped over a pulley connects to a bucket that can be filled with lead pellets. Maggie wants to measure how much applied mass (pellets + bucket) is needed to move the block along the table at a constant speed.



a. If the applied mass of the bucket and the lead pellets is 0.255 kg, and the block has a weight of 12 N, what is the value of μ_k?

If v is constant, $F_{applied} = F_f = \mu_k F_N$

$$\mu_k = \frac{F_{applied}}{F_N} = \frac{m_{bucket + lead}g}{F_N}$$

$$= \frac{(0.255\text{ kg})(9.80\text{ m/s}^2)}{12\text{ N}}$$

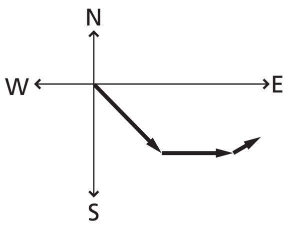
$$= 0.21$$

b. If some extra pellets are added, describe the behavior of the block.

Since $F_{applied}$ now exceeds F_f, $F_{net} \neq 0$, the block will accelerate over time.

9. A boat travels 75 km southeast, then 56 km due east, then 25 km 30.0° north of east.

a. Sketch the vector set on a N-E-S-W grid.



b. Find its net E-W component of displacement and net N-S component of displacement.

$$R_{EW} = A_{EW} + B_{EW} + C_{EW}$$

$$= (75\text{ km})(\cos(-45°)) + (56\text{ km})(\cos 0.0°) + (25\text{ km})(\cos 30.0°)$$

$$= 1.3\times10^2\text{ km}$$

$$R_{NS} = A_{NS} + B_{NS} + C_{NS}$$

$$= (75\text{ km})(\sin(-45°)) + (56\text{ km})(\sin 0.0°) + (25\text{ km})(\sin 30.0°)$$

$$= -41\text{ km}$$

c. Find its net displacement.

$$R = \sqrt{R_{EW}^2 + R_{NS}^2}$$

$$= \sqrt{(1.3\times10^2\text{ km})^2 + (-41\text{ km})^2}$$

$$= 136\text{ km}$$

d. Find its net angle relative to an E-W axis.

$$\theta = \tan^{-1}\left(\frac{R_{NS}}{R_{EW}}\right)$$

$$= \tan^{-1}\left(\frac{-41\text{ km}}{1.3\times10^2\text{ km}}\right)$$

$$= -18°$$

= 18° south of east

10. A 1.25-kg box is being pulled across a level surface where μ_k is 0.80. If the string is suddenly cut, causing the applied force to immediately go to 0.0 N, what is the rate of acceleration of the block?

Let the direction of the applied force be positive.

The net force on the box is due to friction and is in the negative direction.

$$F_{net} = ma = F_f = \mu_k F_N = \mu_k mg$$

$$a = \mu_k g = (0.80)(9.80\text{ m/s}^2)$$

$$= 7.8\text{ m/s}^2 \text{ in the negative direction}$$

11. If the velocity of the box in problem 10 was 5.0 m/s at time zero, what will be its speed after 0.50 s? How far will it travel in that time interval?

$$v_f = v_i + at$$

$$v_f = 5.0\text{ m/s} + (-7.8\text{ m/s}^2)(0.50\text{ s})$$

$$= 1.1\text{ m/s}$$

$$d = \frac{v_f^2 - v_i^2}{2a} = \frac{(1.1\text{ m/s})^2 - (5.0\text{ m/s})^2}{(2)(-7.8\text{ m/s}^2)}$$

$$= 1.5\text{ m}$$

12. A 0.17-kg hockey puck leaves the stick on a slap shot traveling 21 m/s. If no other forces act on the puck, friction eventually will bring it to rest 62 m away.

a. Based on these data, determine the value of μ_k for this hockey puck on ice.

Let the direction of motion be positive. Thus, the force of friction is in the negative direction.

$F_f = -\mu_k F_N$ **(Remember: friction is in the negative direction.)**

$F_f = F_{net} = ma$ **(No negative sign here because the value of a should incorporate that.)**

Thus,

$$-\mu_k F_N = ma$$

$$-\mu_k mg = ma$$

$$\mu_k = \frac{-a}{g}$$

$$v_f^2 - v_i^2 = 2ad, \text{ so } a = \frac{v_f^2 - v_i^2}{2d}$$

$$\mu_k = \frac{-\left(\frac{v_f^2 - v_i^2}{2d}\right)}{g}$$

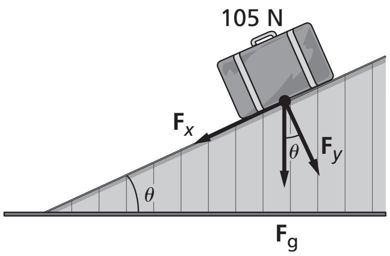
$$= \frac{-(v_f^2 - v_i^2)}{2dg}$$

$$= \frac{-((0.0\text{ m/s})^2 - (21\text{ m/s})^2)}{(2)(62\text{ m})(9.80\text{ m/s}^2)} = 0.36$$

b. Will the answer change if a puck of different mass, but same material and shape is used? Explain why or why not.

No, the result is independent of mass. Note how it cancels in above solution.

13. A 105-N suitcase sits on a rubber ramp at an airport carousel at a 25° angle. The weight vector can be broken into two perpendicular components.



a. What is the magnitude of the component parallel to the ramp surface?

$$F_x = F_w \sin\theta = (105\text{ N})(\sin 25°)$$

$$= 44\text{ N}$$

b. What is the magnitude of the component at a right angle to the ramp surface?

$$F_y = F_w \cos\theta = (105\text{ N})(\cos 25°)$$

$$= 95\text{ N}$$

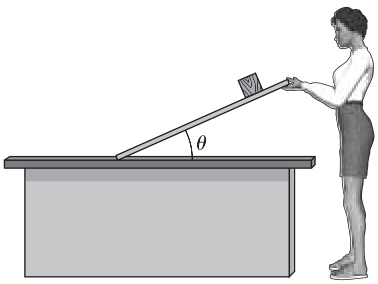
c. Which of those components is the normal force?

F_y

14. In problem 13, which force offsets the kinetic friction force? If F_x exceeds F_f, will the suitcase accelerate down the ramp?

The component parallel to ramp, F_x, offsets the friction force. Since F_{net} along ramp no longer equals zero, the suitcase will accelerate.

15. Dalila decides to determine the coefficient of maximum static friction for wood against wood by conducting an experiment. First she places a block of wood on a small plank; next, she slowly lifts one end of the plank upward. She notes the angle at which the block just begins to slide, and claims that $\mu_s = \tan\theta$. She is correct. Show why.



If there is no motion, F_{net} along the ramp = 0 and

$$F_x = F_w \sin\theta = F_f = \mu_s F_N = \mu_s F_w \cos\theta$$

Thus, $\mu_s = \dfrac{F_w \sin\theta}{F_w \cos\theta} = \tan\theta$

This works, regardless of the weight of the block.

16. Jonathan, with a mass of 81 kg, starts at rest from the top of a water slide angled at 42° from the ground. He exits at the bottom 3.0 s later going 15 m/s. What is μ_k?

$v_f - v_i = at$ **where** $v_i = 0$

$$a = \frac{v_f}{t}$$

$$F_{net} = ma = F_g - F_f = F_g - \mu_k F_n$$

$$= mg \sin\theta - \mu_k mg \cos\theta$$

$$\mu_k = \frac{mg\sin\theta - ma}{mg\cos\theta} = \frac{g\sin\theta - a}{g\cos\theta}$$

$$= \frac{g\sin\theta - \frac{v_f}{t}}{g\cos\theta}$$

$$= \frac{(9.80\ \text{m/s}^2)(\sin 42°) - \left(\frac{15\ \text{m/s}}{3.0\ \text{s}}\right)}{(9.80\ \text{m/s}^2)(\cos 42°)}$$

$$= 0.21$$

17. A 64-N box is pulled by a rope at a constant speed across a rough horizontal surface. If the coefficient of kinetic friction is 0.81, what is the magnitude of the applied force if that force is directed parallel to the floor?

$F_{applied} = F_f$ **since** $F_{net} = 0$

$F_f = \mu_k F_N = (0.81)(64\ \text{N}) = 52\ \text{N}$

18. Suppose that in problem 17 the applied force is directed by the rope at an angle, θ, to the floor.

a. The normal force is no longer simply F_g. Show how to compute net vertical force.

$F_{net,\,y} = F_g + (-F_{applied}\sin\theta)$

b. The frictional force still opposes the horizontal motion of the box. Show how to compute net horizontal force.

$$F_{net,\,x} = F_{applied}\cos\theta + (-F_f)$$

$$= F_{applied}\cos\theta - \mu_k F_N$$

$$= F_{applied}\cos\theta - \mu_k F_{net,\,y}$$

Chapter 6

pages 867–868

1. A football player kicks a field goal from a distance of 45 m from the goalpost. The football is launched at a 35° angle above the horizontal. What initial velocity is required so that the football just clears the goalpost crossbar that is 3.1 m above the ground? Ignore air resistance and the dimensions of the football.

   The origin of the coordinate system is at the point of the kick.

   $v_{x\text{i}} = v_\text{i} \cos\theta$

   $v_{y\text{i}} = v_\text{i} \sin\theta$

   Let t be the time when the football crosses the vertical plane of the uprights. Then:

   $x = v_{x\text{i}}t$

   so $t = \dfrac{x}{v_{x\text{i}}}$

   $$y = v_{y\text{i}}t - \frac{gt^2}{2}$$

   $$= v_{y\text{i}}\left(\frac{x}{v_{x\text{i}}}\right) - \frac{g\left(\frac{x}{v_{x\text{i}}}\right)^2}{2}$$

   $$= (v_\text{i}\sin\theta)\left(\frac{x}{v_\text{i}\cos\theta}\right) - \left(\frac{g}{2}\right)\left(\frac{x^2}{(v_\text{i}\cos\theta)^2}\right)$$

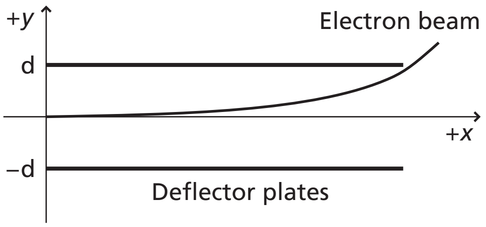
   $$= (\tan\theta)(x) - \frac{gx^2}{2v_\text{i}^2(\cos\theta)^2}$$

   $$v_\text{i} = \sqrt{\frac{gx^2}{2(\cos\theta)^2((\tan\theta)(x) - y)}}$$

   $$= \sqrt{\frac{(9.80\text{ m/s}^2)(45\text{ m})^2}{(2)(\cos 35°)^2((\tan 35°)(45\text{ m}) - 3.1\text{ m})}}$$

   $= 23$ **m/s**

2. In a certain cathode-ray tube, a beam of electrons, moving at a constant velocity, enters a region of constant electric force midway between two parallel plates that are 10.0 cm long and 1.0 cm apart. In this region, the electrons experience an acceleration, a, toward the upper plate. If the electrons enter this region at a velocity of 3.0×10^6 m/s, what is the acceleration that needs to be applied so that the electrons just miss the upper deflection plate?



   Locate the origin of the coordinate system midway between the plates at the left edge. Thereby $y_\text{i} = 0$ and $v_{y\text{i}} = 0$. The position of an electron in the region of the plates is given by:

   $$x = v_{x\text{i}}t,\ y = \frac{at^2}{2}$$

   Eliminating t gives the trajectory:

   $$y = \frac{a}{2}\left(\frac{x}{v_{x\text{i}}}\right)^2 = \frac{a}{2v_{x\text{i}}^2}x^2$$

   We require the trajectory to pass through the point just beyond the deflection plate:

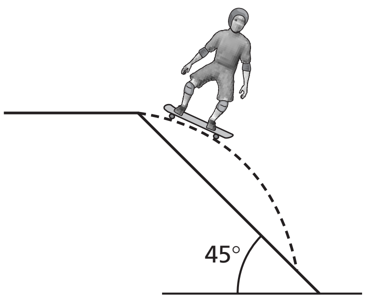
   $$y = \frac{a}{2v_{x\text{i}}^2}x^2$$

   Then,

   $$a = \frac{2v_{x\text{i}}^2y}{x^2} = \frac{(2)(3.0\times10^6\text{ m/s})^2\left(\frac{0.010\text{ m}}{2}\right)}{(0.100\text{ m})^2}$$

   $= 9.0\times10^{12}$ **m/s²**

3. A skateboard track has a horizontal segment followed by a ramp that declines at a 45° angle, as shown.



   a. How long would the ramp need to be to provide a landing for a skateboarder who launches from the horizontal segment at a velocity of 5.0 m/s?

   The skateboarder's trajectory is given by:

   $$y = -\frac{g}{2v_{x\text{i}}^2}x^2,\ \text{for } 0 \le x \le x_\text{L}$$

The ramp can be represented by the equation:

$y = -x$

By eliminating y, we can find the values of x that satisfy both equations.

$$\frac{g}{2v_{xi}^2}x^2 - x = \left(\frac{g}{2v_{xi}^2}x - 1\right)x = 0$$

$$x = 0,\ x = \frac{2v_{xi}^2}{g} = x_L$$

The second solution represents the point where the skateboarder returns to the ramp.

$$x_L = \frac{(2)(5.0\text{ m/s})^2}{9.80\text{ m/s}^2} = 5.1\text{ m}$$

$$y_L = -x_L = -5.1\text{ m}$$

$$x_L = L_{ramp}\cos\theta$$

$$L_{ramp} = \frac{x_L}{\cos\theta} = \frac{-5.1\text{ m}}{\cos 45°} = -7.2\text{ m}$$

The negative sign is because of the coordinate system assigned. The length of the ramp is a positive value: 7.2 m.

b. If the initial velocity is doubled, what happens to the required length of the ramp?

Note that the required ramp length is proportional to the square of the initial velocity. Therefore, the required ramp length is quadrupled to 28.8 m.

4. In an attempt to make a 3-point shot from a distance of 6.00 m, a basketball player lofts the ball at an angle of 68° above the horizontal. The ball has an initial velocity of 10.0 m/s and an initial distance from the floor of 1.50 m.

a. What is the maximum height reached by the ball?

The vertical component of the velocity over time is:

$v_y = v_{yi} - gt$

The maximum height occurs at time t_1 when the vertical velocity is zero.

$$t = \frac{v_{yi}}{g}$$

If the coordinate system is chosen so that the origin is on the floor at the point the ball is thrown, then the height of the ball over time is:

$$y = y_i + v_{yi}t - \frac{gt^2}{2}$$

At time t, the maximum height is

$$y_{max} = y_i + v_{yi}\left(\frac{v_{yi}}{g}\right) - \left(\frac{g}{2}\right)\left(\frac{v_{yi}}{g}\right)^2$$

$$= y_i + \frac{v_{yi}^2}{g} - \frac{gv_{yi}^2}{2g^2}$$

$$= y_i + \frac{v_{yi}^2}{2g} = y_i + \frac{v_i^2(\sin\theta)^2}{2g}$$

$$= 1.50\text{ m} + \frac{(10.0\text{ m/s})^2(\sin 68°)^2}{(2)(9.80\text{ m/s}^2)}$$

$$= 5.9\text{ m}$$

b. If the basket rim height is 3.05 m, how far above the rim is the ball?

The horizontal position of the ball over time is:

$$x = v_{xi}t = (v_i\cos\theta)(t)$$

$$\text{so } t = \frac{x}{v_i\cos\theta}$$

The height of the ball then is:

$$y_{rim} = y_i + v_{yi}t - \frac{gt^2}{2}$$

$$= y_i + v_i\sin\theta\left(\frac{x}{v_i\cos\theta}\right) - \left(\frac{g}{2}\right)\left(\frac{x}{v_i\cos\theta}\right)^2$$

$$= y_i + \tan\theta x - \frac{gx^2}{v_i^2(\cos\theta)^2}$$

$$= 1.50\text{ m} + (\tan 68°)(6.00\text{ m}) - \frac{(9.80\text{ m/s}^2)(6.00\text{ m})^2}{(2)(10.0\text{ m/s})^2(\cos 68°)^2}$$

$$= 3.78\text{ m}$$

height above rim = 3.78 m − 3.05 m = 0.73 m

The ball is 0.73 m above the rim.

5. How far does a baseball that is thrown horizontally at 42.5 m/s drop over a horizontal distance of 18.4 m?

The time needed by the baseball to travel 18.4 m is

$x = v_x t$, so $t = \frac{x}{v_x}$

In this time interval the ball drops

$$\Delta y = \frac{gt^2}{2} = \left(\frac{g}{2}\right)\left(\frac{x}{v_x}\right)^2$$

$$= \left(\frac{9.80\ \text{m/s}^2}{2}\right)\left(\frac{18.4\ \text{m}}{42.5\ \text{m/s}}\right)^2$$

$$= 0.918\ \text{m}$$

6. A projectile is launched from zero height with an initial angle, θ, above the horizontal and with an initial velocity, v_i.

a. Show that the range of the projectile—the distance from the launch point at which the height is again zero—is given by:

$$R = \frac{v_i^2}{g}\sin 2\theta$$

Locate the origin of the coordinate system at the point of launch. The projectile coordinates over time are given by:

$$x = v_{xi}t,\ y = v_{yi}t - \frac{1}{2}gt^2$$

Eliminating t gives the trajectory path.

$$y = \frac{v_{yi}}{v_{xi}}x - \frac{g}{2v_{xi}^2}x^2$$

$$= x\left(\frac{v_{yi}}{v_{xi}} - \frac{g}{2v_{xi}^2}x\right)$$

Setting $y = 0$ gives the two roots of this equation.

$$x = 0,\ \frac{v_{yi}}{v_{xi}} - \frac{g}{2v_{xi}^2}x = 0$$

The second is the solution of interest. Solve for x and rename it as R.

$$R = \frac{2v_{xi}v_{yi}}{g}$$

Substitute:

$v_{xi} = v_i \cos\theta$, $v_{yi} = v_i \sin\theta$,

$$R = \frac{(2)(v_i\cos\theta)(v_i\sin\theta)}{g}$$

$$= \frac{(v_i^2)(2)(\sin\theta)(\cos\theta)}{g}$$

and use the trigonometric identity $2\sin\theta\cos\theta = \sin 2\theta$ to get

$$R = \frac{v_i^2}{g}\sin 2\theta$$

b. What launch angle, θ, results in the largest range?

sine has a maximum value at 90° so, $2\theta = 90°$

$\theta = 45°$

R is maximum when $\theta = 45°$

7. If a ring were constructed as part of a space station, how fast must a 50.0-m-radius ring rotate to simulate Earth's gravity?

For objects in uniform circular motion, the centripetal acceleration is $a_c = \frac{v^2}{r}$. To simulate Earth's gravity, set the centripetal acceleration to g.

$$a_c = \frac{v^2}{r} = g$$

$$v^2 = gr$$

$$v = \sqrt{gr}$$

$$= \sqrt{(9.80\ \text{m/s}^2)(50.0\ \text{m})} = 22.1\ \text{m/s}$$

The required period T is

$$T = \frac{2\pi r}{v} = \frac{(2\pi)(50.0\ \text{m})}{22.1\ \text{m/s}} = 14.2\ \text{s}$$

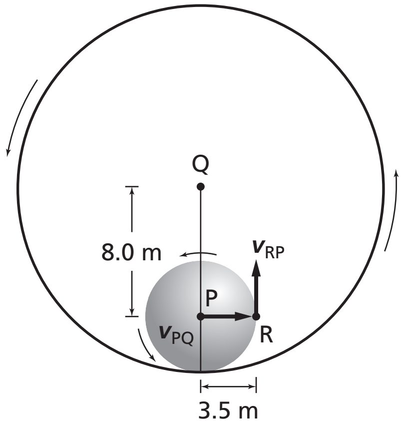
8. A turntable for vinyl records works by constraining the needle to track inside a groove in a very close approximation of uniform circular motion. If the turntable rotational speed is $33\frac{1}{3}$ rpm, what is the needle's centripetal acceleration when it is 14.6 cm from the center?

$$(33\tfrac{1}{3}\ \text{rev/min}) = 0.55\ \text{rev/s}$$

$$T = \frac{1}{0.556\ \text{rev/s}} = 1.80\ \text{s}$$

$$a_c = \frac{4\pi^2 r}{T^2} = \frac{4\pi^2(0.146\ \text{m})}{1.80\ \text{s}} = 3.20\ \text{m/s}^2$$

9. A park ride is designed so that the rider is on the edge of a revolving platform, 3.5 m from the platform's center. This platform is mounted 8.0 m from the center of a larger revolving platform. The smaller platform makes one revolution in 6.0 s and completes 2.0 rev for each revolution of the larger platform. All rotations are counterclockwise. At the instant shown, what are the magnitude and the direction of the rider's velocity with respect to the ground?



Let the velocity of the rider *R* with respect to point *P* be v_{RP}. The period of platform *P* is 6.0 s, so the magnitude and direction of v_{RP} is

$$v_{RP} = \frac{2\pi r}{T} = \frac{(2\pi)(3.5\text{ m})}{6.0\text{ s}}$$

$$= 3.7\text{ m/s, north}$$

The period of platform *Q* is (2.0)(6.0 s) = 12 s, so the magnitude and direction of v_{PQ} is

$$v_{PQ} = \frac{2\pi r}{T} = \frac{(2\pi)(8.0\text{ m})}{12\text{ s}}$$

$$= 4.2\text{ m/s, east}$$

The velocity of the rider with respect to the ground is

$$v_{RQ} = v_{RP} + v_{PQ}$$

$$v_{RQ} = \sqrt{{v_{RP}}^2 + {v_{PQ}}^2}$$

$$|v_{RQ}| = \sqrt{(3.7\text{ m/s})^2 + (4.2\text{ m/s})^2}$$

$$= 5.6\text{ m/s}$$

The direction is:

$$\theta = \tan^{-1}\left(\frac{v_{RP}}{v_{PQ}}\right) = \tan^{-1}\left(\frac{3.7\text{ m/s}}{4.2\text{ m/s}}\right)$$

$$= 41°\text{ north of east}$$

10. Two objects are placed on a flat turntable at 10.0 cm and 20.0 cm from the center, respectively. The coefficient of static friction with the turntable is 0.50. The turntable's rotational speed is gradually increased.

a. Which of the two objects will begin to slide first? Why?

The outer object slides first. The centripetal acceleration $a_c = \frac{4\pi^2 r}{T^2}$ is proportional to the radius, *r*. The centripetal acceleration is provided by the frictional force up to the limit specified by the coefficient of static friction. Therefore, at any given rotational speed, the frictional force is greater for the object at the larger radius, and the force on that object reaches the limit first.

b. At what rotational speed does the inner object begin to slide?

Let *v* be the velocity in m/s. Then, $v = \frac{2\pi r}{T}$, and $a_c = \frac{v^2}{r}$.
At the maximum angular velocity, the frictional force $F_f = \mu_s F_N = \mu_s mg$ must be equal to ma_c.

$$\mu_s mg = \frac{mv^2}{r}$$

$$v = \sqrt{\mu_s gr}$$

$$= \sqrt{(0.50)(9.80\text{ m/s}^2)(0.10\text{ m})}$$

$$= 0.70\text{ m/s}$$

11. An airplane's airspeed is 2.0×10^2 km/h due east. Because of a wind blowing to the north, it is approaching its destination 15° north of east.

a. What is the wind speed?

$$\tan\theta = \frac{v_{wind}}{v_{air}}$$

$v_{wind} = v_{air} \tan\theta$

$= (2.0\times10^2\text{ km/h})(\tan 15°)$

$= 54\text{ km/h}$

b. How fast is the airplane approaching its destination?

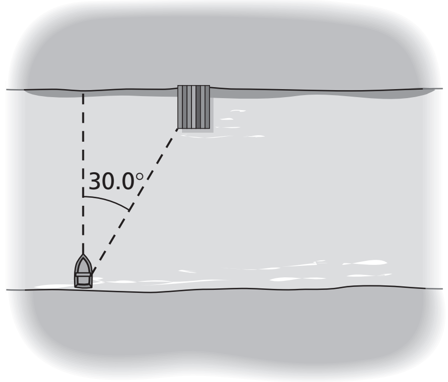
$$\cos\theta = \frac{v_{air}}{v_{ground}}$$

$$v_{ground} = \frac{v_{air}}{\cos\theta}$$

$$= \frac{2.0\times10^2\text{ km/h}}{\cos 15°}$$

$$= 2.1\times10^2\text{ km/h}$$

12. A river is flowing 4.0 m/s to the east. A boater on the south shore plans to reach a dock on the north shore 30.0° downriver by heading directly across the river.



a. What should be the boat's speed relative to the water?

Let $v_{b/w}$ be the boat's speed relative to the water. Then,

$$\tan\theta = \frac{v_w}{v_{b/w}}$$

$$v_{b/w} = \frac{v_w}{\tan\theta} = \frac{4.0\text{ m/s}}{\tan 30.0°}$$

$$= 6.9\text{ m/s}$$

b. What is the boat's speed relative to the dock?

$$v_{b/d} = \sqrt{v_w^2 + v_{b/w}^2}$$

$$= \sqrt{(4.0\text{ m/s})^2 + (6.9\text{ m/s})^2}$$

$$= 8.0\text{ m/s}$$

Chapter 7

pages 868–869

1. A year is defined as the time it takes for a planet to travel one full revolution around the Sun. One Earth year is 365 days. Using the data in Table 7-1, calculate the number of Earth days in one Neptune year. If Neptune takes about 16 h to complete one of its days, how many Neptunian days long is Neptune's year?

$$\left(\frac{T_N}{T_E}\right)^2 = \left(\frac{r_N}{r_E}\right)^3$$

$$T_N = \sqrt{\frac{T_E^2 r_N^3}{r_E^3}}$$

$$= \sqrt{\frac{(365\text{ days})^2(4.50\times10^{12}\text{ m})^3}{(1.50\times10^{11}\text{ m})^3}}$$

$$= 6.00\times10^4\text{ Earth days}$$

For every 16 Earth days, there will be 24 Neptunian days,

$$(6.00\times10^4\text{ Earth days})\left(\frac{24\text{ Neptunian days}}{16\text{ Earth days}}\right)$$

$$= 9.00\times10^4\text{ Neptunian days}$$

2. Suppose a new planet was discovered to orbit the Sun with a period 5 times that of Pluto. Using the data in Table 7-1, calculate the average distance from the Sun for this new planet.

$$\left(\frac{T_A}{T_P}\right)^2 = \left(\frac{r_A}{r_P}\right)^3$$

Let T_P = period for Pluto

T_A = period for new planet = $5T_P$

$$r_A = \sqrt[3]{\frac{T_A^2 r_P^3}{T_P^2}}$$

$$= \sqrt[3]{\frac{(5T_P)^2(5.87\times10^{12}\text{ m})^3}{T_P^2}}$$

$$= 1.72\times10^{13}\text{ m}$$

3. If a meteorite hit the Earth and moved it 2.41×10^{10} m closer to Venus, how many days would there be in an Earth year? Use the data in Table 7-1.

New average distance from the Sun =

$$\left(\frac{T_A}{T_B}\right)^2 = \left(\frac{r_A}{r_B}\right)^3$$

$$T_A = \sqrt{\frac{T_B{}^2 r_A{}^3}{r_B{}^3}}$$

$$= \sqrt{\frac{(365\text{ days})^2(1.50\times10^{11}\text{ m} - 2.41\times10^{10}\text{ m})^3}{(1.50\times10^{11}\text{ m})^3}}$$

= 281 days

4. The Moon is a satellite of the Earth. The Moon travels one full revolution around the Earth in 27.3 days. Given that the mass of the Earth is 5.97×10^{24} kg, what is the average distance from the Earth to the Moon?

Look at units first: The period is given to us in days, which must be converted to seconds due to the units of *G*.

$$(27.3\text{ days})\left(\frac{24\text{ h}}{1\text{ day}}\right)\left(\frac{60\text{ min}}{1\text{ h}}\right)\left(\frac{60\text{ s}}{1\text{ min}}\right) = 2.36\times10^6\text{ s}$$

$$T = 2\pi\sqrt{\frac{r^3}{GM_E}}$$

$$r = \sqrt[3]{\frac{T^2 GM_E}{4\pi^2}}$$

$$= \sqrt[3]{\frac{(2.36\times10^6\text{ s})^2(6.67\times10^{-11}\text{ N·m}^2/\text{kg}^2)(5.97\times10^{24}\text{ kg})}{4\pi^2}}$$

$$= 3.83\times10^8\text{ m}$$

5. A satellite travels 7.18×10^7 m from the center of one of the planets in our solar system at a speed of 4.20×10^4 m/s. Using the data in Table 7-1, identify the planet.

$$v = \sqrt{\frac{GM}{r}}$$

$$M = \frac{v^2 r}{G} = \frac{(4.20\times10^4\text{ m/s})^2(7.18\times10^7\text{ m})}{6.67\times10^{-11}\text{ N·m}^2/\text{kg}^2} = 1.90\times10^{27}\text{ kg, Jupiter}$$

6. Earth's atmosphere is divided into four layers: the troposphere (0–10 km), the stratosphere (10–50 km), the mesosphere (50–80 km), and the thermosphere (80–500 km). What is the minimum velocity an object must have to enter the thermosphere?

$$r = h + r_E = 8.0\times10^4\text{ m} + 6.38\times10^6\text{ m}$$

$$v = \sqrt{\frac{GM_E}{r}}$$

$$= \sqrt{\frac{(6.67\times10^{-11}\text{ N·m}^2/\text{kg}^2)(5.97\times10^{24}\text{ kg})}{8.0\times10^4\text{ m} + 6.38\times10^6\text{ m}}}$$

$$= 7.8\times10^3\text{ m/s}$$

Chapter 8

pages 869–870

1. The rotational velocity of a merry-go-round is increased at a constant rate from 1.5 rad/s to 3.5 rad/s in a time of 9.5 s. What is the rotational acceleration of the merry-go-round?

$$\alpha = \frac{\Delta\omega}{\Delta t} = \frac{(3.5\ \text{rad/s}) - (1.5\ \text{rad/s})}{9.5\ \text{s}}$$

$$= 0.21\ \text{rad/s}^2$$

2. A record player's needle is 6.5 cm from the center of a 45-rpm record. What is the velocity of the needle?

First convert rpm to rad/s.

$$\left(\frac{45\ \text{rev}}{1\ \text{min}}\right)\left(\frac{2\pi\ \text{rad}}{1\ \text{rev}}\right)\left(\frac{1\ \text{min}}{60\ \text{s}}\right) = 4.71\ \text{rad/s}$$

$$v = r\omega = (6.5\ \text{cm})\left(\frac{1\ \text{m}}{100\ \text{cm}}\right)(4.71\ \text{rad/s})$$

$$= 0.31\ \text{m/s}$$

3. Suppose a baseball rolls 3.2 m across the floor. If the ball's angular displacement is 82 rad, what is the circumference of the ball?

$$d = r\theta$$

$$r = \frac{d}{\theta} = \frac{3.2\ \text{m}}{82\ \text{rad}} = 0.039\ \text{m}$$

$$c = 2\pi r = 2\pi(0.039\ \text{m}) = 0.25\ \text{m}$$

4. A painter uses a 25.8-cm long screwdriver to pry the lid off of a can of paint. If a force of 85 N is applied to move the screwdriver 60.0° from the perpendicular, calculate the torque.

$$\tau = Fr \sin\theta = (85\ \text{N})(0.258\ \text{m})(\sin 60.0°)$$

$$= 19\ \text{N·m}$$

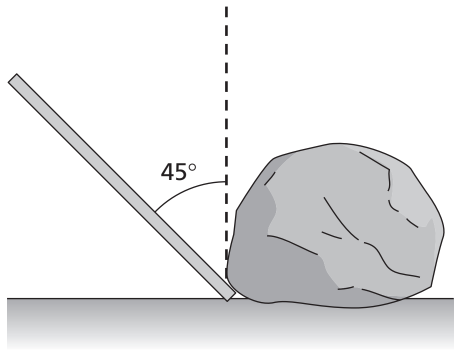
5. A force of 25 N is applied vertically at the end of a wrench handle that is 45 cm long to tighten a bolt in the clockwise direction. What torque is needed by the bolt to keep the wrench from turning?

In order to keep the wrench from turning, the torque on the bolt must be equal in magnitude but opposite in direction of the torque applied by the wrench.

$$\tau = Fr \sin\theta = (25\ \text{N})(0.45\ \text{m})(\sin 90.0°)$$

$$= 11\ \text{N·m counterclockwise}$$

6. A 92-kg man uses a 3.05-m board to attempt to move a boulder, as shown in the diagram below. He pulls the end of the board with a force equal to his weight and is able to move it to 45° from the perpendicular. Calculate the torque applied.



$$\tau = Fr \sin\theta$$

$$= mgr \sin\theta$$

$$= (92\ \text{kg})(9.80\ \text{m/s}^2)(3.05\ \text{m})(\sin 45°)$$

$$= 1.9\times10^3\ \text{N·m}$$

7. If a 25-kg child tries to apply the same torque as in the previous question using only his or her weight for the applied force, what would the length of the lever arm need to be?

$$L = r \sin\theta$$

$$= \frac{\tau}{F} = \frac{\tau}{mg} = \frac{1.9\times10^3\ \text{N·m}}{(25\ \text{kg})(9.80\ \text{m/s}^2)}$$

$$= 7.8\ \text{m}$$

8. Logan, whose mass is 18 kg, sits 1.20 m from the center of a seesaw. If Shiro must sit 0.80 m from the center to balance Logan, what is Shiro's mass?

$$F_L r_L = F_S r_S$$

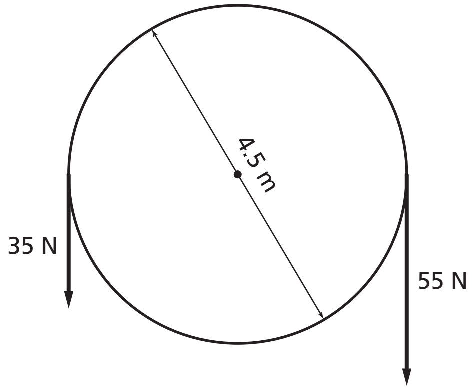
$$m_L g r_L = m_S g r_S$$

$$m_S = \frac{m_L r_L}{r_S}$$

$$= \frac{(18\ \text{kg})(1.20\ \text{m})}{0.80\ \text{m}}$$

$$= 27\ \text{kg}$$

9. Two forces—55-N clockwise and 35-N counterclockwise—are applied to a merry-go-round with a diameter of 4.5 m. What is the net torque?



The net torque is the sum of the individual torques.

$$\tau_{net} = \tau_{ccw} + \tau_{cw}$$
$$= F_{ccw}r \sin\theta + F_{cw}r \sin\theta$$
$$= (F_{ccw} + F_{cw})r \sin\theta$$
$$= (35\ \text{N} - 55\ \text{N})\left(\frac{4.5\ \text{m}}{2}\right)(\sin 90.0°)$$
$$= -45\ \text{N·m}$$

45 N·m clockwise

10. A student sits on a stool holding a 5.0-kg dumbbell in each hand. He extends his arms such that each dumbbell is 0.60 m from the axis of rotation. The student's moment of inertia is 5.0 kg·m^2. What is the moment of inertia of the student and the dumbbells?

$$I_{single\ dumbbell} = mr^2 = (5.0\ \text{kg})(0.60\ \text{m})^2$$
$$= 1.8\ \text{kg·m}^2$$
$$I_{total} = 2I_{single\ dumbbell} + I\ \text{student}$$
$$= (2)(1.8\ \text{kg·m}^2) + 5.0\ \text{kg·m}^2$$
$$= 8.6\ \text{kg·m}^2$$

11. A basketball player spins a basketball with a radius of 15 cm on his finger. The mass of the ball is 0.75 kg. What is the moment of inertia about the basketball?

$$I = \frac{2}{5}mr^2 = \left(\frac{2}{5}\right)(0.75\ \text{kg})(0.15\ \text{m})^2$$
$$= 6.8\times10^{-3}\ \text{kg·m}^2$$

12. A merry-go-round in the park has a radius of 2.6 m and a moment of inertia of 1773 kg·m^2. What is the mass of the merry-go-round?

$$I = \frac{1}{2}mr^2$$
$$m = \frac{2I}{r^2} = \frac{(2)(1773\ \text{kg·m}^2)}{(2.6\ \text{m})^2}$$
$$= 5.2\times10^2\ \text{kg}$$

13. The merry-go-round described in the previous problem is pushed with a constant force of 53 N. What is the angular acceleration?

$$\alpha = \frac{\tau_{net}}{I}$$
$$= \frac{Fr \sin\theta}{1}$$
$$= \frac{(53\ \text{N})(2.6\ \text{m})(\sin 90.0°)}{1773\ \text{kg·m}^2}$$
$$= 7.8\times10^{-2}\ \text{rad/s}^2$$

14. What is the angular velocity of the merry-go-round described in problems 12 and 13 after 85 s, if it started from rest?

$$\alpha = \frac{\Delta\omega}{\Delta t} = \frac{\omega_f - \omega_i}{\Delta t}$$

ω_i = 0 since it started from rest

$$\omega_f = \alpha\Delta t$$
$$= (7.8\times10^{-2}\ \text{rad/s}^2)(85\ \text{s})$$
$$= 6.6\ \text{rad/s}$$

15. An ice-skater with a moment of inertia of 1.1 kg·m^2 begins to spin with her arms extended. After 25 s, she has an angular velocity of 15 rev/s. What is the net torque acting on the skater?

$$\tau_{net} = I\alpha$$
$$= \frac{I(\omega_f - \omega_i)}{\Delta t}$$
$$= \left(\frac{(1.1\ \text{kg·m}^2)(15\ \text{rev/s} - 0\ \text{rev/s})}{255}\right)\left(\frac{2\pi\ \text{rad}}{\text{rev}}\right)$$
$$= 4.1\ \text{N·m}$$

16. A board that is 1.5 m long is supported in two places. If the force exerted by the first support is 25 N and the forced exerted by the second is 62 N, what is the mass of the board?

$F_{net} = F_1 + F_2 + (-F_g)$

Since the system is in equilibrium,

$F_{net} = 0.$

$0 = F_1 + F_2 - F_g$

$F_g = F_1 + F_2$

$mg = F_1 + F_2$

$m = \frac{F_1 + F_2}{g} = \frac{25\text{ N} + 62\text{ N}}{9.80\text{ m/s}^2}$

$= 8.9\text{ kg}$

17. A child begins to build a house of cards by laying an 8.5-cm-long playing card with a mass of 0.75 g across two other playing cards: support card A and support card B. If support card A is 2.0 cm from the end and exerts a force of 1.5×10^{-3} N, how far from the end is support card B located? Let the axis of rotation be at the point support card A comes in contact with the top card.

$F_{net} = F_A + F_B + (-F_g)$

Since the system is in equilibrium,

$F_{net} = 0.$

$0 = F_A + F_B - F_g$

$F_B = F_g - F_A$

$= mg - F_A$

Since the axis of rotation is about support card A, $\tau_A = 0$.

so $\tau_{net} = \tau_B + \tau_g$

The system is in equilibrium, so $\tau_{net} = 0$.

$0 = \tau_B + \tau_g$

$\tau_B = -\tau_g$

$\tau_B = r_B F_B$ **and** $\tau_g = -r_g F_g$

$r_B F_B = r_g F_g$

$r_B = \frac{r_g F_g}{F_B} = \frac{r_g mg}{mg - F_A}$

$= \frac{\left(\left(\frac{1}{2}\right)(0.085\text{ m}) - 0.020\text{ m}\right)(7.5\times10^{-4}\text{ kg})(9.80\text{ m/s}^2)}{(7.5\times10^{-4}\text{ kg})(9.80\text{ m/s}^2) - 1.5\times10^{-3}\text{ N}}$

$= 2.8\times10^{-2}\text{ m}$

$= 28\text{ cm}$

18. If support card A in the previous problem was moved so that it now is 2.5 cm from the end, how far from the other end does support card B need to be to reestablish equilibrium?

$$r_B = \frac{r_g mg}{mg - F_A}$$

$$= \frac{\left(\left(\frac{1}{2}\right)(0.085\text{ m}) - 0.025\text{ m}\right)(7.5\times10^{-4}\text{ kg})(9.80\text{ m/s}^2)}{(7.5\times10^{-4}\text{ kg})(9.80\text{ m/s}^2) - 1.5\times10^{-3}\text{ N}}$$

$$= 2.2\times10^{-2}\text{ m}$$

$$= 22\text{ cm}$$

Chapter 9

pages 870–871

1. A ball with an initial momentum of 6.00 kg·m/s bounces off a wall and travels in the opposite direction with a momentum of 4.00 kg·m/s. What is the magnitude of the impulse acting on the ball?

Choose the direction away from the wall to be positive.

$p_f = +4.00$ kg·m/s

$p_i = -6.00$ kg·m/s

$\text{Impulse} = p_f - p_i = (4.00 \text{ kg·m/s}) - (-6.00 \text{ kg·m/s})$

$= 10.0$ kg·m/s

2. If the ball in the previous problem interacts with the wall for a time interval of 0.22 s, what is the average force exerted on the wall?

$\text{Impulse} = F\Delta t$

$$F = \frac{\text{Impulse}}{\Delta t} = \frac{10.0 \text{ kg·m/s}}{0.22 \text{ s}} = 45 \text{ N}$$

3. A 42.0-kg skateboarder traveling at 1.50 m/s hits a wall and bounces off of it. If the magnitude of the impulse is 150.0 kg·m/s, calculate the final velocity of the skateboarder.

Choose the direction away from the wall to be positive.

$\text{Impulse} = p_f - p_i = mv_f - (-mv_i)$

$= m(v_f + v_i)$

$$v_f = \frac{\text{Impulse}}{m} - v_i$$

$$= \frac{150.0 \text{ kg·m/s}}{42.0 \text{ kg}} - 1.50 \text{ m/s}$$

$= 2.07$ m/s

4. A 50.0-g toy car traveling with a velocity of 3.00 m/s due north collides head-on with an 180.0-g fire truck traveling with a velocity of 0.50 m/s due south. The toys stick together after the collision. What are the magnitude and direction of their velocity after the collision?

Choose north to be positive.

$p_i = p_f$

$p_{ci} + p_{ti} = p_f$

$m_c v_{ci} + m_t v_{ti} = (m_c + m_t)v_f$

$$v_f = \frac{m_c v_{ci} + m_t v_{ti}}{m_c + m_t}$$

$$= \frac{(50.0 \text{ g})(3.00 \text{ m/s}) + (180.0 \text{ g})(-0.50 \text{ m/s})}{50.0 \text{ g} + 180.0 \text{ g}}$$

$= 0.26$ m/s, due north

5. A 0.040-kg bullet is fired into a 3.50-kg block of wood, which was initially at rest. The bullet remains embedded within the block of wood after the collision. The bullet and the block of wood move at a velocity of 7.40 m/s. What was the original velocity of the bullet?

$p_i = p_f$

$p_{bi} + p_{wi} = p_f$

$m_b v_{bi} + m_w v_{wi} = (m_b + m_w)v_f$

where $v_{wi} = 0$. **Thus,**

$$v_{bi} = \frac{(0.040 \text{ kg} + 3.50 \text{ kg})(7.40 \text{ m/s})}{0.040 \text{ kg}}$$

$$= 6.5\times10^2 \text{ m/s}$$

6. Ball A, with a mass of 0.20 kg, strikes ball B, with a mass of 0.30 kg. The initial velocity of ball A is 0.95 m/s. Ball B is initially at rest. What are the final speed and direction of ball A and B after the collision if they stick together?

$p_i = p_f$

$m_A v_{Ai} = (m_A + m_B)v_f$

$$v_f = \frac{m_A v_{Ai}}{m_A + m_B}$$

$$= \frac{(0.20 \text{ kg})(0.95 \text{ m/s})}{0.20 \text{ kg} + 0.30 \text{ kg}}$$

= 0.38 m/s in the same direction as ball A's initial velocity

7. An ice-skater with a mass of 75.0 kg pushes off against a second skater with a mass of 42.0 kg. Both skaters are initially at rest. After the push, the larger skater moves off with a speed of 0.75 m/s eastward. What is the velocity (magnitude and direction) of the smaller skater after the push?

$p_i = p_f$

$= m_1 v_{f1} + m_2 v_{f2}$

$$v_{f2} = \frac{-m_1 v_{f1}}{m_2}$$

$$= \frac{-(75.0 \text{ kg})(0.75 \text{ m/s})}{42.0 \text{ kg}}$$

$$= -1.3 \text{ m/s}$$

The second skater moves west with a velocity of 1.3 m/s.

8. Suppose a 55.0-kg ice-skater, who was initially at rest, fires a 2.50-kg gun. The 0.045-kg bullet leaves the gun at a velocity of 565.0 m/s. What is the velocity of the ice-skater after she fires the gun?

$p_i = p_f$

$0 = p_{fs} + p_{fb}$

$= (m_s + m_g)v_{fs} + m_b v_{fb}$

because the final mass of the skater includes the mass of the gun held by the skater. Then,

$$v_{fs} = \frac{-m_b v_{fb}}{m_s + m_g}$$

$$= \frac{-(0.045 \text{ kg})(565.0 \text{ m/s})}{55.0 \text{ kg} + 2.50 \text{ kg}}$$

$$= -0.44 \text{ m/s}$$

9. A 1200-kg cannon is placed at rest on an ice rink. A 95.0-kg cannonball is shot from the cannon. If the cannon recoils at a speed of 6.80 m/s, what is the speed of the cannonball?

$p_i = p_f$

Since the cannon and cannonball are at rest before the blast, $p_i = 0.00$ **kg·m/s.**

So $p_{fc} = -p_{fb}$

$m_c v_{fc} = -m_b v_{fb}$

$$v_{fb} = \frac{-m_c v_{fc}}{m_b}$$

$$= \frac{-(1200 \text{ kg})(6.80 \text{ m/s})}{95.0 \text{ kg}}$$

$$= -86 \text{ m/s}$$

10. An 82-kg receiver, moving 0.75 m/s north, is tackled by a 110.0-kg defensive lineman moving 0.15 m/s east. The football players hit the ground together. Calculate their final velocity (magnitude and direction).

$p_{ri} = m_r v_{ri,\,y} = (82 \text{ kg})(0.75 \text{ m/s})$

= 62 kg·m/s north

$p_{di} = m_d v_{di,\,x} = (110.0 \text{ kg})(0.15 \text{ m/s})$

= 16 kg·m/s, east

Law of conservation of momentum states

$p_i = p_f$

$p_{f,x} = p_{i,x} = 16\ \text{kg·m/s}$

$p_{f,y} = p_{i,y} = 62\ \text{kg·m/s}$

$p_f = (p_{f,x}{}^2 + p_{f,y}{}^2)^{\frac{1}{2}}$

$= ((16\ \text{kg·m/s})^2 + (62\ \text{kg·m/s})^2)^{\frac{1}{2}}$

$= 64\ \text{kg·m/s}$

$v_f = \dfrac{p_f}{m_r + m_d} = \dfrac{64\ \text{kg·m/s}}{82\ \text{kg} + 110.0\ \text{kg}}$

$= 0.33\ \text{m/s}$

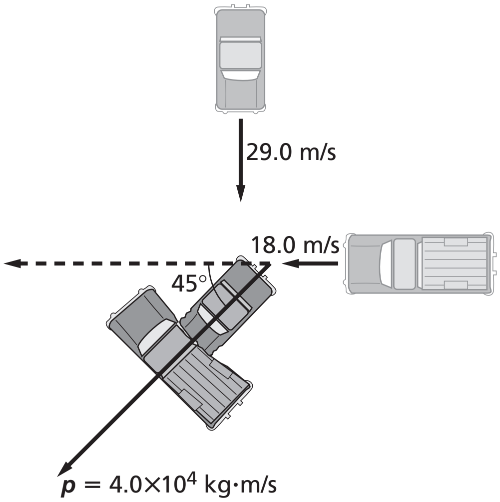
$\theta = \tan^{-1}\left(\dfrac{p_{f,y}}{p_{f,x}}\right)$

$= \tan^{-1}\left(\dfrac{m_r v_{ri,y}}{m_d v_{di,x}}\right)$

$= \tan^{-1}\left(\dfrac{(82\ \text{kg})(0.75\ \text{m/s})}{(110.0\ \text{kg})(0.15\ \text{m/s})}\right)$

$= 75°$

11. A 985-kg car traveling south at 29.0 m/s hits a truck traveling 18.0 m/s west, as shown in the figure below. After the collision, the vehicles stick together and travel with a final momentum of 4.0×10^4 kg·m/s at an angle of 45°. What is the mass of the truck?



$p_f{}^2 = p_{fx}{}^2 + p_{fy}{}^2$

$p_f{}^2 = p_{ix}{}^2 + p_{iy}{}^2$

$p_f{}^2 = m_c{}^2 v_{ci}{}^2 + m_t{}^2 v_{ti}{}^2$

$m_t = \left(\dfrac{p_f{}^2 - m_c{}^2 v_{ci}{}^2}{v_{ti}{}^2}\right)^{\frac{1}{2}}$

$= \left(\dfrac{(4.0\times10^4\ \text{kg·m/s}) - (985\ \text{kg})^2(29.0\ \text{m/s})^2}{(18.0\ \text{m/s})^2}\right)^{\frac{1}{2}}$

$= 1.6\times10^3\ \text{kg}$

12. A 77.0-kg woman is walking 0.10 m/s east in the gym. A man throws a 15.0-kg ball south and accidentally hits the woman. The woman and the ball move together with a velocity of 0.085 m/s. Calculate the direction the woman and the ball move.

$$\theta = \cos^{-1}\left(\frac{p_{fx}}{p_f}\right)$$

$$= \cos^{-1}\left(\frac{p_{ix}}{p_f}\right)$$

$$= \cos^{-1}\left(\frac{m_w v_{iw}}{(m_w + m_b)v_f}\right)$$

$$= \cos^{-1}\left(\frac{(77.0\text{ kg})(0.10\text{ m/s})}{(77.0\text{ kg} + 15.0\text{ kg})(0.085\text{ m/s})}\right)$$

$$= 1.0\times10^{1}\text{ degrees south of east}$$

Chapter 10

page 871

1. A toy truck is pushed across a table 0.80 m north, and pulled back across the table 0.80 m south. If a constant horizontal force of 15 N was applied in both directions, what is the net work?

Choose north to be the positive direction.

$$W_{net} = W_{north} + W_{south}$$
$$= (Fd) + (-Fd)$$
$$= (15\ N)(0.80\ m) + (-15\ N)(0.80\ m)$$
$$= 0.0\ J$$

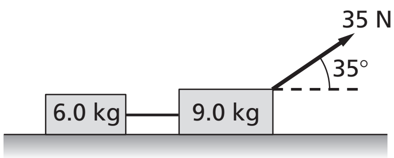
2. A 15-kg child experiences an acceleration of 0.25 m/s^2 as she is pulled 1.7 m horizontally across the floor by her sister. Calculate the change in the child's kinetic energy.

$$\Delta KE = W = Fd = mad$$
$$= (15\ kg)(0.25\ m/s^2)(1.7\ m)$$
$$= 6.4\ J$$

3. A man pushes a couch a distance of 0.75 m. If 113 J of work is done, what is the magnitude of the horizontal force applied?

$$W = Fd$$
$$F = \frac{W}{d} = \frac{113\ J}{0.75\ m} = 1.5\times10^2\ N$$

4. Two blocks are tied together by a horizontal string and pulled a distance of 2.7 m across an air hockey table with a constant force of 35 N. The force is directed at an upward angle of 35° from the 9.0-kg block, as shown in the figure. What is the change in kinetic energy in the two-block system?



$$W = \Delta KE = Fd\cos\theta$$
$$= (35\ N)(2.7\ m)(\cos 35°)$$
$$= 77\ J$$

5. If the two-block system described in the previous problem was initially at rest, what is the final velocity?

$$\Delta KE = \frac{1}{2}m\Delta v^2$$
$$= \frac{1}{2}m(v_f - v_i)^2$$

$v_i = 0$ since blocks were initially at rest.

So $\Delta KE = \frac{1}{2}mv_f^2$

$$v_f = \sqrt{\frac{2\Delta KE}{m}} = \sqrt{\frac{(2)(77\ J)}{15\ kg}}$$
$$= 3.2\ m/s$$

6. A toy car with a mass of 0.75 kg is pulled 3.2 m across the floor with a constant force of 110 N. If 67 J of work is done, what is the upward angle of the force?

$$W = Fd\cos\theta$$
$$\theta = \cos^{-1}\left(\frac{W}{Fd}\right)$$
$$= \cos^{-1}\left(\frac{67\ J}{(110\ N)(3.2\ m)}\right) = 79°$$

7. If a 75-W lightbulb is left on for 2.0 h, how much work is done?

$$(2.0\ h)\left(\frac{3600\ s}{1.0\ h}\right) = 7.2\times10^3\ s$$
$$P = \frac{W}{t}$$
$$W = Pt = (75\ W)(7.2\times10^3\ s)$$
$$= 5.4\times10^5\ J$$

8. A 6.50-horsepower (hp) self-propelled lawn mower is able to go from 0.00 m/s to 0.56 m/s in 0.050 s. If the mass of the lawn mower is 48.0 kg, what distance does the lawn mower travel in this time? (Use 1 hp = 746 W.)

$$(6.50\ hp)\left(\frac{746\ W}{1\ hp}\right) = 4.85\times10^3\ W$$
$$a = \frac{\Delta v}{t}$$

$$P = \frac{W}{t}$$

$$= \frac{Fd}{t} = \frac{mad}{t}$$

$$= \frac{m\left(\frac{\Delta v}{t}\right)d}{t} = \frac{m(v_f - v_i)d}{t^2}$$

$$d = \frac{Pt^2}{m(v_f - v_i)}$$

$$= \frac{(4.85\times10^3 \text{ W})(0.050 \text{ s})^2}{(48.0 \text{ kg})(0.36 \text{ m/s} - 0.00 \text{ m/s})}$$

$$= 0.45 \text{ m}$$

9. A winch that's powered by a 156-W motor lifts a crate 9.8 m in 11 s. What is the mass of the crate?

$$v_{avg} = \frac{d}{t} = \frac{9.8 \text{ m}}{11 \text{ s}} = 0.89 \text{ m/s}$$

If the crate is initially at rest:

$$v_{avg} = \frac{v_i + v_f}{2} = \frac{v_f}{2}$$

$$v_f = 2v_{avg} = (2)(0.89 \text{ m/s}) = 1.8 \text{ m/s}$$

$$P = \frac{W}{t} = \frac{\Delta KE}{t} = \frac{m\Delta v^2}{2t}$$

$$m = \frac{2Pt}{\Delta v^2} = \frac{2Pt}{(v_f - v_i)^2}$$

$$= \frac{(2)(156 \text{ W})(11 \text{ s})}{(1.8 \text{ m/s})^2}$$

$$= 1.1\times10^3 \text{ kg}$$

10. A man exerts a force of 310 N on a lever to raise a crate with a mass of 910 kg. If the efficiency of the lever is 78 percent, what is the lever's *IMA*?

$$\left(\frac{\frac{F_r}{F_e}}{e}\right)(100) = \left(\frac{\frac{mg}{F_e}}{e}\right)(100)$$

$$= \left(\frac{\frac{(910 \text{ kg})(9.80 \text{ m/s}^2)}{310 \text{ N}}}{78}\right)(100)$$

$$= 37$$

11. A worker uses a pulley to lift a 45-kg object. If the mechanical advantage of the pulley is 5.2, what is the effort force exerted by the worker?

$$MA = \frac{F_r}{F_e}$$

$$Fe = \frac{F_r}{MA} = \frac{mg}{MA} = \frac{(45 \text{ kg})(9.80 \text{ m/s}^2)}{5.2}$$

$$= 85 \text{ N}$$

12. When the chain on a bicycle is pulled 0.95 cm, the rear wheel rim moves a distance of 14 cm. If the gear has a radius of 3.5 cm, what is the radius of the rear wheel?

$$IMA = \frac{d_e}{d_r} = \frac{r_e}{r_r}$$

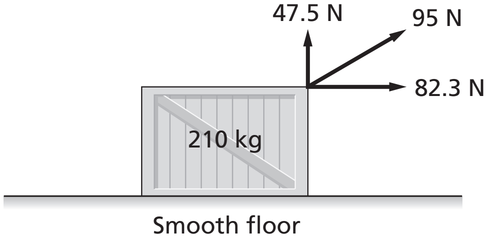
$$r_r = \frac{r_e d_r}{d_e} = \frac{(3.50 \text{ cm})(14.0 \text{ cm})}{0.95 \text{ cm}}$$

$$= 52 \text{ cm}$$

Chapter 11

page 872

1. A crate with a mass of 210 kg is horizontally accelerated by a force of 95 N. The force is directed at an upward angle so that the vertical part of the force is 47.5 N and the horizontal part of the force is 82.3 N (see the diagram below). If the crate is pulled 5.5 m across the floor, what is the change in kinetic energy of the crate?



$W = \Delta KE = Fd$

$= (82.3\ \text{N})(5.5\ \text{m})$

$= 4.5\times10^2\ \text{J}$

2. Assuming that the crate described in problem 1 was initially at rest, what is the final velocity of the crate?

$\Delta KE = KE_f - KE_i$

$KE_f = \frac{1}{2}mv_f^2$

$KE_i = \frac{1}{2}mv_i^2$

Since the crate was initially at rest, $KE_i = 0$.

So, $\Delta KE = KE_f = \frac{1}{2}mv_f^2$

$v_f = \sqrt{\frac{2\Delta KE}{m}} = \sqrt{\frac{(2)(4.5\times10^2\ \text{J})}{210\ \text{kg}}}$

$= 2.1\ \text{m/s}$

3. If the crate described in problem 1 experienced a frictional force of 15 N, what is the final kinetic energy of the crate?

Let the direction of the motion of the crate be positive.

$W = \Delta KE = Fd$

$F = F_H + F_f = 82.3\ \text{N} + (-15\ \text{N})$

$= 67\ \text{N}$

$\Delta KE = W = Fd = (67\ \text{N})(5.5\ \text{m})$

$= 3.7\times10^2\ \text{J}$

Since the crate was initially at rest,

$\Delta KE = KE_f$

$KE_f = 3.7\times10^2\ \text{J}$

4. A 150-kg roller-coaster car climbs to the top of a 91-m-high hill. How much work is done against gravity as the car is lifted to the top of the hill?

$W = Fd$

$F = mg$

$W = mgd$

$= (150\ \text{kg})(9.80\ \text{m/s}^2)(91\ \text{m})$

$= 1.3\times10^5\ \text{J}$

5. A pendulum bob with a mass of 0.50 kg swings to a maximum height of 1.0 m. What is the kinetic energy when the pendulum bob is at a height of 0.40 m?

$E_{tot} = KE + PE$

Since energy is conserved, the total energy is constant.

When the pendulum bob is at the top of the swing, $E_{tot} = PE$ at the top of the swing.

$PE = mgh = (0.50\ \text{kg})(9.80\ \text{m/s}^2)(1.0\ \text{m})$

$= 4.9\ \text{J}$

When the pendulum bob is at 0.40 m,

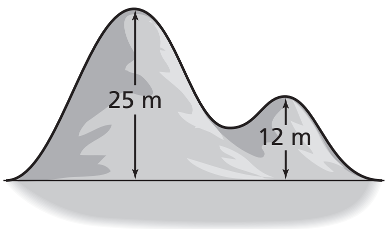
$PE = mgh = (0.50\ \text{kg})(9.80\ \text{m/s}^2)(0.40\ \text{m})$

$= 2.0\ \text{J}$

$KE = E_{tot} - PE = 4.9\ \text{J} - 2.0\ \text{J}$

$= 2.9\ \text{J}$

6. A sled and its rider, with a total mass of 95 kg, are perched on top of a 25-m-tall hill. A second hill is 12 m tall (see the diagram below). The rider is given an initial push providing 3674 J of kinetic energy. Neglecting friction, what is the velocity at the top of the top of the 12-m-tall hill?



$E = KE + PE$

At the top of the 25-m-high hill:

$KE = 3674\text{ J}$

$PE = mgh = (95\text{ kg})(9.80\text{ m/s}^2)(25\text{ m})$

$= 2.3\times10^4\text{ J}$

$E = KE + PE = 3674\text{ J} + 2.3\times10^4\text{ J}$

$= 2.7\times10^4\text{ J}$

At the top of the 12-m-high hill:

$PE = mgh = (95\text{ kg})(9.80\text{ m/s}^2)(12\text{ m})$

$= 1.1\times10^4\text{ J}$

$KE = E - PE = 2.7\times10^4\text{ J} - 1.1\times10^4\text{ J}$

$= 1.6\times10^4\text{ J}$

$v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{(2)(1.6\times10^4\text{ J})}{95\text{ kg}}}$

$= 18\text{ m/s}$

7. A 35-kg child is riding on a swing that rises to a maximum height of 0.80 m. Neglecting friction, what is the child's gravitational potential energy at the top of the swing? What is the child's kinetic energy at the top of the swing?

$PE = mgh = (35\text{ kg})(9.80\text{ m/s}^2)(0.80\text{ m})$

$= 2.7\times10^2\text{ J}$

When the swing is at its maximum height, the velocity is zero.

$KE = \frac{1}{2}mv^2 = 0\text{ J}$

8. A sled and its rider are perched at the top of a hill that is 35 m tall. If the gravitational potential energy is 3.0×10^4 J, what is the weight of the sled and rider?

$PE = mgh$

$F_g = mg$

$PE = F_g h$

$F_g = \frac{PE}{h} = \frac{3.0\times10^4\text{ J}}{35\text{ m}} = 8.6\times10^2\text{ N}$

9. The big hill on a roller-coaster ride is 91 m tall. If the mass of the roller-coaster car and its two riders is 314 kg and the maximum velocity reached by this roller-coaster ride is 28 m/s, how much energy was lost to friction?

At the top of the 91-m-high hill:

$E = PE = mgh$

$= (314\text{ kg})(9.80\text{ m/s}^2)(91\text{ m})$

$= 2.8\times10^5\text{ J}$

At the bottom of the hill:

$E = KE = \frac{1}{2}mv^2$

$v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{(2)(2.8\times10^5\text{ J})}{314\text{ kg}}}$

= 42 m/s if no energy is lost to friction

The actual *KE* at the bottom of the hill:

$KE = \frac{1}{2}mv^2 = \left(\frac{1}{2}\right)(314\text{ kg})(28\text{ m/s})^2$

$= 1.2\times10^5\text{ J}$

$E = KE + E_f$

$E_f = E - KE = 2.8\times10^5\text{ J} - 1.2\times10^5\text{ J}$

$= 1.6\times10^5\text{ J}$

10. A dartboard with a mass of 2.20 kg is suspended from the ceiling such that it is initially at rest. A 0.030-kg dart is thrown at the dartboard with a velocity of 1.3 m/s. After the dart hits the dartboard, the dart and the board initially move with a velocity of 0.025 m/s. How much kinetic energy is lost in the system?

$KE_i = \frac{1}{2}m_d v_d^2 = \left(\frac{1}{2}\right)(0.030\text{ kg})(1.3\text{ m/s})^2$

$= 2.5\times10^{-2}\text{ J}$

$KE_f = \left(\frac{1}{2}\right)(m_d + m_b)v_f^2$

$= \left(\frac{1}{2}\right)(0.030\text{ kg} + 2.20\text{ kg})(0.025\text{ m/s})^2$

$= 6.97\times10^{-4}\text{ J}$

$E_{lost} = KE_i - KE_f$

$= (2.5\times10^{-2}\ J) - (6.97\times10^{-4}\ J)$

$= 2.4\times10^{-2}\ J$

11. In a physics laboratory, students crash carts together on a frictionless track. According to the following data, was kinetic energy conserved?

	Mass (kg)	v_i (m/s)	v_f (m/s)
Cart A	0.25	0.18	−0.21
Cart B	0.36	−0.20	0.11

$KE_{iA} = \frac{1}{2}m_A v_{iA}^2$

$= \left(\frac{1}{2}\right)(0.25\ kg)(0.18\ m/s)^2$

$= 4.0\times10^{-3}\ J$

$KE_{iB} = \frac{1}{2}m_B v_{iB}^2$

$= \left(\frac{1}{2}\right)(0.36\ kg)(-0.20\ m/s)^2$

$= 7.2\times10^{-3}\ J$

$KE_{fA} = \frac{1}{2}m_A v_{fA}^2$

$= \left(\frac{1}{2}\right)(0.25\ kg)(-0.21\ m/s)^2$

$= 5.5\times10^{-3}\ J$

$KE_{fB} = \frac{1}{2}m_B v_{fB}^2$

$= \left(\frac{1}{2}\right)(0.36\ kg)(0.11\ m/s)^2$

$= 2.2\times10^{-3}\ J$

If *KE* is conserved:

$KE_i = KE_f$

$KE_i = KE_{iA} + KE_{iB}$

$= 4.0\times10^{-3}\ J + 7.2\times10^{-3}\ J$

$= 11.2\times10^{-3}\ J$

$KE_f = KE_{fA} + KE_{fB}$

$= 5.5\times10^{-3}\ J + 2.2\times10^{-3}\ J$

$= 7.7\times10^{-3}\ J$

***KE* is not conserved.**

12. A 0.150-kg ball that is thrown at a velocity of 30.0 m/s hits a wall and bounces back in the opposite direction with a speed of 25.0 m/s. How much work was done by the ball?

Conservation of energy:

$W_{ball} - \Delta KE = 0$

$W_{ball} = \Delta KE = KE_f - KE_i$

$KE_i = \frac{1}{2}mv_i^2 = \left(\frac{1}{2}\right)(0.150\ kg)(30.0\ m/s)^2$

$= 67.5\ J$

$KE_f = \frac{1}{2}mv_f^2 = \frac{1}{2}(0.150\ kg)(-25.0\ m/s)^2$

$= 46.9\ J$

$W_{ball} = KE_f - KE_i$

$= 46.9\ J - 67.5\ J$

$= -20.6\ J$

Chapter 12

pages 872–874

1. Convert the following Celsius temperatures to Kelvin temperatures.

   a. −196°C

   $T_K = T_C + 273 = -196 + 273 = 77\ K$

   b. 32°C

   $T_K = T_C + 273 = 32 + 273 = 305\ K$

   c. 212°C

   $T_K = T_C + 273 = 212 + 273 = 485\ K$

   d. −273°C

   $T_K = T_C + 273 = -273 + 273 = 0\ K$

   e. 273°C

   $T_K = T_C + 273 = 273 + 273 = 546\ K$

   f. 27°C

   $T_K = T_C + 273 = 27 + 273 = 300\ K$

2. Find the Celsius and the Kelvin temperatures for the following objects.

   a. average body temperature

   98.6°F is about 37°C, 310 K

   b. hot coffee

   about 70°C, 343 K

   c. iced tea

   about 0°C, 273 K

   d. boiling water

   100°C, 373 K

3. Convert the following Kelvin temperatures to Celsius temperatures.

   a. 4 K

   $T_C = T_K - 273 = 4 - 273 = -269°C$

   b. 25 K

   $T_C = T_K - 273 = 25 - 273 = -248°C$

   c. 272 K

   $T_C = T_K - 273 = 272 - 273 = -1°C$

   d. 373 K

   $T_C = T_K - 273 = 373 - 273 = 100°C$

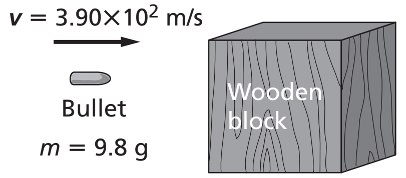
   e. 298 K

   $T_C = T_K - 273 = 298 - 273 = 25°C$

   f. 316 K

   $T_C = T_K - 273 = 316 - 273 = 43°C$

4. A 9.8-g lead bullet with a muzzle velocity of 3.90×10^2 m/s is stopped by a wooden block. What is the change in temperature of the bullet if one-fourth of its original kinetic energy goes into heating the bullet?



$$KE = \frac{1}{2}mv^2$$

and $\frac{1}{4}KE = Q = mC\Delta T$

$$\left(\frac{1}{4}\right)\left(\frac{1}{2}\right)mv^2 = mC\Delta T$$

$$\Delta T = \frac{\frac{1}{8}v^2}{C}$$

$$= \frac{\left(\frac{1}{8}\right)(3.90\times10^2\ \text{m/s})^2}{130\ \text{J/kg·K}}$$

$$= 1.5\times10^2\ \text{K}$$

5. What is the change in temperature of 2.2 kg of the following substances if 8.5×10^3 J of thermal energy is added to each of the substances?

   a. ice

   $$\Delta T = \frac{Q}{mC}$$

   $$= \frac{8.5\times10^3\ \text{J}}{(2.2\ \text{kg})(2060\ \text{J/kg·K})}$$

   $$= 1.9\ \text{K}$$

   b. water

   $$\Delta T = \frac{Q}{mC}$$

   $$= \frac{8.5\times10^3\ \text{J}}{(2.2\ \text{kg})(4180\ \text{J/kg·K})}$$

   $$= 0.92\ \text{K}$$

c. steam

$$\Delta T = \frac{Q}{mC}$$

$$= \frac{8.5\times10^3\ \text{J}}{(2.2\ \text{kg})(2020\ \text{J/kg·K})}$$

$$= 1.9\ \text{K}$$

d. aluminum

$$\Delta T = \frac{Q}{mC}$$

$$= \frac{8.5\times10^3\ \text{J}}{(2.2\ \text{kg})(897\ \text{J/kg·K})}$$

$$= 4.3\ \text{K}$$

e. silver

$$\Delta T = \frac{Q}{mC}$$

$$= \frac{8.5\times10^3\ \text{J}}{(2.2\ \text{kg})(235\ \text{J/kg·K})}$$

$$= 16\ \text{K}$$

f. copper

$$\Delta T = \frac{Q}{mC}$$

$$= \frac{8.5\times10^3\ \text{J}}{(2.2\ \text{kg})(300\ \text{J/kg·K})}$$

$$= 1.0\times10^1\ \text{K}$$

6. A 2350-kg granite tombstone absorbs 2.8×10^7 J of energy from the Sun to change its temperature from 5.0°C at night to 20.0°C during an autumn day. Determine the specific heat of granite from this information.

$$Q = mC\Delta T$$

$$C = \frac{Q}{m\Delta T} = \frac{2.8\times10^7\ \text{J}}{(2350\ \text{kg})(20.0°\text{C} - 5.0°\text{C})} = 7.9\times10^2\ \text{J/kg·K}$$

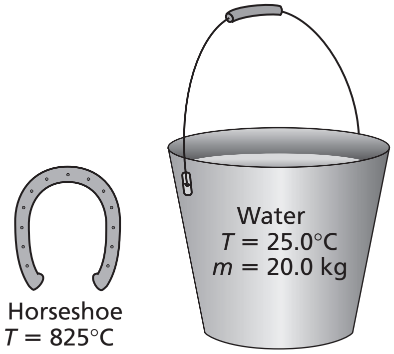
7. A 2.00×10^3-g sample of water at 100.0°C is mixed with a 4.00×10^3-g sample of water at 0.0°C in a calorimeter. What is the equilibrium temperature of the mixture?

$$m_A C_A(T_f - T_{Ai}) + m_B C_B(T_f - T_{Bi}) = 0$$

Since $C_A = C_B$ in this case, the specific heat cancels out.

$$T_f = \frac{m_A T_{Ai} + m_B T_{Bi}}{m_A + m_B} = \frac{(2.00\ \text{kg})(100.0°\text{C}) + (4.00\ \text{kg})(0.0°\text{C})}{2.00\ \text{kg} + 4.00\ \text{kg}} = 33°\text{C}$$

8. A 220-g iron horseshoe is heated to 825°C and then plunged into a bucket filled with 20.0 kg of water at 25.0°C. Assuming that no energy is transferred to the surroundings, what is the final temperature of the water at equilibrium?

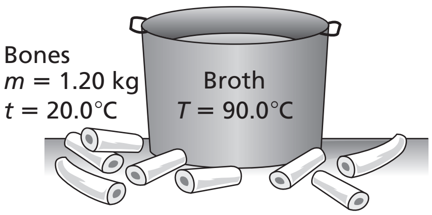


$$\mathbf{m_A C_A (T_f - T_{Ai}) + m_B C_B (T_f - T_{Bi}) = 0}$$

$$\mathbf{T_f = \frac{m_A C_A T_{Ai} + m_B C_B T_{Bi}}{m_A C_A + m_B C_B}}$$

$$\mathbf{= \frac{(0.22\ kg)(450\ J/kg{\cdot}K)(825°C) + (20.0\ kg)(4180\ J/kg{\cdot}K)(25.0°C)}{(0.22\ kg)(450\ J/kg{\cdot}K) + (20.0\ kg)(4180\ J/kg{\cdot}°K)} = 26°C}$$

9. A cook adds 1.20 kg of soup bones to 12.5 kg of hot broth for flavoring. The temperatures of the bones and the broth are 20.0°C and 90.0°C, respectively. Assume that the specific heat of the broth is the same as that of water. Also assume that no heat is lost to the environment. If the equilibrium temperature is 87.2°C, what is the specific heat of the bones?



$$\mathbf{m_A C_A (T_f - T_{Ai}) + m_B C_B (T_f - T_{Bi}) = 0}$$

$$\mathbf{C_A = -\frac{m_B C_B (T_f - T_{Bi})}{m_A (T_f - T_{Ai})}}$$

$$\mathbf{= -\frac{(12.5\ kg)(4180\ J/kg{\cdot}K)(87.2°C - 90.0°C)}{(1.20\ kg)(87.2°C - 20.0°C)}}$$

$$\mathbf{= 1.81{\times}10^3\ J/kg{\cdot}K}$$

10. A 150.0-g copper cylinder at 425°C is placed on a large block of ice at 0.00°C. Assume that no energy is transferred to the surroundings. What is the mass of the ice that will melt?

The energy for melting the ice comes from the cooling of the copper.

$$\mathbf{Q = mC\Delta T}$$

This quantity of energy is available to melt the ice, so

$$\mathbf{Q = m_{ice} H_f}$$

$$\mathbf{m_{ice} = \frac{Q}{H_f} = \frac{mC\Delta T}{H_f}}$$

$$\mathbf{= \frac{(0.1500\ kg)(385\ J/kg{\cdot}°C)(425°C - 0.00°C)}{3.34{\times}10^5\ J/kg}}$$

$$\mathbf{= 0.0735\ kg\ of\ ice}$$

11. How much energy is needed to melt one troy ounce, 31.1 g, of gold at its melting point?

$$Q = mH_f$$
$$= (0.0311\text{ kg})(6.30\times10^4\text{ J/kg})$$
$$= 1.96\times10^3\text{ J}$$

12. Trying to make an interesting pattern, an artist slowly pours 1.00 cm^3 of liquid gold onto a large block of ice at 0.00°C. While being poured, the liquid gold is at its melting point of 1064°C. The density of gold is 19.3 g/cm^3, and its specific heat is 128 J/kg·K. What mass of ice will melt after all the gold cools to 0.00°C?

The energy to melt the ice comes from the energy released when the gold solidifies and then released as the gold cools from its melting temperature to 0.00°C.

$$Q_{tot} = Q_{solidification} + Q_{cooling}$$
$$Q_{solidification} = mH_f$$
$$= (0.0193\text{ kg/cm}^3)(1.00\text{ cm}^3)(6.30\times10^4\text{ J/kg})$$
$$= 1216\text{ J}$$
$$Q_{cooling} = mC\Delta T$$
$$= (0.0193\text{ kg/cm}^3)(1.00\text{ cm}^3)(128\text{ J/kg·°C})(1064\text{°C} - 0.00\text{ °C})$$
$$= 2628\text{ J}$$
$$Q_{tot} = 1216\text{ J} + 2628\text{ J} = 3844\text{ J}$$
$$Q_{ice} = mH_f$$
$$m = \frac{Q_{ice}}{H_f}$$
$$= \frac{3844\text{ J}}{3.34\times10^5\text{ J/kg}} = 1.15\times10^{-2}\text{ kg}$$

13. A cylinder containing 1.00 g of water at the boiling point is heated until all the water turns into steam. The expanding steam pushes a piston 0.365 m. There is a 215-N frictional force acting against the piston. What is the change in the thermal energy of the water?

$$\Delta U = Q - W$$
$$Q = mH_v$$
$$= (1.00\times10^{-3}\text{ kg})(2.26\times10^6\text{ J/kg})$$
$$= 2.26\times10^3\text{ J}$$
$$W = Fd = (215\text{ N})(0.365\text{ m}) = 78.5\text{ J}$$
$$\Delta U = Q - W$$
$$= 2.26\times10^3\text{ J} - 78.5\text{ J}$$
$$= 2.18\times10^3\text{ J}$$

14. What is the change in temperature of water after falling over a 50.0-m-tall waterfall? Assume that the water is at rest just before falling off and just after it reaches the bottom of the falls.

$$\Delta U = Q - W$$
$$\Delta U = 0 \text{ and } W = \Delta KE = PE = mgh$$
$$Q = mC\Delta T$$
Thus, $mC\Delta T = mgh$
$$\Delta T = \frac{gh}{C} = \frac{(9.80\text{ m/s}^2)(50.0\text{ m})}{4180\text{ J/kg·K}}$$
$$= 0.117\text{ K}$$

15. Two 6.35-kg lead bricks are rubbed against each other until their temperature rises by 1.50 K. How much work was done on the bricks?

$$\Delta U = Q - W \text{ and } \Delta U = 0$$
$$W = Q = mC\Delta T$$
$$= (12.70\text{ kg})(130\text{ J/kg})(1.50\text{ K})$$
$$= 2500\text{ J}$$

Chapter 13

pages 874–875

1. Use Table 13.1 to estimate the pressure in atmospheres (atm) on a climber standing atop Mt. Everest. Is this more or less than half standard atmospheric pressure (1.0 atm)?

$$(3\times10^4\ \text{Pa})\left(\frac{1.0\ \text{atm}}{1.0\times10^5\ \text{Pa}}\right) = 0.3\ \text{atm}$$

This is less than half of standard atmospheric pressure.

2. A woman wearing high heels briefly supports all her weight on the heels. If her mass is 45 kg and each heel has an area of 1.2 cm^2, what pressure does she exert on the floor?

$$P = \frac{F}{A}$$

$$= \frac{mg}{A}$$

$$= \left(\frac{(45\ \text{kg})(9.80\ \text{m/s}^2)}{(2)(1.2\ \text{cm}^2)}\right)\left(\frac{100\ \text{cm}}{1\ \text{m}}\right)^2$$

$$= 1.8\times10^3\ \text{kPa}$$

3. A typical brick has dimensions of 20.0 cm × 10.0 cm × 5.0 cm and weighs 20.0 N. How does the pressure exerted by a typical brick when it is resting on its smallest side compare to the pressure exerted when it is resting on its largest side?

$$p_{small} = \frac{F}{A_{small}}$$

$$= \left(\frac{20.0\ \text{N}}{(10.0\ \text{cm})(5.0\ \text{cm})}\right)\left(\frac{100\ \text{cm}}{1\ \text{m}}\right)^2$$

$$= 4.0\times10^3\ \text{Pa}$$

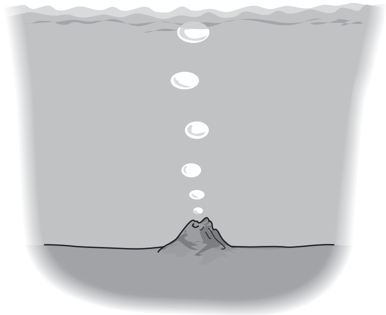
$$p_{large} = \frac{F}{A_{large}}$$

$$= \left(\frac{20.0\ \text{N}}{(20.0\ \text{cm})(10.0\ \text{cm})}\right)\left(\frac{100\ \text{cm}}{1\ \text{m}}\right)^2$$

$$= 1.00\times10^3\ \text{Pa}$$

The pressure is four times as large when the brick rests on its smallest side.

4. As shown in the figure below, a bubble of gas with a volume of 1.20 cm^3 is released under water. As it rises to the surface, the temperature of the bubble increases from 27°C to 54°C, and the pressure is cut to one-third of its initial value. What is the volume of the bubble at the surface?



$$T_1 = 27 + 273 = 300\ \text{K}$$

$$T_2 = 54 + 273 = 327\ \text{K}$$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$V_2 = \frac{P_1V_1T_2}{T_1P_2}$$

$$= \frac{P_1(1.20\ \text{cm}^3)(327\ \text{K})}{(300\ \text{K})\left(\frac{1}{3}\right)P_1}$$

$$= 3.9\ \text{cm}^3$$

5. A sample of ethane gas (molar mass = 30.1 g/mol) occupies 1.2×10^{-2} m^3 at 46°C and 2.4×10^5 Pa. How many moles of ethane are present in the sample? What is the mass of the sample?

$$n = \frac{PV}{RT}$$

$$= \frac{(2.4\times10^5\ \text{Pa})(1.2\times10^{-2}\ \text{m}^3)}{(8.31\ \text{Pa·m}^3/\text{mol·K})(319\ \text{K})}$$

$$= 1.1\ \text{mol of ethane}$$

$$m = Mn$$

$$= (30.1\ \text{g/mol})(1.1\ \text{mol})$$

$$= 33\ \text{g}$$

6. The constant R equals 8.31 Pa·m^3/mol·K as it is presented in the ideal gas law in this chapter. One mole of an ideal gas occupies 22.4 L at standard temperature and pressure, STP, which is defined as 0.00°C and 1.00 atm. Given this information, deduce the value of R in L·atm/mol·K.

$$R = \frac{PV}{nT}$$

$$= \frac{(1.00\text{ atm})(22.4\text{ L})}{(1\text{ mol})(273\text{ K})}$$

$$= 0.0821\text{ L·atm/mol·K}$$

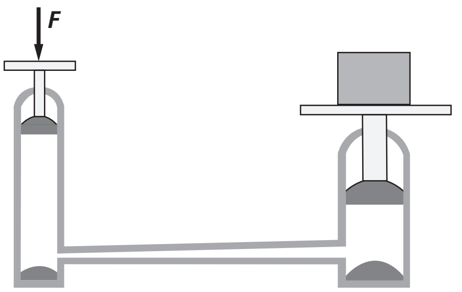
7. Suppose that two linked pistons are both cylindrical in shape. Show that the ratio of forces generated is directly proportional to the square of the radii of the two cross-sectional circular areas.

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

$$\frac{F_1}{\pi r_1^2} = \frac{F_2}{\pi r_2^2}$$

$$\frac{F_1}{F_2} = \frac{r_1^2}{r_2^2}\text{, a direct proportion}$$

8. The cross-sectional areas of the pistons in the system shown below have a ratio of 25 to 1. If the maximum force that can be applied to the small piston is 12 N, what is the maximum weight that can be lifted?



$$F_1 = \frac{F_2 A_1}{A_2}$$

$$= \frac{(12\text{ N})(25)}{1}$$

$$= 3.0\times10^2\text{ N}$$

9. A car of mass 1.35×10^3 kg sits on a large piston that has a surface area of 1.23 m^2. The large piston is linked to a small piston of area 144 cm^2. What is the weight of the car? What force must a mechanic exert on the small piston to raise the car?

$$F_g = mg = (1.35\times10^3\text{ kg})(9.80\text{ m/s}^2)$$

$$= 1.32\times10^4\text{ N}$$

$$F_2 = \frac{F_1 A_2}{A_1}$$

$$= \frac{mgA_2}{A_1}$$

$$= \frac{(1.35\times10^3\text{ kg})(9.80\text{ m/s}^2)(1.44\times10^{-2}\text{ m}^2)}{1.23\text{ m}^2}$$

$$= 155\text{ N}$$

10. At what depth in freshwater does the water exert a pressure of 1.00 atm (1 atm = 1.013×10^5 Pa) on a scuba diver?

$$P = \rho g h$$

$$h = \frac{P}{\rho g}$$

$$= \frac{1.013\times10^5\ \text{N/m}^2}{(1.00\times10^3\ \text{kg/m}^3)(9.80\ \text{m/s}^2)}$$

$$= 10.3\ \text{m}$$

11. An iceberg floats in seawater, partly under water and partly exposed. Show that the value of $V_{submerged}/V_{total}$ equals $\rho_{ice}/\rho_{seawater}$. What percentage of the iceberg is exposed? Use 1.03×10^3 kg/m^3 for the density of seawater, and 0.92×10^3 kg/m^3 for the density of ice.

Because the ice floats,

$$F_{buoyant} = F_g$$

$$\rho_{seawater}V_{submerged}g = \rho_{ice}V_{total}g$$

$$\frac{V_{submerged}}{V_{total}} = \frac{\rho_{ice}}{\rho_{seawater}}$$

This is a general result for floating solids.

$$\frac{\rho_{ice}}{\rho_{seawater}} = \frac{0.92\times10^3\ \text{kg/m}^3}{1.03\times10^3\ \text{kg/m}^3}$$

$$= 0.89$$

So, 89 percent is submerged and 11 percent is exposed.

12. A concrete block ($\beta = 36\times10^{-6}{}^\circ\text{C}^{-1}$) of volume 0.035 m^3 at 30.0°C is cooled to −10.0°C. What is the change in volume?

$$\Delta V = \beta V \Delta T$$

$$= (36\times10^{-6}{}^\circ\text{C}^{-1})(0.035\ \text{m}^3)(-10.0^\circ\text{C} - 30.0^\circ\text{C})$$

$$= -5.0\times10^{-5}\ \text{m}^3$$

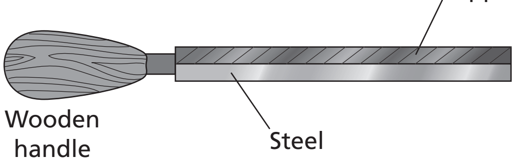
13. A glass mirror used in a mountaintop telescope is subject to temperatures ranging from −15°C to 45°C. At the lowest temperature, it has a diameter of 5.1 m. If the coefficient of linear expansion for this glass is $3.0\times10^{-6}{}^\circ\text{C}^{-1}$, what is the maximum change in diameter the mirror undergoes due to thermal expansion?

$$\Delta L = \alpha L \Delta T$$

$$= (3.0\times10^{-6}{}^\circ\text{C}^{-1})(5.1\ \text{m})(45^\circ\text{C} - (-15^\circ\text{C}))$$

$$= 9.2\times10^{-4}\ \text{m}$$

14. As shown in the figure below, a bimetallic strip is made from a piece of copper ($\alpha = 16\times10^{-6}{}^\circ\text{C}^{-1}$) and a piece of steel ($\alpha = 8\times10^{-6}{}^\circ\text{C}^{-1}$). The two pieces are equal in length at room temperature.



a. As the strip is heated from room temperature, what is the ratio of the change in the length of the copper to that of the steel?

$$\frac{\Delta L_{copper}}{\Delta L_{steel}} = \frac{\alpha_{copper}L_1\Delta T}{\alpha_{steel}L_1\Delta T}$$

$$= \frac{\alpha_{copper}}{\alpha_{steel}}$$

$$= \frac{16\times10^{-6}{}^\circ\text{C}^{-1}}{8\times10^{-6}{}^\circ\text{C}^{-1}}$$

$$= \frac{2}{1}$$

b. How will the strip bend when it is heated above room temperature? When it is cooled below room temperature?

When heated, it bends with copper on the outside of the arc. When it is cooled, the copper will be on the inside of the bend.

15. A fishing line's lead sinker has a volume of 1.40×10^{-5} m^3. The density of lead is 1.2×10^4 kg/m^3. What is the apparent weight of the sinker when immersed in freshwater? Seawater is slightly denser than freshwater. Is the sinker's apparent weight bigger or smaller in seawater? Explain.

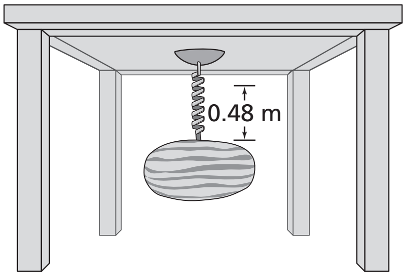
$$F_{apparent} = F_g - F_{buoyant}$$
$$= \rho_{lead}gV - \rho_{water}gV$$
$$= gV(\rho_{lead} - \rho_{water})$$
$$= (9.80\ \text{m/s}^2)(1.40\times10^{-5}\ \text{m}^3)(1.2\times10^4\ \text{kg/m}^3 - 1.00\times10^3\ \text{kg/m}^3)$$
$$= 1.5\ \text{N}$$

The buoyant force is slightly bigger in seawater, due to its greater density. Thus, the apparent weight is slightly smaller than in freshwater.

Chapter 14

pages 875–876

1. What is the mass of the watermelon shown below, if the spring constant is 128 N/m?



$$F = kx = mg$$
$$m = \frac{kx}{g} = \frac{(128\ \text{N/m})(0.48\ \text{m})}{9.80\ \text{m/s}^2}$$
$$= 6.3\ \text{kg}$$

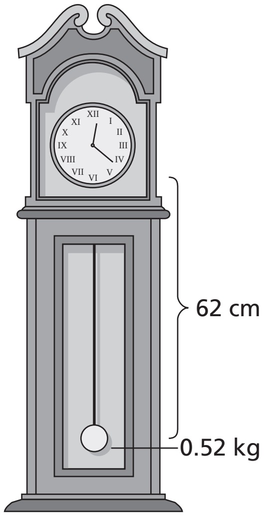
2. How many centimeters will a spring stretch when a 2.6-kg block is hung vertically from a spring with a spring constant of 89 N/m?

$$F = kx = mg$$
$$x = \frac{mg}{k} = \frac{(2.6\ \text{kg})(9.80\ \text{m/s}^2)}{89\ \text{N/m}}$$
$$= 0.29\ \text{m or 29 cm}$$

3. How much elastic potential energy does a spring with a constant of 54 N/m have when it is stretched 18 cm?

$$PE_{sp} = \frac{1}{2}kx^2 = \left(\frac{1}{2}\right)(54\ \text{N/m})(0.18\ \text{m})^2$$
$$= 0.87\ \text{J}$$

4. What is the period of the pendulum of the clock below?



$$T = 2\pi\sqrt{\frac{l}{g}}$$
$$= 2\pi\sqrt{\frac{0.62\ \text{m}}{9.80\ \text{m/s}^2}}$$
$$= 1.6\ \text{s}$$

5. A clock pendulum has a period of 0.95 s. How much longer will it have to be to have a period of 1.0 s?

$$T = 2\pi\sqrt{\frac{l}{g}}$$

$$l = \frac{gT^2}{4\pi^2}$$

$$l_2 - l_1 = \frac{g}{4\pi^2}(T_2{}^2 - T_1{}^2)$$

$$= \left(\frac{9.80\ \text{m/s}^2}{4\pi^2}\right)((1.0\ \text{s})^2 - (0.95\ \text{s})^2)$$

$$= 0.024\ \text{m} = 2.4\ \text{cm}$$

The pendulum will have to be 2.4 cm longer.

6. What is the length of a pendulum with a period of 89.4 ms?

$$T = 2\pi\sqrt{\frac{l}{g}}$$

$$l = \frac{gT^2}{4\pi^2} = \frac{(9.80\ \text{m/s}^2)(89.4\times10^{-3}\ \text{s})^2}{4\pi^2}$$

$$= 1.98\times10^{-3}\ \text{m} = 1.98\ \text{mm}$$

7. Al is chopping wood across a clearing from Su. Su sees the axe come down and hears the sound of the impact 1.5 s later. How wide is the clearing?

$$d = vt$$

$$= (343\ \text{m/s})(1.5\ \text{s}) = 5.1\times10^2\ \text{m}$$

8. When an orchestra is tuning up, the first violinist plays a note at 256 Hz.

a. What is the wavelength of that sound wave if the speed of sound in the concert hall is 340 m/s?

$$\lambda = \frac{v}{f} = \frac{340\ \text{m/s}}{256\ \text{Hz}} = 1.3\ \text{m}$$

b. What is the period of the wave?

$$T = \frac{1}{f} = \frac{1}{256\ \text{Hz}}$$

$$= 0.00391\ \text{s or } 3.91\ \text{ms}$$

9. Geo is standing on a breakwater and he notices that one wave goes by every 4.2 s. The distance between crests is 12.3 m.

a. What is the frequency of the wave?

$$f = \frac{1}{T} = \frac{1}{4.2\ \text{s}} = 0.24\ \text{Hz}$$

b. What is the speed of the wave?

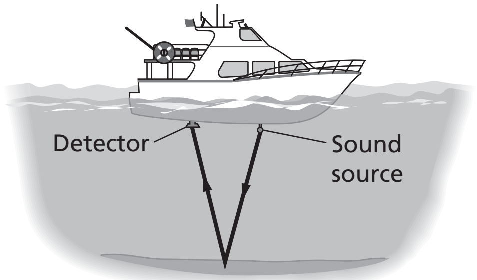
$$v = \lambda f = \lambda\left(\frac{1}{T}\right) = (12.3\ \text{m})\left(\frac{1}{4.2\ \text{s}}\right)$$

$$= 2.9\ \text{m/s}$$

Chapter 15

page 876

1. Sound waves are being used to determine the depth of a freshwater lake, as shown in the figure below. If the water is 25°C and it takes 1.2 s for the echo to return to the sensor, how deep is the lake?



$$\textbf{depth} = vt = (1493\ \text{m/s})\left(\frac{1.2\ \text{s}}{2}\right)$$

$$= 9.0\times10^{2}\ \text{m}$$

2. Find the wavelength of an 8300-Hz wave in copper.

$$\lambda = \frac{v}{f}$$

$$= \frac{3560\ \text{m/s}}{8300\ \text{Hz}}$$

$$= 0.43\ \text{m}$$

3. Janet is standing 58.2 m from Ninovan. If Ninovan shouts, how long will it take Janet to hear her? Use 343 m/s for the speed of sound.

$$t = \frac{d}{v} = \frac{58.2\ \text{m}}{343\ \text{m/s}}$$

$$= 0.170\ \text{s}$$

4. The engine on a motorcycle hums at 85 Hz. If the motorcycle travels toward a resting observer at a velocity of 29.6 m/s, what frequency does the observer hear? Use 343 m/s for the speed of sound.

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right) \text{ and } v_d = 0, \text{ so}$$

$$f_d = f_s\left(\frac{1}{1 - \frac{v_s}{v}}\right)$$

$$= (85\ \text{Hz})\left(\frac{1}{1 - \frac{29.6\ \text{m/s}}{343\ \text{m/s}}}\right)$$

$$= 93\ \text{Hz}$$

5. If the speed of a wave on a 78-cm-long guitar string is known to be 370 m/s, what is the fundamental frequency?

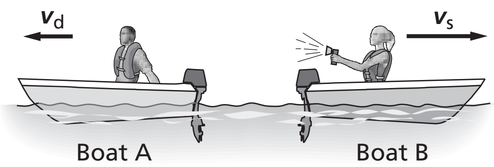
$$\lambda_1 = 2L = (2)(0.78\ \text{m}) = 1.56\ \text{m}$$

$$f_1 = \frac{v}{2L}$$

$$= \frac{370\ \text{m/s}}{1.56\ \text{m}}$$

$$= 240\ \text{Hz}$$

6. Boat A is traveling at 4.6 m/s. Boat B is moving away from boat A at 9.2 m/s, as shown in the figure below. The captain of boat B blows an air horn with a frequency of 550 Hz. What frequency does boat A hear? Use 343 m/s for the speed of sound.



$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right)$$

$$= (550\ \text{Hz})\left(\frac{343\ \text{m/s} - 4.6\ \text{m/s}}{343\ \text{m/s} - (-9.2\ \text{m/s})}\right)$$

$$= 5.3\times10^{2}\ \text{Hz}$$

7. A submarine is traveling toward a stationary detector. If the submarine emits a 260-Hz sound that is received by the detector as a 262-Hz sound, how fast is the submarine traveling? Use 1533 m/s for the speed of sound in seawater.

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right) \text{ and } v_d = 0, \text{ so}$$

$$v - v_s = \frac{f_s v}{f_d}$$

$$v_s = v\left(1 - \frac{f_s}{f_d}\right)$$

$$= (1533\ \text{m/s})\left(1 - \frac{260\ \text{Hz}}{262\ \text{Hz}}\right)$$

$$= 12\ \text{m/s}$$

8. The end of a pipe is inserted into water. A tuning fork is held over the pipe. If the pipe resonates at lengths of 15 cm and 35 cm, what is the frequency of the tuning fork? Use 343 m/s for the speed of sound.

closed pipe:

$$\lambda = 2(L_B - L_A)$$

$$= (2)(0.35\text{ m} - 0.15\text{ m}) = 0.40\text{ m}$$

$$f = \frac{v}{\lambda} = \frac{343\text{ m/s}}{0.40\text{ m}}$$

$$= 8.6\times10^2\text{ Hz}$$

9. A 350-Hz tuning fork is held over the end of a pipe that is inserted into water. What is the spacing between the resonance lengths of the pipe if the speed of sound is 348 m/s?

$\lambda = \frac{v}{f}$ **and**

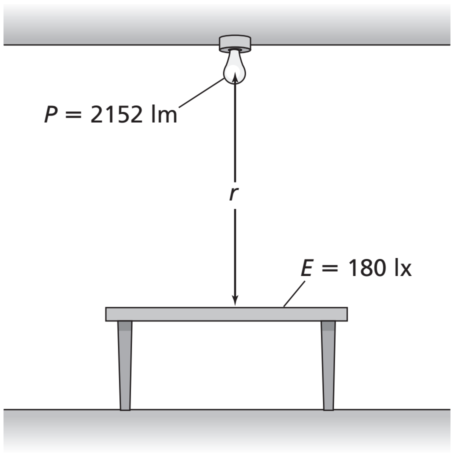
$L_B - L_A = \frac{\lambda}{2}$ **for a closed pipe, so**

$$L_B - L_A = \frac{v}{2f} = \frac{348\text{ m/s}}{(2)(350\text{ Hz})} = 0.50\text{ m}$$

Chapter 16

pages 876–877

1. What is the distance, *r*, between the lightbulb and the table in the figure below?



$$E = \frac{P}{4\pi r^2}$$

$$r = \sqrt{\frac{P}{4\pi E}} = \sqrt{\frac{2152\text{ lm}}{4\pi(180\text{ lx})}} = 0.98\text{ m}$$

2. What is the luminous flux of a flashlight that provides an illuminance of 145 lx to the surface of water when held 0.50 m above the water?

$$E = \frac{P}{4\pi r^2}$$

$$P = 4\pi r^2 E = 4\pi(0.50\text{ m})^2(145\text{ lx})$$

$$= 4.6\times10^2\text{ lm}$$

3. An overhead light fixture holds three lightbulbs. Each lightbulb has a luminous flux of 1892 lm. The light fixture is 1.8 m above the floor. What is the illuminance on the floor?

$$E = \frac{P}{4\pi r^2} = \frac{(3)(1892\text{ lm})}{4\pi(1.8\text{ m})^2} = 1.4\times10^2\text{ lx}$$

4. What is the wavelength in air of light that has a frequency of 4.6×10^{14} Hz?

$$\lambda = \frac{c}{f} = \frac{3.00\times10^8\text{ m/s}}{4.6\times10^{14}\text{ Hz}}$$

$$= 6.5\times10^{-7}\text{ m} = 650\text{ nm}$$

5. A helium atom is in a galaxy traveling at a speed of 4.89×10^6 m/s away from the Earth. An astronomer on Earth observes a frequency from the helium atom of 6.52×10^{14} Hz. What frequency of light is emitted from the helium atom?

$$f_{obs} = f\left(1 \pm \frac{v}{c}\right)$$

They are moving away from each other so use the plus form.

$$f = f_{obs}\left(1 + \frac{v}{c}\right)$$

$$= (6.52\times10^{14}\ \text{Hz})\left(1 + \frac{4.89\times10^6\ \text{m/s}}{3.00\times10^8\ \text{m/s}}\right)$$

$$= 6.63\times10^{14}\ \text{Hz}$$

6. An astronomer observes that a molecule in a galaxy traveling toward Earth emits light with a wavelength of 514 nm. The astronomer identifies the molecule as one that actually emits light with a wavelength of 525 nm. At what velocity is the galaxy moving?

$$\Delta\lambda = \lambda_{obs} - \lambda$$

$$= 5.14\times10^{-7}\ \text{m} - 5.25\times10^{-7}\ \text{m}$$

$$\Delta\lambda = -\frac{v}{c}\lambda$$

$$v = -c\left(\frac{\Delta\lambda}{\lambda}\right)$$

$$= -(3.00\times10^8\ \text{m/s})\left(\frac{5.14\times10^{-7}\ \text{m} - 5.25\times10^{-7}\ \text{m}}{5.25\times10^{-7}\ \text{m}}\right)$$

$$= 6.29\times10^6\ \text{m/s}$$

Chapter 17

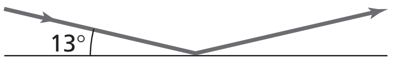
page 877

1. A light ray is reflected off a plane mirror at an angle of 25° from the normal. A light ray from another source is reflected 54° from the normal. What is the difference in the angles of incidence for the two light sources?

Difference = 54° − 25°

= 29°

2. A light ray is reflected off a plane mirror, as shown. What is the angle of reflection?



$$\theta_i = 90° - \text{angle to mirror}$$

$$= 90° - 13° = 77°$$

$$\theta_r = \theta_i$$

$$= 77°$$

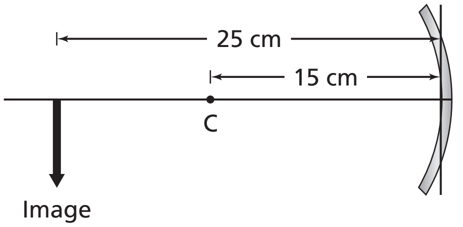
3. The angle between an incident and a reflected ray is 70.0°. What is the angle of reflection?

$$\theta_r = \theta_i$$

$$= \frac{70.0°}{2}$$

$$= 35.0°$$

4. An image is produced by a concave mirror, as shown. What is the object's position?



$$f = \frac{r}{2}$$

$$= \frac{15\ \text{cm}}{2}$$

$$= 7.5\ \text{cm}$$

$d_o = \frac{fd_i}{d_i - f}$

$= \frac{(7.5\text{ cm})(25\text{ cm})}{25\text{ cm} - 7.5\text{ cm}}$

$= 1.0\times10^1\text{ cm}$

5. What is the magnification of the object in problem 4?

$m = \frac{-d_i}{d_o}$

$= \frac{-25\text{ cm}}{11\text{ cm}}$

$= -2.3$

6. If the object in problem 4 is 3.5 cm tall, how tall is the image?

$m = \frac{h_i}{h_o}$

$h_i = mh_o$

$= (-2.3)(3.5\text{ cm})$

$= -8.2\text{ cm}$

The image is 8.2 cm tall. The negative sign means it is inverted.

7. A 6.2-m-tall object is 2.3 m from a convex mirror with a −0.8-m focal length. What is the magnification?

$d_i = \frac{fd_o}{d_o - f}$

$= \frac{(-0.8\text{ m})(2.3\text{ m})}{2.3\text{ m} - (-0.8\text{ m})}$

$= -0.6\text{ m}$

$m = \frac{-d_i}{d_o}$

$= \frac{-(-0.6\text{ m})}{2.3\text{ m}}$

$= 0.3$

8. How tall is the image in problem 7?

$m = \frac{h_i}{h_o}$

$h_i = mh_o$

$= (0.3)(6.2\text{ m})$

$= 2\text{ m}$

9. A ball is 6.5 m from a convex mirror with a magnification of 0.75. If the image is 0.25 m in diameter, what is the diameter of the actual ball?

$m = \frac{h_i}{h_o}$

The variable *h* can be used for any dimension in plane and spherical mirrors. In this problem, h_o = diameter of the ball.

$h_o = \frac{h_i}{m}$

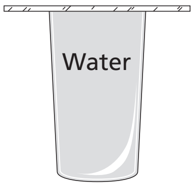
$= \frac{0.25\text{ m}}{0.75}$

$= 0.33\text{ m}$

Chapter 18

pages 877–878

1. A piece of flint glass is lying on top of a container of water (see figure below). When a red beam of light in air is incident upon the flint glass at an angle of 28°, what is the angle of refraction in the flint glass?



$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin \theta_1}{n_2}\right)$$

$$= \sin^{-1}\left(\frac{(1.0003)(\sin 28°)}{1.62}\right) = 17°$$

2. When the angle of refraction in the flint glass of problem 1 is 22°, what is the angle of refraction in the water?

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin \theta_1}{n_2}\right)$$

$$= \sin^{-1}\left(\frac{(1.62)(\sin 22°)}{1.33}\right) = 27°$$

3. When the beam of light in problem 1 enters the flint glass from the water, what is the maximum angle of incidence in the water such that light will transmit into the air above the flint glass? *Hint: Use an angle of refraction of the light beam in air that is almost 90°.*

This will occur when the angle of refraction of the light beam in the air is almost 90°. Use $\theta_2 = 89.9°$.

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

At the flint glass and air boundary:

$$\theta_1 = \sin^{-1}\left(\frac{n_2 \sin \theta_2}{n_1}\right)$$

$$= \sin^{-1}\left(\frac{(1.0003)(\sin 89.9°)}{1.62}\right) = 38.1°$$

At the water and flint glass boundary:

$$\theta_1 = \sin^{-1}\left(\frac{n_2 \sin \theta_2}{n_1}\right)$$

$$= \sin^{-1}\left(\frac{(1.62)(\sin 38.1°)}{1.33}\right) = 48.7°$$

4. An object that is 24 cm from a convex lens produces a real image that is 13 cm from the lens. What is the focal length of the lens?

$$f = \frac{d_i d_o}{d_i + d_o} = \frac{(13\text{ cm})(24\text{ cm})}{13\text{ cm} + 24\text{ cm}}$$

$$= 8.4\text{ cm}$$

5. A 5.0-cm-tall object is placed 16 cm from a convex lens with a focal length of 8.4 cm. What are the image height and orientation?

$$d_i = \frac{f d_o}{d_o - f} = \frac{(8.4\text{ cm})(16\text{ cm})}{16\text{ cm} - 8.4\text{ cm}}$$

$$= 17.7\text{ cm}$$

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o} = \frac{-(17.7\text{ cm})(5.0\text{ cm})}{16\text{ cm}}$$

$$= -5.5\text{ cm}$$

The image is inverted relative to the object.

6. An object is 185 cm from a convex lens with a focal length of 25 cm. When an inverted image is 12 cm tall, how tall is the associated object?

$$d_i = \frac{f d_o}{d_o - f} = \frac{(25\text{ cm})(185\text{ cm})}{185\text{ cm} - 25\text{ cm}}$$

$$= 29\text{ cm}$$

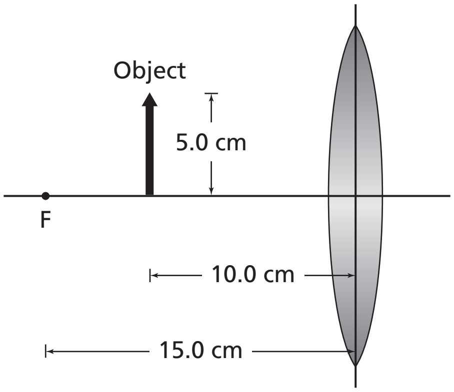
$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_o = \frac{-d_o h_i}{d_i} = \frac{-(185\text{ cm})(-12\text{ cm})}{29\text{ cm}}$$

$$= 77\text{ cm}$$

The object is 77 cm tall.

7. What are the image height and orientation produced by the setup in the following figure?



$$d_i = \frac{fd_o}{d_o - f} = \frac{(15.0\text{ cm})(10.0\text{ cm})}{10.0\text{ cm} - 15.0\text{ cm}}$$

$$= -3.0\times10^1\text{ cm}$$

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o} = \frac{-(-3.0\times10^1\text{ cm})}{10.0\text{ cm}}$$

$$= 15\text{ cm}$$

The image is upright relative to the object.

8. A convex lens can be used as a magnifying glass. When an object that is 15.0 cm from the lens has an image that is exactly 55 times the size of the object, what is the focal length of the lens?

$$m = \frac{-d_i}{d_o}$$

$$d_i = -md_o = -(55)(15.0\text{ cm})$$

$$= -825\text{ cm}$$

$$f = \frac{d_i d_o}{d_i + d_o}$$

$$= \frac{(-825\text{ cm})(15.0\text{ cm})}{(-825\text{ cm}) + (15.0\text{ cm})}$$

$$= 15.3\text{ cm}$$

9. A concave lens with a focal length of −220 cm produces a virtual image that is 36 cm tall. When the object is placed 128 cm from the lens, what is the magnification?

$$d_i = \frac{fd_o}{d_o - f} = \frac{(-220\text{ cm})(128\text{ cm})}{128\text{ cm} - (-220\text{ cm})}$$

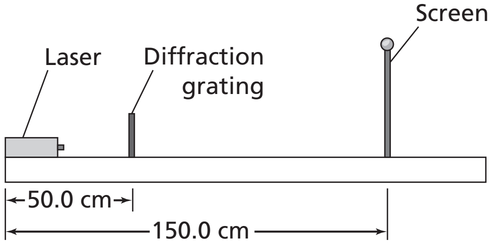
$$= -81\text{ cm}$$

$$m = \frac{-d_i}{d_o} = \frac{-(-81\text{ cm})}{128\text{ cm}} = 0.63$$

Chapter 19

pages 878–879

1. A physics student performs a double-slit diffraction experiment on an optical bench, as shown in the figure below. The light from a helium-neon laser has a wavelength of 632.8 nm. The laser light passes through two slits separated by 0.020 mm. What is the distance between the centers of the central band and the first-order band?



$$L = 150.0\ \text{cm} - 50.0\ \text{cm}$$
$$= 100.0\ \text{cm}$$
$$\lambda = \frac{xd}{L}$$
$$x = \frac{\lambda L}{d}$$
$$= \frac{(6.328\times10^{-7}\ \text{m})(1.000\ \text{m})}{2.0\times10^{-5}\ \text{m}}$$
$$= 3.2\times10^{-2}\ \text{m} = 3.2\ \text{cm}$$

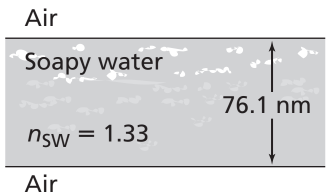
2. A laser of unknown wavelength replaces the helium-neon laser in the experiment described in problem 1. To obtain the best diffraction pattern, the screen had to be moved to 104.0 cm. The distance between the centers of the central band and the first-order band is 1.42 cm. What wavelength of light is produced by the laser?

$$L = 104.0\ \text{cm} - 50.0\ \text{cm}$$
$$= 54.0\ \text{cm}$$
$$\lambda = \frac{xd}{L}$$
$$= \frac{(1.42\times10^{-2}\ \text{m})(2.0\times10^{-5}\ \text{m})}{0.540\ \text{m}}$$
$$= 5.3\times10^{-7}\ \text{m} = 530\ \text{nm}$$

3. Light with a wavelength of 454.5 nm passes through two slits that are 95.2 cm from a screen. The distance between the centers of the central band and the first-order band is 15.2 mm. What is the slit separation?

$$\lambda = \frac{xd}{L}$$
$$d = \frac{\lambda L}{x}$$
$$= \frac{(4.545\times10^{-7}\ \text{m})(0.952\ \text{m})}{0.0152\ \text{m}}$$
$$= 2.85\times10^{-5}\ \text{m}$$

4. What color of light would be reflected from the soapy water film shown in the figure below?



$$2d = \left(m + \frac{1}{2}\right)\frac{\lambda}{n_{sw}}$$

For $m = 0$, $2d = \frac{1}{2}\frac{\lambda}{n_{sw}}$.

$$\lambda = 4dn_{sw}$$
$$= (4)(76.1\ \text{nm})(1.33)$$
$$= 405\ \text{nm}$$

The light is violet in color.

5. A 95.7-nm film of an unknown substance is able to prevent 555-nm light from being reflected when surrounded by air. What is the index of refraction of the substance?

$$2d = \left(m + \frac{1}{2}\right)\frac{\lambda}{n_{sub}}$$

For $m = 0$, $2d = \frac{1}{2}\frac{\lambda}{n_{sub}}$.

$$n_{sub} = \frac{\lambda}{4d}$$
$$= \frac{555\ \text{nm}}{(4)(95.7\ \text{nm})}$$
$$= 1.45$$

6. An oil film (n = 1.45) on the surface of a puddle of water on the street is 118 nm thick. What frequency of light would be reflected?

$$2d = \left(m + \frac{1}{2}\right)\frac{\lambda}{n_{oil}}$$

For $m = 0$, $2d = \frac{1}{2}\frac{\lambda}{n_{oil}}$.

$$\lambda = 4dn_{oil}$$
$$= (4)(118\text{ nm})(1.45)$$
$$= 685\text{ nm}$$

$$\lambda = \frac{c}{f}$$

$$f = \frac{c}{\lambda}$$
$$= \frac{3.00\times10^{8}\text{ m/s}}{6.85\times10^{-7}\text{ m}}$$
$$= 4.38\times10^{14}\text{ Hz}$$

7. Violet light (λ = 415 nm) falls on a slit that is 0.040 mm wide. The distance between the centers of the central bright band and the third-order dark band is 18.7 cm. What is the distance from the slit to the screen?

$$x_m = \frac{mL\lambda}{w}$$

$$L = \frac{x_m w}{m\lambda}$$
$$= \frac{(0.187\text{ m})(4.0\times10^{-5}\text{ m})}{(3)(4.15\times10^{-7}\text{ m})}$$
$$= 6.0\text{ m}$$

8. Red light (λ = 685 nm) falls on a slit that is 0.025 mm wide. The distance between the centers of the central bright band and the second-order dark band is 6.3 cm. What is the width of the central band?

$$x_m = \frac{mL\lambda}{w}$$

$$L = \frac{x_m w}{m\lambda}$$
$$= \frac{(0.063\text{ m})(2.5\times10^{-5}\text{ m})}{(2)(6.85\times10^{-7}\text{ m})}$$
$$= 1.1\text{ m}$$

$$2x_1 = \frac{2\lambda L}{w}$$
$$= \frac{(2)(6.85\times10^{-7}\text{ m})(1.1\text{ m})}{2.5\times10^{-5}\text{ m}}$$
$$= 0.063\text{ m}$$

9. The width of the central bright band of a diffraction pattern is 2.9 cm. Laser light of unknown wavelength passes through a single slit that is 0.042 mm wide and onto a screen that is 1.5 m from the slit. What is the wavelength of the light?

$$2x_1 = \frac{2\lambda L}{w}$$

$$\lambda = \frac{2x_1 w}{2L}$$
$$= \frac{(0.029\text{ m})(4.2\times10^{-5}\text{ m})}{(2)(1.5\text{ m})}$$
$$= 4.1\times10^{-7}\text{ m}$$

10. A diffraction grating has 13,400 lines per inch. What is the slit separation distance? (Use 1 in = 2.54 cm)

$$d = \left(\frac{1\text{ in}}{13{,}400\text{ lines}}\right)\left(\frac{2.54\text{ cm}}{1\text{ in}}\right)\left(\frac{1\text{ m}}{100\text{ cm}}\right)$$
$$= 1.90\times10^{-6}\text{ m/line}$$

11. Light from a helium-neon laser (λ = 632.8 nm) passes through the diffraction grating described in problem 10. What is the angle between the central bright line and the first-order bright line?

$$\lambda = d\sin\theta$$

$$\theta = \sin^{-1}\left(\frac{\lambda}{d}\right)$$
$$= \sin^{-1}\left(\frac{6.328\times10^{-7}\text{ m}}{1.90\times10^{-6}\text{ m}}\right)$$
$$= 19.5°$$

12. A diffraction grating with slits separated by 3.40×10^{-6} m is illuminated by light with a wavelength of 589 nm. The separation between lines in the diffraction pattern is 0.25 m. What is the distance between the diffraction grating and the screen?

$$\lambda = d \sin \theta$$

$$\theta = \sin^{-1}\left(\frac{\lambda}{d}\right)$$

$$= \sin^{-1}\left(\frac{5.89\times10^{-7}\ \text{m}}{3.40\times10^{-6}\ \text{m}}\right)$$

$$= 9.98°$$

$$\tan \theta = \frac{x}{L}$$

$$L = \frac{x}{\tan \theta}$$

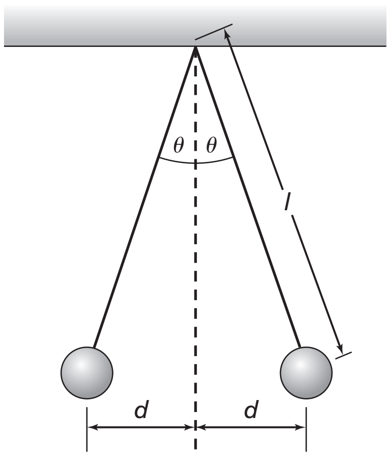
$$= \frac{0.25\ \text{m}}{\tan 9.98°}$$

$$= 1.4\ \text{m}$$

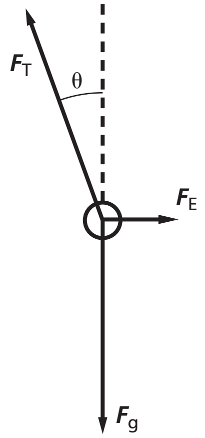
Chapter 20

page 879

1. The magnitude of a charge, q, is to be determined by transferring the charge equally to two pith balls. Each of the pith balls has a mass of m, and is suspended by an insulating thread of length l. When the charge is transferred, the pith balls separate to form an equilibrium in which each thread forms an angle, θ, with the vertical.



a. Draw a force diagram showing the forces that are acting on the rightmost pith ball.



where:

F_T = thread tension

F_E = electrostatic force

F_g = gravitational force

b. Derive an expression for q as a function of θ, m, and l.

Since the system is in equilibrium, the net horizontal and vertical forces must be zero.

$$-F_T \sin\theta + F_E = 0$$

$$F_T \cos\theta - F_g = 0$$

Rearrange and substitute F_E and F_g.

$$F_T \sin\theta = F_E = K\frac{q_A q_B}{(2d)^2} = K\frac{\left(\frac{q}{2}\right)^2}{4d^2} = K\frac{q^2}{16d^2}$$

$$F_T \cos\theta = F_g = mg$$

Divide the first equation by the second to eliminate F_T.

$$\frac{\sin\theta}{\cos\theta} = \tan\theta = K\frac{q^2}{16mgd^2}$$

From the diagram, *d* = *l* sin *θ*. Substitute for *d* and solve for *q*.

$$q^2 = \frac{16mgl^2 \sin^2\theta \tan\theta}{K}$$

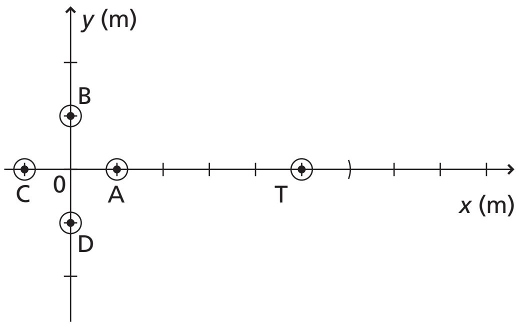
$$q = 4l \sin\theta \sqrt{\frac{mg \tan\theta}{K}}$$

c. Use your derived expression to determine the value of q when $\theta = 5.00°$, $m = 2.00$ g, and $l = 10.0$ cm.

$$q = (4)(10.0\times10^{-2}\ \text{m})(\sin 5.0°)\sqrt{\frac{(2.00\times10^{-3}\ \text{kg})(9.80\ \text{m/s}^2)(\tan 5.0°)}{(9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)}}$$

$$= 1.52\times10^{-8}\ \text{C}$$

2. As shown in the figure below, four charges, each with charge q, are distributed symmetrically around the origin, O(0, 0), at A(1.000, 0), B(0, 1.000), C(−1.000, 0), and D(0, −1.000). Find the force on a fifth charge, q_T, located at T(5.000, 0).



Because of symmetry, the force components on charge *T* in the direction of the *y*-axis cancel, and only the *x*-direction forces need to be computed.

$$F_{T,x} = F_{AT,x} + F_{BT,x} + F_{CT,x} + F_{DT,x}$$

$$= Kqq_T\left(\frac{1}{|AT|^2} + \frac{\cos\theta_B}{|BT|^2} + \frac{1}{|CT|^2} + \frac{\cos\theta_D}{|DT|^2}\right)$$

$$= Kqq_T\left(\frac{1}{16} + (2)\left(\frac{\frac{5}{\sqrt{1^2+5^2}}}{1^2+5^2}\right) + \frac{1}{36}\right)$$

$$= 0.1657Kqq_T\ \text{N}$$

3. Consider that the four charges in the previous problem are now combined into a single charge, $4q$, located at the origin. What is the force on charge q_T?

$$K\frac{(4q)(q_T)}{5^2} = Kqq_T\left(\frac{4}{25}\right)$$

$$= 0.1600Kqq_T\ \text{N}$$

A charge uniformly spread over a spherical surface may be treated as if all of the charge is concentrated at the sphere's center. The previous problem is a two-dimensional approximation of this condition.

Chapter 21

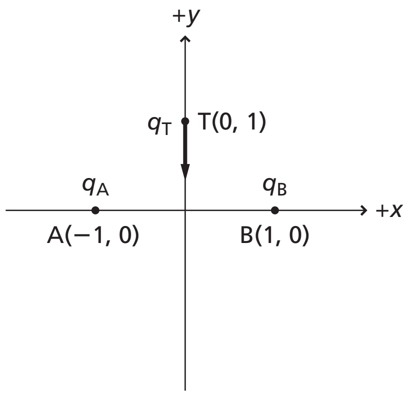
pages 879–880

1. What are the magnitude and the sign of a point charge that experiences a force of 0.48 N east when placed in an electric field of 1.6×10^{5} N/C west?

$$q = \frac{F}{E} = \frac{0.48\ \text{N}}{1.6\times10^{5}\ \text{N/C}} = 3.0\times10^{-6}\ \text{C}$$

Because the force exerted on the charge is opposite the direction of the electric field, the charge must be negative.

2. A test charge of -1.0×10^{-6} C, located at the point T(0, 1) m, experiences a force of 0.19 N directed toward the origin, along the y-axis, due to two identical point charges located at A(−1, 0) m and B(1, 0) m.



a. What is the sign of the charges at A and B?

The charges at *A* and *B* must be positive to cause an attractive force on the test charge.

b. What are the magnitude and direction of the electric field at T?

$$E = \frac{F}{q} = \frac{0.19\ \text{N}}{1.0\times10^{-6}\ \text{C}}$$

$$E = 1.9\times10^{5}\ \text{N/C}$$

The direction is opposite the force because it is a negative charge. So, $E = 1.9\times10^{5}$ N/C, away from the origin.

3. A test charge of -0.5×10^{-7} C is placed in an electric field of 6.2×10^{4} N/C, directed 15° north of east. What is the force experienced by the charge?

$$F = qE$$

$$= (0.5\times10^{-7}\ \text{C})(6.2\times10^{4}\ \text{N/C})$$

$$= 3.1\times10^{-3}\ \text{N}$$

The direction is opposite that of the electric field because the charge is negative. So, $E = 3.1\times10^{-3}$ N, 15° south of west

4. By what percent must the distance from a point charge increase in order to have a reduction in the electric field strength by 40 percent?

The electric field strength of a point charge,

$$E = K\frac{q}{r^2},$$

is inversely proportional to the square of the distance from the charge.

$$\frac{E_1}{E_2} = \frac{{r_2}^2}{{r_1}^2}$$

$${r_2}^2 = \frac{E_1}{E_2}{r_1}^2$$

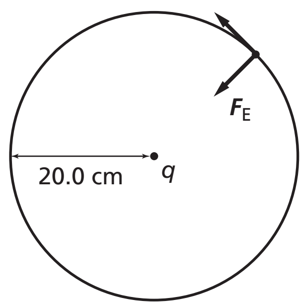
$$r_2 = \sqrt{\frac{E_1}{E_2}}r_1$$

In this case, $E_2 = (1 - 0.40)E_1 = 0.60E_1$

Then, $r_2 = \sqrt{\frac{1}{0.60}}r_1 = 1.2r_1$

The distance must increase by 30 percent.

5. A particle of mass $m = 2.0\times10^{-6}$ kg is in a circular orbit about a point charge. The charge, q, is 3.0×10^{-5} C and is at a distance of $r = 20.0$ cm.



a. What is the electric field strength at all points on the orbit around the point charge?

Since the orbit is circular, the distance of the particle from the point charge is constant. From Example Problem 2, the electric field strength depends only on the distance and the charge, and is given by

$$E = K\frac{q}{r^2}$$

$$= (9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)\left(\frac{3.0\times10^{-5}\ \text{C}}{(0.200\ \text{m})^2}\right)$$

$$= 6.8\times10^{6}\ \text{N/C, radially outward at all points on the orbit}$$

b. Considering only electrostatic forces, what charge, q, on the particle is required to sustain an orbital period of 3.0×10^{-3} s?

The electrostatic force F_E must be toward the point charge to account for the centripetal acceleration of the particle in orbit. Therefore, the particle charge must be negative. The force required to keep the particle in orbit is (see Chapter 6, Motion in Two Dimensions):

$$F_E = ma_c = m\frac{4\pi^2 r}{T^2}\text{, radially inward.}$$

The charge on the particle must then be

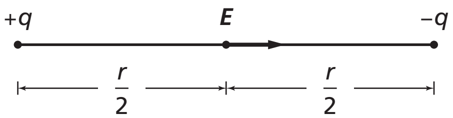
$$q = \frac{F_E}{E}$$

$$= \frac{-4\pi^2 rm}{ET^2}$$

$$= \frac{-4\pi^2(0.200\ \text{m})(2.0\times10^{-6}\ \text{kg})}{(6.8\times10^{6}\ \text{N/C})(3.0\times10^{-3}\ \text{s})^2}$$

$$= -2.6\times10^{-7}\ \text{C}$$

6. Two charges of equal magnitude and opposite sign are placed 0.50 m apart. The electric field strength midway between them is 4.8×10^{4} N/C toward the negative charge. What is the magnitude of each charge?



The electric field strength is the sum of two components, one due to each charge, both pointing toward the negative charge. At the midpoint, the magnitudes of the component field strengths are equal.

$$E = E_q + E_{-q} = \frac{2Kq}{\left(\frac{r}{2}\right)^2} = \frac{8Kq}{r^2}$$

Solve for q in terms of E.

$$q = \frac{Er^2}{8K} = \frac{(4.8\times10^{4}\ \text{N/C})(0.50\ \text{m})^2}{(8)(9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)}$$

$$= 1.7\times10^{-7}\ \text{C}$$

7. A pith ball weighing 3.0×10^{-2} N carries a charge of -1.0×10^{-6} C. The pith ball is placed between two large, parallel, metal plates, that are separated by 0.050 m. What is the potential difference, ΔV, that must be applied in order to suspend the pith ball between the plates?

$$\Delta V = Ed$$

$$= \frac{F_E d}{q}$$

$$= \frac{(3.0\times10^{-2}\ \text{N})(0.050\ \text{m})}{-1.0\times10^{-6}\ \text{C}}$$

$$= 1.5\times10^{3}\ \text{V}$$

8. The electric field strength, defined as a force per unit charge, has the units newtons per coulomb, N/C. The formula for electric potential difference, $\Delta V = Ed$, however, suggests that E also can be expressed as volts per meter, V/m.

a. By analysis of the units, show that these two expressions for the units of electric field strength are equivalent.

$$\frac{\text{V}}{\text{m}} = \frac{\text{J/C}}{\text{m}} = \frac{(\text{N·m})/\text{C}}{\text{m}} = \frac{\text{N}}{\text{C}}$$

b. Suggest a reason why V/m is often a more useful way to express electric field strength.

In practice, electric potential differences and distances are much easier to measure than forces on charges.

9. Suppose you have two parallel, metal plates that have an electric field between them of strength 3.0×10^4 N/C, and are 0.050 m apart. Consider a point, P, located 0.030 m from plate A, the negatively charged plate, when answering the following questions.

a. What is the electric potential at P relative to plate A?

$$\Delta V_{PA} = (3.0\times10^4 \text{ V/m})(0.030 \text{ m}) = 9.0\times10^2 \text{ V}$$

b. What is the electric potential at P relative to plate B, the positively charged plate?

$$\Delta V_{PB} = -(3.0\times10^4 \text{ V/m})(0.020 \text{ m}) = -6.0\times10^2 \text{ V}$$

10. A certain 1.5-V size-AA battery has a storage capacity of 2500 C. How much work can this battery perform?

$$W = q\Delta V = (2.5\times10^3 \text{ C})(1.5 \text{ V}) = 3.8\times10^3 \text{ J}$$

11. In a vacuum tube, electrons accelerate from the cathode element to the plate element, which is maintained at a positive potential with respect to the cathode. If the plate voltage is +240 V, how much kinetic energy has an electron acquired when it reaches the plate?

The kinetic energy gained by an electron is the same as the potential energy lost by the electron as it moves through the potential difference of 240 V.

$$\Delta KE = -W = -e\Delta V$$

$$= (1.60\times10^{-19} \text{ C})(240 \text{ V})$$

$$= 3.8\times10^{-17} \text{ J}$$

12. An oil drop with five excess electrons is suspended in an electric field of 2.0×10^3 N/C. What is the mass of the oil drop?

$$F_g = mg = F_E = qE = neE$$

$$m = \frac{F_g}{g} = \frac{neE}{g}$$

$$= \frac{(5)(1.60\times10^{-19} \text{ C})(2.0\times10^3 \text{ N/C})}{9.80 \text{ m/s}^2}$$

$$= 1.6\times10^{-16} \text{ kg}$$

13. An oil drop weighing 7.5×10^{-15} N carries three excess electrons.

a. What potential difference is required to suspend the drop between parallel plates separated by 2.3 cm?

$$F_g = F_E = qE = neE = ne\frac{\Delta V}{d}$$

$$\Delta V = \frac{F_g d}{ne}$$

$$= \frac{(7.5\times10^{-15} \text{ N})(2.3\times10^{-2} \text{ m})}{(3)(1.60\times10^{-19} \text{ C})}$$

$$= 3.6\times10^2 \text{ V}$$

b. If the oil drop picks up another electron, by how much must the potential difference between the plates be reduced to maintain the oil drop in suspension?

$$\Delta V = \frac{F_g d}{ne}$$

So the potential difference is inversely proportional to the number of excess electrons.

$$\frac{\Delta V_2}{\Delta V_1} = \frac{n_1}{n_2}$$

$$\Delta V_2 = \frac{n_1}{n_2}\Delta V_1$$

$$= \left(\frac{3}{4}\right)(3.6\times10^2 \text{ V}) = 2.7\times10^2 \text{ V}$$

Reduction of 90 V

14. A charge of 2.00×10^{-6} C is moved against a constant electric field. If 4.50×10^{-4} J of work is done on the charge, what is the potential difference between the initial and the final locations of the charge?

$$\Delta V = \frac{W_q}{q} = \frac{4.50\times10^{-4} \text{ J}}{2.00\times10^{-6} \text{ C}}$$

$$= 225 \text{ V}$$

15. Capacitors $C_1 = 220$ μF and $C_2 = 470$ μF are connected across a 48.0-V electric potential difference.

a. What are the charges, q_1 and q_2, on each of the capacitors?

$$C = \frac{q}{\Delta V}$$

$q_1 = C_1\Delta V = (220\times10^{-6}\text{ F})(48.0\text{ V})$

$= 1.1\times10^{-2}\text{ C}$

$q_2 = C_2\Delta V = (470\times10^{-6}\text{ F})(48.0\text{ V})$

$= 2.3\times10^{-2}\text{ C}$

b. What is the total charge, q_T, on both capacitors?

$q_T = q_1 + q_2$

$= C_1\Delta V + C_2\Delta V$

$= (C_1 + C_2)\Delta V$

$= (220\times10^{-6}\text{ F} + 470\times10^{-6}\text{ F})(48.0\text{ V})$

$= 3.3\times10^{-2}\text{ C}$

c. Repeat steps **a** and **b** for a new potential difference, $\Delta v' = 96.0$ V.

$q_1' = C_1\Delta V' = (220\times10^{-6}\text{ F})(96.0\text{ V})$

$= 2.1\times10^{2}\text{ C}$

$q_2' = C_2\Delta V' = (470\times10^{-6}\text{ F})(96.0\text{ V})$

$= 4.5\times10^{-2}\text{ C}$

$q_T' = q_1' + q_2'$

$= (C_1 + C_2)\Delta V$

$= (220\times10^{-6}\text{ F} + 470\times10^{-6}\text{ F})(96.0\text{ V})$

$= 6.6\times10^{-2}\text{ C}$

d. Now consider the two capacitors as a system. What would be a single equivalent capacitor, C_{eq}, that could replace C_1 and C_2, and be capable of yielding the same results?

Let $C_{eq} = C_1 + C_2 = 690\ \mu\text{F}$

Then,

$q_T = C_{eq}\Delta V$

$= (690\times10^{-6}\text{ F})(48.0\text{ V})$

$= 3.3\times10^{-2}\text{ C}$

and

$q_T' = C_{eq}\Delta V'$

$= (690\times10^{-6}\text{ F})(96.0\text{ V})$

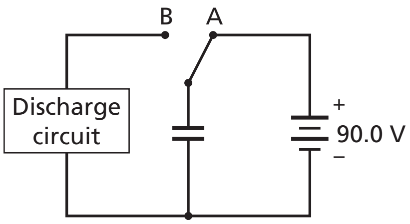
$= 6.6\times10^{-2}\text{ C}$

yielding similar results as previously.

e. Based on your responses to the above, make a conjecture concerning the equivalent capacitance of a system of capacitors—all of which are connected across the same potential difference.

The equivalent capacitance is the sum of all of the individual capacitances.

16. A new 90.0-V battery with a storage capacity of 2.5×10^4 C charges a 6800-μF capacitor with the switch in position A. Then the switch is thrown to position B to discharge the capacitor.



a. How many times can this cycle be repeated before the battery is completely discharged?

When the capacitor is completely charged, it contains

$q_c = C\Delta V = (6800\times10^{-6}\ \mu\text{F})(90.0\text{ V})$

$= 0.61\text{ C}$

The number of cycles *N* is

$N = \frac{2.5\times10^4\text{ C}}{0.61\text{ C/cycle}}$

$= 4.1\times10^4\text{ cycles}$

b. If the capacitor discharge occurs in 120 ms, what is the average power dissipated in the discharge circuit during one cycle?

The energy stored in the fully charged capacitor equals the work performed to store the charge.

$W = q_c\Delta V$

The average power dissipated equals the total energy dissipated divided by the time required.

$P = \frac{E}{t} = \frac{W}{t} = \frac{q_c\Delta V}{t}$

$$= \frac{(0.61\ \text{C})(90.0\ \text{V})}{0.12\ \text{s}}$$

$$= 4.6\times10^{2}\ \text{W}$$

17. A 0.68-μF capacitor carries a charge on one plate of 1.36×10^{-5} C. What is the potential difference across the leads of this capacitor?

$$C = \frac{q}{\Delta V}$$

$$\Delta V = \frac{q}{C} = \frac{1.36\times10^{-5}\ \text{C}}{0.68\times10^{-6}\ \text{F}}$$

$$= 2.0\times10^{1}\ \text{V}$$

Chapter 22

pages 881–882

1. A decorative lightbulb rated at 7.50 W draws 60.0 mA when lit. What is the voltage drop across the bulb?

$$P = VI$$

$$V = \frac{P}{I} = \frac{(7.50\ \text{W})}{(60.0\times10^{-3}\ \text{A})} = 125\ \text{V}$$

2. A 1.2-V nickel-cadmium battery has a rated storage capacity of 4.0×10^{3} mAh (milliamp-hours).

a. What is the battery charge capacity in coulombs? *Hint: 1 C = 1 A·s.*

$$q = (4.0\times10^{3}\ \text{mAh})\left(\frac{1\ \text{A}}{1000\ \text{mA}}\right)\left(\frac{3600\ \text{s}}{1\ \text{h}}\right)$$

$$= 1.4\times10^{4}\ \text{A·s} = 1.4\times10^{4}\ \text{C}$$

b. How long can this battery supply a current of 125 mA?

$$q = It$$

$$t = \frac{4.0\times10^{3}\ \text{mAh}}{125\ \text{mA}} = 32\ \text{h}$$

3. A heating element of an electric furnace consumes 5.0×10^{3} W when connected across a 240-V source. What current flows through the element?

$$P = VI$$

$$I = \frac{P}{V} = \frac{5.0\times10^{3}\ \text{W}}{240\ \text{V}} = 21\ \text{A}$$

4. The cold filament resistance of a lightbulb is 20.0 Ω. The bulb consumes 75 W when it is operating from a 120-V source. By what factor does the start-up current in the bulb exceed the operating current?

$$I_{\text{start}} = \frac{V}{R}$$

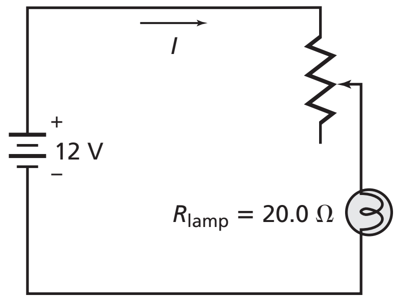
$$I_{\text{operate}} = \frac{P}{V}$$

$$\frac{I_{\text{start}}}{I_{\text{operate}}} = \frac{\frac{V}{R}}{\frac{P}{V}} = \frac{V^2}{RP} = \frac{(120\ \text{V})^2}{(20.0\ \Omega)(75\ \text{W})}$$

$$= 9.6$$

The start-up current is 9.6 times larger than the operating current.

5. In the circuit shown below, a potentiometer is used to vary the current to the lamp. If the only resistance is due to the lamp, what is the current in the circuit?



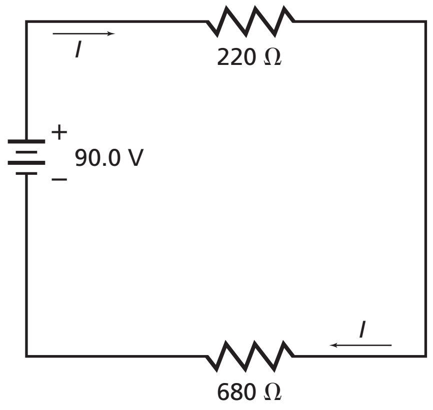
$$I = \frac{V}{R_{lamp}} = \frac{12\text{ V}}{20.0\ \Omega} = \mathbf{0.60\ A}$$

6. An electric toaster consumes 1875 W in operation. If it is plugged into a 125-V source, what is its resistance?

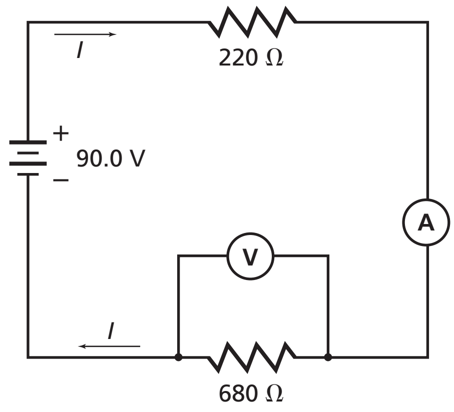
$$P = \frac{V^2}{R}$$

$$R = \frac{V^2}{P} = \frac{(125\text{ V})^2}{1875\text{ W}} = \mathbf{8.33\ \Omega}$$

7. Draw a circuit diagram to include a 90.0-V battery, a 220-Ω resistor, and a 680-Ω resistor in series. Show the direction of conventional current.



8. Modify the diagram of the previous problem to include an ammeter and a voltmeter to measure the voltage drop across the 680-Ω resistor.



9. If the total resistance in the circuit in problem 8 is 9.0×10^2 Ω, what would the ammeter and the voltmeter indicate?

Ammeter reading is

$$I = \frac{V}{R}$$

$$= \frac{90.0\text{ V}}{9.0\times10^2\ \Omega} = \mathbf{0.10\ A}$$

Voltmeter reading is

$$V = IR$$

$$= (0.10\text{ A})(680\ \Omega) = \mathbf{68\ V}$$

10. An electric motor with a load delivers 5.2 hp to its shaft (1 hp = 746 W). Under these conditions, it operates at 82.8 percent efficiency. (Efficiency is defined as the ratio of power output to power input.)

a. How much current does the motor draw from a 240-V source?

$$\text{Efficiency} = \frac{P_{output}}{P_{input}} = 0.828$$

$$I = \frac{P_{input}}{V} = \frac{\frac{P_{output}}{\text{Efficiency}}}{V}$$

$$= \frac{\frac{(5.2\text{ hp})(746\text{ W/hp})}{0.828}}{240\text{ V}}$$

$$= \mathbf{2.0\times10^1\ A}$$

b. What happens to the remaining 17.2 percent of the input power?

It is primarily dissipated as I^2R losses in the motor windings. Ultimately, this energy is converted to thermal energy and must be removed from the motor by fans or other means.

11. An industrial heating process uses a current of 380 A supplied at 440-V potential.

a. What is the effective resistance of the heating element?

$$R = \frac{V}{I} = \frac{440\text{ V}}{380\text{ A}} = 1.2\ \Omega$$

b. How much energy is used by this process during an 8-h shift?

$$E = Pt = VIt$$

$$= (440\text{ V})(380\text{ A})(8\text{ h})\left(\frac{3600\text{ s}}{1\text{ h}}\right)$$

$$= 5\times10^9\text{ J}$$

12. An 8.0-Ω electric heater operates from a 120-V source.

a. How much current does the heater require?

$$I = \frac{V}{R} = \frac{120\text{ V}}{8.0\ \Omega} = 15\text{ A}$$

b. How much time does the heater need to generate 2.0×10^4 J of thermal energy?

$$E = Pt = VIt$$

$$t = \frac{E}{VI} = \frac{2.0\times10^4\text{ J}}{(120\text{ V})(15\text{ A})} = 11\text{ s}$$

13. A manufacturer of lightbulbs advertises that its 55-W bulb, which produces 800.0 lm of light output, provides almost the same light as a 60.0-W bulb with an energy savings. The 60.0-W bulb produces 840.0 lm.

a. Which bulb most efficiently converts electric energy to light?

The 55-W bulb produces $\frac{800.0\text{ lm}}{55\text{ W}}$, or 14.5 lm/W. The 60.0-W bulb produces $\frac{840.0\text{ lm}}{60.0\text{ W}}$, or 14.0 lm/W. The 55-W bulb is more efficient.

b. Assume a bulb has a lifetime of 1.0×10^3 h and an electric energy cost of $0.12/kWh. How much less does the 55-W bulb cost to operate over its lifetime?

The 60.0-W bulb costs

$$(0.0600\text{ kW})(1.0\times10^3\text{ h})(\$0.12/\text{kWh}) = \$7.20$$

The 55-W bulb costs

$$(0.055\text{ kW})(1.0\times10^3\text{ h})(\$0.12/\text{kWh}) = \$6.60$$

The difference in cost is $7.20 − $6.60 = $0.60

c. Is most of the cost savings due to higher bulb efficiency, or due to the consumer's willingness to accept lower light output?

Most of the savings is due to a willingness to accept lower light output. If the 60.0-W bulb could be made to output 800.0 lm, its cost would be $\left(\frac{800.0}{840.0}\right)(\$7.20) = \$6.86$,resulting in a savings of $0.26 for the 55-W bulb. So of the $0.60 savings over the bulb lifetime, only $0.26, or 43 percent, is due to higher efficiency.

14. By what factor would the I^2R loss in transmission wires be reduced if the transmission voltage were boosted from 220 V to 22 kV? Assume that the rate of energy delivered is unchanged.

The power required is the same. The current, however, would be reduced by the same factor that the voltage was boosted, 10^2. The I^2R loss would be reduced by a factor of 10^4 because the current is squared.

15. The electric-utility invoice for a household shows a usage of 1245 kWh during a certain 30-day period. What is the average power consumption during this period?

$$P = \frac{E}{t} = \left(\frac{1.245\times10^6\text{ Wh}}{30\text{ d}}\right)\left(\frac{1\text{ d}}{24\text{ h}}\right)$$

$$= 2\times10^3\text{ W}$$

Chapter 23

pages 882–884

1. A series circuit contains a 47-Ω resistor, an 82-Ω resistor, and a 90.0-V battery. What resistance, R_3, must be added in series to reduce the current to 350 mA?

$$I = \frac{V_{source}}{R}$$

$$R = \frac{V_{source}}{I}$$

$$= \frac{90.0\ V}{0.350\ A}$$

$$= 257\ \Omega$$

For a series circuit, $R = R_1 + R_2 + R_3$

$$R_3 = R - R_1 - R_2$$

$$= 257\ \Omega - 47\ \Omega - 82\ \Omega$$

$$= 128\ \Omega$$

2. What is the minimum number of 100.0-Ω resistors that must be connected in series together with a 12.0-Ω battery to ensure that the current does not exceed 10.0 mA?

$I = \frac{V_{source}}{R}$**, where** $I \leq 0.0100$ **A**

Let n **equal the number of 100.0-Ω resistors. Thus, for this series circuit,** $R = 100.0n$

$$0.0100\ A \geq \frac{12.0\ V}{R}$$

$$0.0100\ A \geq \frac{12.0\ V}{100.0n}$$

$$n \geq \frac{12.0}{(0.0100)(100.0)} = 12.0$$

There must be at least 12 resistors.

3. A 120.0-Ω generator is connected in series with a 100.0-Ω resistor, a 400.0-Ω resistor, and a 700.0-Ω resistor.

a. How much current is flowing in the circuit?

$$I = \frac{V_{source}}{R}$$

$$= \frac{120.0\ V}{100.0\ \Omega + 400.0\ \Omega + 700.0\ \Omega}$$

$$= 0.1000\ A$$

b. What is the voltage drop in the 400-Ω resistor?

$$V_{400\ \Omega} = IR_{400\ \Omega}$$

$$= (0.1000\ A)(400.0\ \Omega)$$

$$= 40.00\ V$$

4. Show that the total power dissipated in a circuit of series-connected resistors is $P = I^2R$, where R is the equivalent resistance.

The total dissipated power is equal to the sum of the power dissipations in each of the resistors.

$$P = P_1 + P_2 + \ldots$$

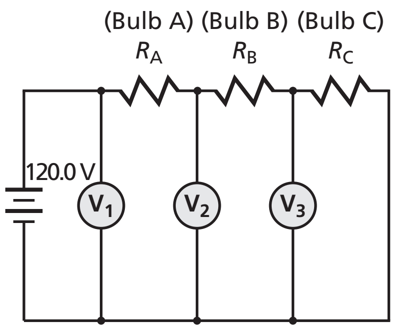
$$= I^2R_1 + I^2R_2 + \ldots$$

$$= I^2(R_1 + R_2 + \ldots)$$

$$= I^2R$$

5. In an experiment, three identical lightbulbs are connected in series across a 120.0-V source, as shown. When the switch is closed, all of the bulbs are illuminated. However, when the experiment is repeated the next day, bulbs A and B are illuminated brighter than normal, and bulb C is dark. A voltmeter is used to measure the voltages in the circuit as shown. The voltmeter readings are:

$V_1 = 120.0$ V
$V_2 = 60.0$ V
$V_3 = 0.0$ V



a. What has happened in this circuit?

Bulb C has developed a short circuit in its base and thus, no current flows through its filament and it remains dark. The short acts as a zero resistance and allows the circuit current

to flow. The measurements confirm that the available voltage is dropped across the remaining two bulbs.

b. Explain why bulbs A and B are brighter than normal.

The voltage drop across each bulb increased from $\frac{120.0\ V}{3} = 40.00\ V$, to $\frac{120.0\ V}{2} = 60.00\ V$. The power dissipated in each bulb, $P = \frac{V^2}{R}$, has increased because of the increased *V*.

c. Is there more or less current flowing now in the circuit?

More current flows through the circuit. The equivalent resistance of two bulbs and a short circuit is lower than that of three bulbs. This lower equivalent resistance results in an increased current.

6. A string of holiday lights has 25 identical bulbs connected in series. Each bulb dissipates 1.00 W when the string is connected to a 125-V outlet.

a. How much power must be supplied by the 125-V source?

$$P = (25\ \text{bulbs})(1.00\ \text{W/bulb}) = 25.0\ \text{W}$$

b. What is the equivalent resistance of this circuit?

$$P = \frac{V^2}{R}$$

$$R = \frac{V^2}{P} = \frac{(125\ \text{V})^2}{25.0\ \text{W}} = 625\ \Omega$$

c. What is the resistance of each bulb?

Because the bulbs are in series,

$$R_{bulb} = \frac{R}{25} = \frac{625\ \Omega}{25} = 25.0\ \Omega$$

d. What is the voltage drop across each bulb?

Because the bulbs are in series,

$$V_{bulb} = \frac{V}{25} = \frac{125\ \text{V}}{25} = 5.00\ \text{V}$$

7. Two resistors are connected in series across a 12.0-V battery. The voltage drop across one of the resistors is 5.5 V.

a. What is the voltage drop across the other resistor?

12.0 V − 5.5 V = 6.5 V

b. If the current in the circuit is 5.0 mA, what are the two resistor values?

$$R = \frac{V}{I}$$

$$R_1 = \frac{5.5\ \text{V}}{0.0050\ \text{A}} = 1100\ \Omega$$

$$R_2 = \frac{6.5\ \text{V}}{0.0050\ \text{A}} = 1300\ \Omega$$

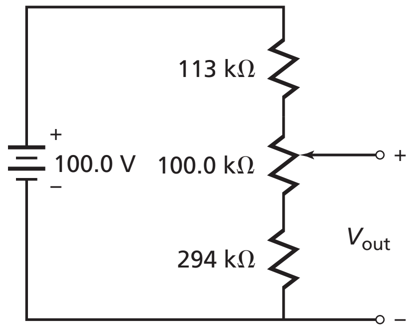
8. In problem 7, the specifications for the resistors state that their resistance may vary from the listed nominal value. If the possible ranges of actual resistance values are as follows, $1050\ \Omega \leq R_1 \leq 1160\ \Omega$, and $1240\ \Omega \leq R_2 \leq 1370\ \Omega$, what is the possible minimum and maximum value of the nominal 5.5-V voltage drop?

Construct a table to determine the voltage drops resulting from the extreme values of the resistors. The voltage drop is calculated using the equation $\frac{12R_1}{R_1 + R_2}$.

Resistor R_1 kΩ	Resistor R_2 kΩ	Voltage Drop (V)
1.05	1.24	5.5
1.05	1.37	5.2
1.16	1.24	5.8
1.16	1.37	5.5

The voltage drop will range from 5.2 V to 5.8 V.

9. A voltage-divider circuit is constructed with a potentiometer, as shown below. There are two fixed resistances of 113 kΩ and 294 kΩ. The resistance of the potentiometer can range from 0.0 to 100.0 kΩ.



a. What is V_{out} when the potentiometer is at its minimum setting of 0.0 Ω?

$$V_{out} = V_{min}$$
$$= \left(\frac{294\text{ k}\Omega}{294\text{ k}\Omega + 100.0\text{ k}\Omega + 113\text{ k}\Omega}\right)(100.0\text{ V})$$
$$= 58.0\text{ V}$$

b. What is V_{out} when the potentiometer is at its maximum setting of 100.0 kΩ?

$$V_{out} = V_{max}$$
$$= \left(\frac{294\text{ k}\Omega + 100.0\text{ k}\Omega}{294\text{ k}\Omega + 100.0\text{ k}\Omega + 113\text{ k}\Omega}\right)(100.0\text{ V})$$
$$= 77.7\text{ V}$$

c. What potentiometer setting is required to adjust V_{out} to exactly 65.0 Ω?

The setting is the same as the ratio of the range from V_{min} to 65.0 V to the total available range.

$$\frac{(65.0\text{ V}) - V_{min}}{V_{max} - V_{min}} = \frac{65.0\text{ V} - 58.0\text{ V}}{77.7\text{ V} - 58.0\text{ V}}$$
$$= 35.5\%$$

10. Two lightbulbs, one rated at 25.0 W and one rated at 75.0 W, are connected in parallel across a 125-V source.

a. Which bulb is the brightest?

The 75.0-W bulb dissipates the most power and therefore burns the brightest.

b. What is the operating resistance of each of the bulbs?

Since the bulbs are connected in parallel, the same voltage is connected across each of them.

$$P = \frac{V^2}{R}$$
$$R = \frac{V^2}{P}$$
$$R_{75} = \frac{(125\text{ V})^2}{75.0\text{ W}} = 208\ \Omega$$
$$R_{25} = \frac{(125\text{ V})^2}{25.0\text{ W}} = 625\ \Omega$$

c. The bulbs are rewired in series. What is the dissipated power in each bulb? Which bulb is the brightest?

The current in the circuit is now:

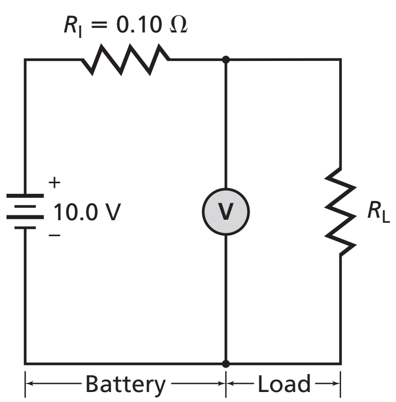
$$I = \frac{V_{source}}{R}$$
$$= \frac{V}{R_{25} + R_{75}}$$
$$= \frac{125\text{ V}}{833\ \Omega}$$
$$= 0.150\text{ A}$$

The power dissipated in each bulb is:

$$P_{75} = I^2R_{75} = (0.150\text{ A})^2(208\ \Omega)$$
$$= 4.68\text{ W}$$
$$P_{25} = I^2R_{25} = (0.150\text{ A})^2(625\ \Omega)$$
$$= 14.1\text{ W}$$

The 25-W bulb is the brightest.

11. A 10.0-V battery has an internal resistance of 0.10 Ω. The internal resistance can be modeled as a series resistor, as shown.



a. Derive an expression for the battery terminal voltage, V, as a function of the current, I.

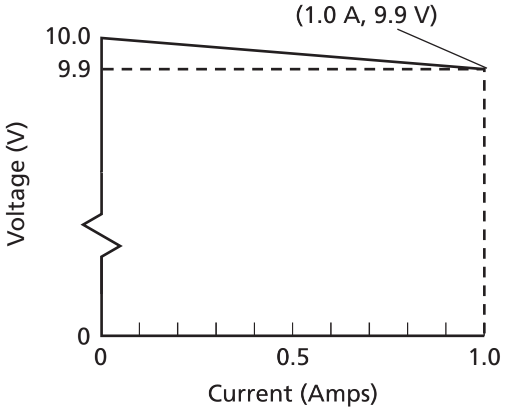
voltage rise = sum of voltage drops

$$10.0 = IR_I + V$$

$$V = 10.0 - IR_I$$

$$= 10.0 - 0.10I$$

b. Create a graph of voltage versus current for a current range of 0.0 to 1.0 A.



c. What value of load resistor R_L needs to be placed across the battery terminals to give a current of 1.0 A?

$$I = \frac{V_{source}}{R} = \frac{V_{source}}{R_I + R_L}$$

$$R_L = \frac{V_{source}}{I} - R_I = \frac{10.0\ V}{1.0\ A} - 0.10\ \Omega$$

$$= 9.9\ \Omega$$

d. How does the V-I function differ from that of an ideal voltage source?

An ideal voltage source provides the specified potential difference regardless of the amount of current drawn from it.

12. Show that the total power dissipated in a circuit of parallel-connected resistors is: $P = \frac{V^2}{R}$, where R is the equivalent resistance.

The total dissipated power is equal to the sum of the power dissipations in each of the resistors.

$$P = P_1 + P_2 + \ldots$$

$$P = \frac{V^2}{R_1} + \frac{V^2}{R_2} + \ldots$$

$$= V^2\left(\frac{1}{R_1} + \frac{1}{R_2} + \ldots\right)$$

$$= \frac{V^2}{R}$$

13. A holiday light string of ten bulbs is equipped with shunts that short out the bulbs when the voltage drop increases to line voltage, which happens when a bulb burns out. Each bulb has a resistance of 200.0 Ω. The string is connected to a household circuit at 120.0 V. If the string is protected by a 250.0-mA fuse, how many bulbs can fail without blowing the fuse?

The string will operate as long as the current is less than 250.0 mA.

$$I = \frac{V}{R}$$

$$0.250\ A \geq \frac{V}{nR_{bulb}}$$

$$0.250\ A \geq \frac{120.0\ V}{(n)(200.0\ \Omega)}$$

$$n \geq \frac{120.0\ V}{(0.250\ A)(200.0\ \Omega)}$$

$$n \geq 2.4$$

The string will operate with at least three good bulbs, or no more than seven failed bulbs.

14. A 60.0-W lightbulb and a 75.0-W lightbulb are connected in series with a 120-V source.

a. What is the equivalent resistance of the circuit?

$$P = \frac{V^2}{R}$$

$$R = \frac{V^2}{P} = \frac{(120\ V)^2}{60.0\ W + 75.0\ W}$$

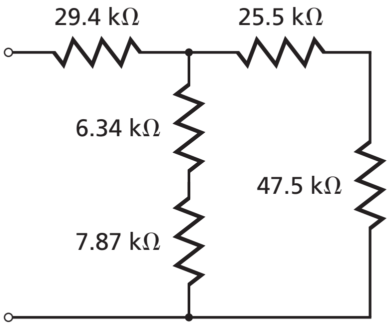
$$= 1.1\times10^2\ \Omega$$

b. Suppose an 1875-W hair dryer is now plugged into the parallel circuit with the lightbulbs. What is the new equivalent resistance of the circuit?

$$R = \frac{V^2}{P} = \frac{(120\ V)^2}{60.0\ W + 75.0\ W + 1875\ W}$$

$$= 7.2\ \Omega$$

15. What is the equivalent resistance of the following resistor network?



R_1 = 29.4 kΩ

R_{23} = 6.34 kΩ + 7.87 kΩ

= 14.21 kΩ

R_{45} = 25.5 kΩ + 47.5 kΩ

= 73.0 kΩ

$$\frac{1}{R_p} = \frac{1}{R_{23}} + \frac{1}{R_{45}} = \frac{1}{14.21\ \text{k}\Omega} + \frac{1}{73.0\ \text{k}\Omega}$$

R_p = 11.9 kΩ

$R = R_1 + R_p$ = 29.4 kΩ + 11.9 kΩ

= 41.3 kΩ

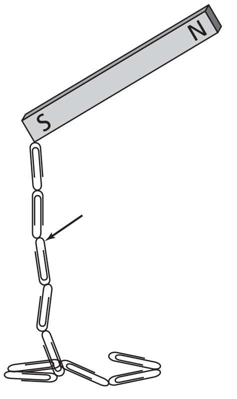
Chapter 24

pages 884–885

1. The magnetic field of Earth resembles the field of a bar magnet. The north pole of a compass needle, used for navigation, generally points toward the geographic north pole. Which magnetic pole of the Earth is the compass needle pointing toward?

the south magnetic pole of Earth

2. A magnet is used to collect some spilled paper clips. What is the magnetic pole at the end of the paper clip that is indicated in the figure?



north

3. Jingdan turned a screwdriver into a magnet by rubbing it with a strong bar magnet to pick up a screw that has fallen into an inaccessible spot. How could he demagnetize his screwdriver after picking up the screw?

He could drop it, heat it, hit it with a hammer, or somehow otherwise jiggle the magnetic domains into randomness.

4. A long, straight, current-carrying wire carries a current from west to east. A compass is held above the wire.

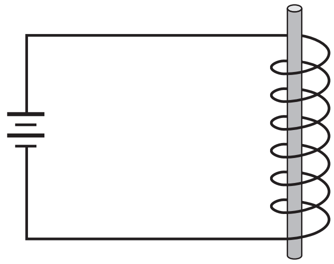
a. Which direction does the north pole of the compass point?

south

b. When the compass is moved underneath the wire, in which direction does the north pole point?

north

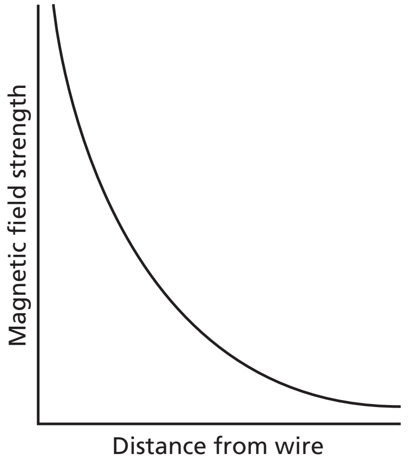
5. Consider the sketch of the electromagnet in the figure below. Which components could you change to increase or decrease the strength of the electromagnet? Explain your answer.



To increase the strength of the magnet, the voltage of the power source could be increased, the number of the wraps could be increased, or ferromagnetic cores could be added.

To decrease the strength of the magnet, the voltage of the power source could be decreased, fewer wraps could be used, or hollow or nonmagnetic cores could be used.

6. Sketch a graph showing the relationship between the magnetic field around a straight, current-carrying wire, and the distance from the wire.



This is a graph of $y = 1/x$. The units/numbers do not matter. The y-axis should be labeled *magnetic field strength* and the x-axis *distance from wire*.

7. How long is a wire in a 0.86-T field that carries a current of 1.4 A and experiences a force of 13 N?

$$F = ILB$$

$$L = \frac{F}{IB} = \frac{13\text{ N}}{(1.4\text{ A})(0.86\text{ T})} = 11\text{ m}$$

8. A 6.0-T magnetic field barely prevents a 0.32-m length of copper wire with a current of 1.8 A from dropping to the ground. What is the mass of the wire?

$$F = ILB = mg$$

$$m = \frac{ILB}{g} = \frac{(1.8\text{ A})(0.32\text{ m})(6.0\text{ T})}{9.80\text{ m/s}^2} = 0.35\text{ kg}$$

9. How much current will be needed to produce a force of 1.1 N on a 21-cm-long piece of wire at right angles to a 0.56-T field?

$$I = \frac{F}{LB} = \frac{1.1\text{ N}}{(0.21\text{ m})(0.56\text{ T})} = 9.4\text{ A}$$

10. Alpha particles (particles containing two protons, two neutrons, but no electrons) are traveling at right angles to a 47-μT field with a speed of 36 cm/s. What is the force on each particle?

$$F = qvB$$

$$= (3.20\times10^{-19}\text{ C})(0.36\text{ m/s})(4.7\times10^{-5}\text{ T})$$

$$= 5.4\times10^{-24}\text{ N}$$

11. A force of 7.1×10^{-12} N is exerted on some Al^{3+} ions (an atom missing three electrons) that are traveling at 430 km/s perpendicular to a magnetic field. What is the magnetic field?

$$B = \frac{F}{qv} = \frac{7.1\times10^{-12}\text{ N}}{(4.80\times10^{-19}\text{ C})(4.3\times10^{5}\text{ m/s})}$$

$$= 34\text{ T}$$

12. Electrons traveling at right angles to a magnetic field experience a force of 8.3×10^{-13} N when they are in a magnetic field of 6.2×10^{-1} T. How fast are the electrons moving?

$$v = \frac{F}{qB} = \frac{8.3\times10^{-13}\text{ N}}{(1.60\times10^{-19}\text{ C})(6.2\times10^{-1}\text{ T})}$$

$$= 8.4\times10^{6}\text{ m/s}$$

Chapter 25

page 885

1. A 72-cm wire is moved at an angle of 72° through a magnetic field of 1.7×10^{-2} T and experiences an *EMF* of 1.2 mV. How fast is the wire moving?

$$v = \frac{EMF}{LB \sin\theta}$$

$$= \frac{1.2\times10^{-3}\text{ V}}{(0.72\text{ m})(1.7\times10^{-2}\text{ T})(\sin 72°)}$$

$$= 0.10\text{ m/s}$$

2. A 14.2-m wire moves 3.12 m/s perpendicular to a 4.21-T field.

a. What *EMF* is induced in the wire?

$$EMF = BLv \sin\theta$$

$$= (4.21\text{ T})(14.2\text{ m})(3.12\text{ m/s})(\sin 90.0°)$$

$$= 187\text{ V}$$

b. Assume that the resistance in the wire is 0.89 Ω. What is the amount of current in the wire?

$$I = \frac{V}{R} = \frac{187\text{ V}}{0.89\ \Omega} = 2.1\times10^{2}\text{ A}$$

3. A 3.1-m length of straight wire has a resistance of 3.1 Ω. The wire moves at 26 cm/s at an angle of 29° through a magnetic field of 4.1 T. What is the induced current in the wire?

$$EMF = BLv \sin\theta$$

$$= (4.1\text{ T})(3.1\text{ m})(0.26\text{ m/s}^2)(\sin 29°)$$

$$= 1.6\text{ V}$$

$$I = \frac{EMF}{R} = \frac{1.6\text{ V}}{3.1\ \Omega} = 0.52\text{ A}$$

4. A generator delivers an effective current of 75.2 A to a wire that has a resistance of 0.86 Ω.

a. What is the effective voltage?

$$V_{eff} = I_{eff}R = (75.2)(0.86) = 65\text{ V}$$

b. What is the peak voltage of the generator?

$$V_{max} = \frac{V_{eff}}{\sqrt{2}} = 92\text{ V}$$

5. What is the RMS voltage of a household outlet if the peak voltage is 125 V?

$$V_{eff} = \sqrt{2}V_{max} = (\sqrt{2})(165\text{ V}) = 117\text{ V}$$

6. An outlet has a peak voltage of 170 V.

a. What is the effective voltage?

$$V_{eff} = \sqrt{2}V_{max}$$

$$= (\sqrt{2})(170\text{ V}) = 120\text{ V}$$

b. What effective current is delivered to an 11-Ω toaster?

$$I = \frac{V}{R} = \frac{120\text{ V}}{11\ \Omega} = 11\text{ A}$$

7. A step-up transformer has a primary coil consisting of 152 turns and a secondary coil with 3040 turns. The primary coil receives a peak voltage of 98 V.

a. What is the effective voltage in the primary coil?

$$V_{eff} = \sqrt{2}V_{max} = (\sqrt{2})(98\text{ V}) = 69\text{ V}$$

b. What is the effective voltage in the secondary coil?

$$V_2 = \frac{n_2}{n_1}V_1 = \left(\frac{3040}{152}\right)(69\text{ V}) = 1.4\text{ kV}$$

8. A step-down transformer has 9000 turns on the primary coil and 150 turns on the secondary coil. The *EMF* in the primary coil is 16 V. What is the voltage being applied to the secondary coil?

$$V_1 = \frac{n_1}{n_2}V_2 = \left(\frac{150}{9000}\right)(16\text{ V}) = 0.27\text{ V}$$

9. A transformer has 124 turns on the primary coil and 18,600 turns on the secondary coil.

a. Is this a step-down or a step-up transformer?

step-up

b. If the effective voltage in the secondary coil is 3.2 kV, what is the peak voltage being delivered to the primary coil?

$$V_{1,\,eff} = \frac{n_1}{n_2}V_{2,\,eff}$$

$$= \left(\frac{124}{18{,}600}\right)(3.2\text{ kV}) = 21\text{ V}$$

$$V_{1,\,max} = \sqrt{2}V_{1,\,eff} = (\sqrt{2})(21\text{ V})$$

$$= 3.0\times10^{1}$$

Chapter 26

pages 885–886

1. A stream of singly ionized (1−) fluorine atoms passes undeflected through a magnetic field of 2.5×10^{-3} T that is balanced by an electric field of 3.5×10^{3} V/m. The mass of the fluorine atoms is 19 times that of a proton.

a. What is the speed of the fluorine ions?

The electric force and magnetic forces balance each other.

$$Bqv = Eq$$

$$v = \frac{E}{B}$$

$$= \frac{3.5\times10^{3}\text{ V/m}}{2.5\times10^{-3}\text{ T}}$$

$$= 1.4\times10^{6}\text{ m/s}$$

b. If the electric field is switched off, what is the radius of the circular path followed by the ions?

The magnetic force acts as a centripetal force.

$$Bqv = \frac{mv^2}{r}$$

$$r = \frac{mv}{Bq}$$

$$= \frac{(19)(1.67\times10^{-27}\text{ kg})(1.4\times10^{6}\text{ m/s})}{(1.60\times10^{-19}\text{ C})(2.5\times10^{-3}\text{ T})}$$

$$= 110\text{ m}$$

2. An electron moves perpendicular to Earth's magnetic field with a speed of 1.78×10^{6} m/s. If the strength of Earth's magnetic field is about 5.00×10^{-5} T, what is the radius of the electron's circular path?

$$Bqv = \frac{mv^2}{r}$$

$$r = \frac{mv}{Bq}$$

$$= \frac{(9.11\times10^{-31}\text{ kg})(1.78\times10^{6}\text{ m/s})}{(5.00\times10^{-5}\text{ T})(1.60\times10^{-19}\text{ C})}$$

$$= 0.203\text{ m}$$

3. A proton with a velocity of 3.98×10^4 m/s perpendicular to the direction of a magnetic field follows a circular path with a diameter of 4.12 cm. If the mass of a proton is 1.67×10^{-27} kg, what is the strength of the magnetic field?

$$Bqv = \frac{mv^2}{r}$$

$$B = \frac{mv}{rq}$$

$$= \frac{(1.67\times10^{-27}\text{ kg})(3.98\times10^{4}\text{ m/s})}{(2.06\times10^{-2}\text{ m})(1.60\times10^{-19}\text{ C})}$$

$$= 2.02\times10^{-2}\text{ T}$$

4. A beam of doubly ionized (2+) calcium atoms is analyzed by a mass spectrometer. If $B = 4.5\times10^{-3}$ T, $r = 0.125$ m, and the mass of the calcium ions is 6.68×10^{-26} kg, what is the voltage of the mass spectrometer?

$$\frac{q}{m_{\text{calcium}}} = \frac{2V}{B^2r^2}$$

$$V = \frac{qB^2r^2}{2m}$$

$$= \frac{(3.20\times10^{-19}\text{ C})(4.5\times10^{-3}\text{ T})^2(0.125\text{ m})^2}{(2)(6.68\times10^{-26}\text{ kg})}$$

$$= 0.76\text{ V}$$

5. The speed of light in crown glass is 1.97×10^8 m/s. What is the dielectric constant of crown glass?

$$v = \frac{c}{\sqrt{K}}$$

$$K = \left(\frac{c}{v}\right)^2$$

$$= \left(\frac{3.00\times10^8\text{ m/s}}{1.97\times10^8\text{ m/s}}\right)^2$$

$$= 2.32$$

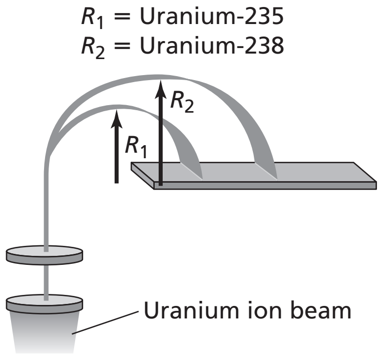
6. The dielectric constant of diamond is 6.00. What is the speed of light in diamond?

$$v = \frac{c}{\sqrt{K}}$$

$$= \frac{3.00\times10^8\text{ m/s}}{\sqrt{6.00}}$$

$$= 1.22\times10^8\text{ m/s}$$

7. By curving different isotopes through paths with different radii, a mass spectrometer can be used to purify a sample of mixed uranium-235 and uranium-238 isotopes. Assume that $B = 5.00\times10^{-3}$ T, $V = 55.0$ V, and that each uranium isotope has a 5+ ionization state. Uranium-235 has a mass that is 235 times that of a proton, while uranium-238 has a mass that is 238 times that of a proton. By what distance will the two isotopes be separated by the mass spectrometer?



$$\frac{q}{m} = \frac{2V}{B^2r^2}$$

$$r_{\text{U-235}} = \sqrt{\frac{2Vm}{qB^2}}$$

$$= \sqrt{\frac{(2)(55.0\text{ V})(235)(1.67\times10^{-27}\text{ kg})}{(5)(1.60\times10^{-19}\text{ kg})(5.00\times10^{-3}\text{ T})^2}}$$

$$= 1.47\text{ m}$$

$$r_{\text{U-238}} = \sqrt{\frac{2Vm}{qB^2}}$$

$$= \sqrt{\frac{(2)(55.0\text{ V})(238)(1.67\times10^{-27}\text{ kg})}{(5)(1.60\times10^{-19}\text{ kg})(5.00\times10^{-3}\text{ T})^2}}$$

$$= 1.48\text{ m}$$

$$\text{Separation} = r_{\text{U-238}} - r_{\text{U-235}}$$

$$= 1.48\text{ m} - 1.47\text{ m}$$

$$= 0.01\text{ m}$$

8. A mass spectrometer often is used in carbon dating to determine the ratio of C-14 isotopes to C-12 isotopes in a biological sample. This ratio then is used to estimate how long ago the once-living organism died. Because a mass spectrometer is sensitive to the charge-to-mass ratio, it is possible for a contaminant particle to alter the value measured for the C-14/C-12 ratio, and thus, yield erroneous results. When ionized, C-14 forms an ion with a +4 charge, and the mass of C-14 is 14 times that of a proton. Consider a contaminant lithium particle. If the most common lithium isotope has a mass that is seven times that of a proton, what must be the charge of the lithium ion needed to contaminate a carbon-14 experiment?

$$\frac{q_{\text{C}}}{m_{\text{C}}} = \frac{2V}{B^2r^2} = \frac{q_{\text{Li}}}{m_{\text{Li}}}$$

$$q_{\text{Li}} = q_{\text{C}}\frac{m_{\text{Li}}}{m_{\text{C}}}$$

$$= (+4)\left(\frac{7m_p}{14m_p}\right)$$

$$= +2$$

9. What is the wavelength of a radio wave with a frequency of 90.7 MHz?

$$\lambda = \frac{c}{f}$$

$$= \frac{3.00\times10^{8}\text{ m/s}}{90.7\times10^{6}\text{ Hz}}$$

$$= 3.31\text{m}$$

10. What is the frequency of a microwave with a wavelength of 3.27 mm?

$$\lambda = \frac{c}{f}$$

$$f = \frac{c}{\lambda}$$

$$= \frac{3.00\times10^{8}\text{ m/s}}{3.27\times10^{-3}\text{ m}}$$

$$= 9.17\times10^{10}\text{ Hz}$$

11. What is the frequency of an X ray with a wavelength of 1.00×10^{-10} m?

$$\lambda = \frac{c}{f}$$

$$f = \frac{c}{\lambda}$$

$$= \frac{3.00\times10^{8}\text{ m/s}}{1.00\times10^{-10}\text{ m}}$$

$$= 3.00\times10^{18}\text{ Hz}$$

12. In recent years, physicists have slowed the speed of light passing through a material to about 1.20 mm/s. What is the dielectric constant of this material?

$$v = \frac{c}{\sqrt{K}}$$

$$K = \left(\frac{c}{v}\right)^2$$

$$= \left(\frac{3.00\times10^{8}\text{ m/s}}{1.20\times10^{-3}\text{ m/s}}\right)^2$$

$$= 6.25\times10^{22}$$

Chapter 27

pages 886–887

1. If the maximum kinetic energy of emitted photoelectrons is 1.4×10^{-18} J, what is the stopping potential of a certain photocell?

   $$KE = -qV_0$$

   $$V_0 = \frac{-KE}{q}$$

   $$= \frac{-1.4\times10^{-18}\ \text{J}}{-1.60\times10^{-19}\ \text{C}}$$

   $$= 8.8\ \text{V}$$

2. The stopping potential of a photocell is 2.3 V. What is the initial velocity of an emitted photoelectron that is brought to a stop by the photocell?

   $$KE = -qV_0 = \frac{1}{2}mv^2$$

   $$v = \sqrt{\frac{-2qV_0}{m}}$$

   $$= \sqrt{\frac{(-2)(-1.60\times10^{-19}\ \text{C})(2.3\ \text{V})}{9.11\times10^{-31}\ \text{kg}}}$$

   $$= 9.0\times10^{5}\ \text{m/s}$$

3. If a photoelectron traveling at 8.7×10^{5} m/s is stopped by a photocell, what is the photocell's stopping potential?

   $$KE = -qV_0 = \frac{1}{2}mv^2$$

   $$V_0 = \frac{-mv^2}{2q}$$

   $$= \frac{-(9.11\times10^{-31}\ \text{kg})(8.7\times10^{5}\ \text{m/s})^2}{(2)(-1.60\times10^{-19}\ \text{C})}$$

   $$= 2.2\ \text{V}$$

4. Light with a frequency of 7.5×10^{14} Hz is able to eject electrons from the metal surface of a photocell that has a threshold frequency of 5.2×10^{14} Hz. What stopping potential is needed to stop the emitted photoelectrons?

   $KE = h_f - h_{f0} = h(f - f_0)$ **and** $KE = -qV_0$

   Thus,

   $$V_0 = \frac{-KE}{q} = \frac{-h(f-f_0)}{q} = \frac{-(6.626\times10^{-34}\ \text{J/Hz})(7.5\times10^{14}\ \text{Hz} - 5.2\times10^{14}\ \text{Hz})}{-1.60\times10^{-19}\ \text{C}}$$

   $$= 0.95\ \text{V}$$

5. A metal has a work function of 4.80 eV. Will ultraviolet radiation with a wavelength of 385 nm be able to eject a photoelectron from the metal?

First calculate the energy of the photon.

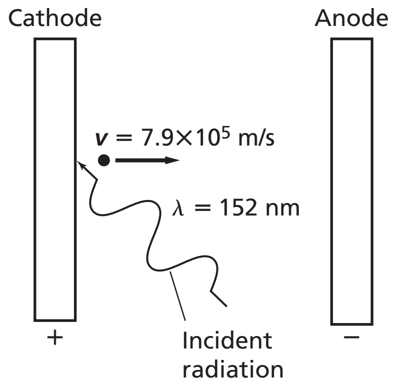
$$E = \frac{1240\ \text{eV·nm}}{\lambda}$$

$$= \frac{1240\ \text{eV·nm}}{385\ \text{nm}}$$

$$= 3.22\ \text{eV}$$

To eject a photoelectron from the metal, the energy of the incident radiation must be greater than the work function of the metal. Because the energy of the incident radiation, 3.22 eV, is less than the work function, 4.80 eV, a photoelectron will not be ejected.

6. When a metal is illuminated with radiation with a wavelength of 152 nm, photoelectrons are ejected with a velocity of 7.9×10^5 m/s. What is the work function, in eV, of the metal?



First calculate the energy of the photon in joules.

$$E = \frac{hc}{\lambda}$$

$$= \frac{(6.626\times10^{-34}\ \text{J/Hz})(2.998\times10^{8}\ \text{m/s})}{1.52\times10^{-7}\ \text{m}}$$

$$= 1.31\times10^{-18}\ \text{J}$$

Next, calculate the kinetic energy.

$$KE = \frac{1}{2}mv^2$$

$$= \left(\frac{1}{2}\right)(9.11\times10^{-31}\ \text{kg})(7.9\times10^{5}\ \text{m/s})^2$$

$$= 2.8\times10^{-19}\ \text{J}$$

$$KE = E - W$$

$$W = E - KE$$

$$= 1.31\times10^{-18}\ \text{J} - 2.8\times10^{-19}\ \text{J}$$

$$= 1.0\times10^{-18}\ \text{J}$$

$$= (1.0\times10^{-18}\ \text{J})\left(\frac{1\ \text{eV}}{1.60\times10^{-19}\ \text{J}}\right)$$

$$= 6.2\ \text{eV}$$

7. The de Broglie wavelength for an electron traveling at 9.6×10^5 m/s is 7.6×10^{-10} m. What is the mass of the electron?

$$\lambda = \frac{h}{mv}$$

$$m = \frac{h}{\lambda v}$$

$$= \frac{6.626\times10^{-34}\ \text{J/Hz}}{(7.6\times10^{-10}\ \text{m})(9.6\times10^{5}\ \text{m/s})}$$

$$= 9.1\times10^{-31}\ \text{kg}$$

8. What is the de Broglie wavelength of a 68-kg man moving with a kinetic energy of 8.5 J?

$$KE = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2KE}{m}}$$

The de Broglie wavelength is then,

$$\lambda = \frac{h}{mv} = \frac{h}{m}\sqrt{\frac{m}{2KE}}$$

$$= h(2mKE)^{-\frac{1}{2}}$$

$$= (6.626\times10^{-34}\ \text{J/Hz})((2)(68\ \text{kg})(8.5\ \text{J}))^{-\frac{1}{2}}$$

$$= 1.9\times10^{-35}\ \text{m}$$

9. An electron has a de Broglie wavelength of 5.2×10^{-10} m. What potential difference is responsible for this wavelength?

$$\lambda = \frac{h}{mv}$$

$$v = \frac{h}{\lambda m}$$

and

$$KE = -qV_0 = \frac{1}{2}mv^2$$

$$V_0 = \frac{-mv^2}{2q}$$

$$= \frac{-mh^2}{2q\lambda^2m^2}$$

$$= \frac{-h^2}{2q\lambda^2 m}$$

$$= \frac{-(6.626\times10^{-34}\ \text{J/Hz})^2}{(2)(-1.60\times10^{-19}\ \text{C})(5.2\times10^{-10}\ \text{m})^2(9.11\times10^{-31}\ \text{kg})}$$

$$= 5.6\ \text{V}$$

Chapter 28

page 887

1. An electron in a hydrogen atom makes a transition from E_3 to E_1. How much energy does the atom lose?

$$E_n = -13.6 \text{ eV} \times \frac{1}{n^2}$$

$$\Delta E = E_1 - E_3$$

$$= \frac{-13.6}{1^2} - \left(\frac{-13.6}{3^2}\right)$$

$$= -12.1 \text{ eV}$$

2. An electron in the hydrogen atom loses 3.02 eV as it falls to energy level E_2. From which energy level did the atom fall?

$$\Delta E = E_f - E_i$$

$$-3.02 \text{ eV} = -13.6\left(\frac{1}{n_y{}^2} - \frac{1}{n_x{}^2}\right)$$

$$-3.02 \text{ eV} + 3.40 \text{ eV} = \frac{13.6 \text{ eV}}{n_x{}^2}$$

$$n_x = 6$$

3. Which energy level in a hydrogen atom has a radius of 7.63×10^{-9} m?

$$r = \frac{h^2n^2}{4\pi^2Kmq^2}$$

$$n = \sqrt{\frac{4\pi^2Kmq^2r}{h^2}}$$

$$= \sqrt{\frac{4\pi^2(9.0\times10^9 \text{ N·m}^2/\text{C}^2)(9.11\times10^{-31} \text{ kg})(1.60\times10^{-19} \text{ C})^2(7.63\times10^{-9} \text{ m})}{(6.626\times10^{-34} \text{ J·s})^2}}$$

$$= 12$$

Alternatively, $r = r_0 m^2$ where r_0 is the Bohr radius in hydrogen, 530 mm.

Thus, $m = \sqrt{\frac{r}{r_0}} = \sqrt{\frac{7.63\times10^{-9} \text{ m}}{5.30\times10^{-11} \text{ m}}} = \sqrt{144} = 12$

4. When an electron falls from E_4 to E_1, what is the frequency of the emitted photon?

$$\Delta E = E_1 - E_4$$

$$= (-2.17\times10^{-18} \text{ J})\left(\frac{1}{1^2}\right) - \left((-2.17\times10^{-18} \text{ J})\left(\frac{1}{4^2}\right)\right)$$

$$= 2.04\times10^{-18} \text{J}$$

$$E = hf$$

$$f = \frac{E}{h}$$

$$= \frac{2.04\times10^{-18} \text{ J}}{6.626\times10^{-34} \text{ J·s}}$$

$$= 3.08\times10^{15} \text{ Hz}$$

5. If an electron moves from E_3 to E_5, what is the wavelength of the photon absorbed by the atom?

$$\Delta E = E_5 - E_3$$

$$= (-2.17\times10^{-18}\ \text{J})\left(\frac{1}{5^2}\right) - \left((-2.17\times10^{-18}\ \text{J})\left(\frac{1}{3^2}\right)\right)$$

$$= 1.54\times10^{-19}\ \text{J}$$

$$\Delta E = hf = \frac{hc}{d}$$

$$d = \frac{hc}{\Delta E}$$

$$= \frac{(6.626\times10^{-34}\ \text{J·s})(3.00\times10^{8}\ \text{m/s})}{1.54\times10^{-19}\ \text{J}}$$

$$= 1.29\times10^{-6}\ \text{m}$$

6. If a hydrogen atom in its ground state absorbs a photon with a wavelength of 93 nm, it jumps to an excited state. What is the value of the energy in that excited state?

$$E = hf = \frac{hc}{\lambda}$$

$$= \frac{(6.626\times10^{-34}\ \text{J·s})(3.00\times10^{8}\ \text{m/s})}{9.3\times10^{-8}\ \text{m}}$$

$$= 2.14\times10^{-18}\ \text{J}$$

$$= (2.14\times10^{-18}\ \text{J})\left(\frac{1\ \text{eV}}{1.60\times10^{-19}\ \text{J}}\right)$$

$$= 13.3\ \text{eV absorbed}$$

$$E_f = E_i + \Delta E$$

$$= -13.6\ \text{eV} + 13.3\ \text{eV}$$

$$= -0.27\ \text{eV}$$

Chapter 29

pages 887–888

1. Indium has 3 free electrons per atom. Use Appendix D and determine the number of free electrons in 1.0 kg of indium.

$$\frac{\text{free e}^-}{\text{kg}} = (\text{free e}^-/\text{atom})(N_A)\left(\frac{1}{M}\right)\left(\frac{1000\text{ g}}{1\text{ kg}}\right)$$

Substitute: free e⁻/atom = 3 free e⁻/1 atom,

$N_A = 6.02\times10^{23}$ atoms/mol, M = 114.82 g/mol

$$\frac{\text{free e}^-}{\text{kg}} = \left(\frac{3\text{ free e}^-}{1\text{ atom}}\right)\left(\frac{6.02\times10^{23}\text{ atoms}}{1\text{ mol}}\right)\left(\frac{1\text{ mol}}{114.82\text{ g}}\right)\left(\frac{1000\text{ g}}{1\text{ kg}}\right)$$

$$= 1.57\times10^{25}\text{ free e}^-/\text{kg for indium}$$

2. Cadmium has 2 free electrons per atom. Use Appendix D and determine the number of free electrons in 1.0 dm^3 of Cd.

$$\frac{\text{free e}^-}{\text{dm}^3} = (\text{free e}^-/\text{atom})(N_A)\left(\frac{1}{M}\right)(\rho)\left(\frac{1000\text{ cm}^3}{1\text{ dm}^3}\right)$$

Substitute: free e^-/atom = 2 free e^-/1 atom,

$N_A = 6.02\times10^{23}$ atoms/mol, M = 112.41 g/mol,

$\rho = 8.65\text{ g/cm}^3$

$$\frac{\text{free e}^-}{\text{dm}^3} = \left(\frac{2\text{ free e}^-}{1\text{ atom}}\right)\left(\frac{6.02\times10^{23}\text{ atoms}}{1\text{ mol}}\right)\left(\frac{1\text{ mol}}{112.41\text{ g}}\right)\left(\frac{8.65\text{ g}}{1\text{ cm}^3}\right)\left(\frac{1000\text{ cm}^3}{1\text{ dm}^3}\right)$$

$$= 9.26\times10^{25}\text{ free e}^-/\text{dm}^3\text{ in cadmium}$$

3. Copper has 1 free electron per atom. What length of 1.00-mm diameter copper wire contains 7.81×10^{24} free electrons? Use Appendix D for physical constants.

$$L_{wire} = \left(\frac{1}{\pi r^2}\right)(\text{number of free e}^-)\left(\frac{\text{atoms}}{\text{free e}^-}\right)\left(\frac{1}{N_A}\right)(M)\left(\frac{1}{\rho}\right)$$

Substitute: $N_A = 6.02\times10^{23}$ atoms/mol,

M = 63.546 g/mol, $\rho = 8.92\text{ g/cm}^3$,

number of free e^- = 7.81×10^{24} free e^-,

r_{wire} = 1.00 mm/2 = 0.50 mm = 0.050 cm

$$L_{wire} = \left(\frac{1}{\pi\left(\frac{0.100\text{ cm}}{2}\right)^2}\right)(7.81\times10^{24}\text{ free e}^-)\left(\frac{1\text{ atom}}{1\text{ free e}^-}\right)$$

$$\left(\frac{1\text{ mol}}{6.022\times10^{23}\text{ atoms}}\right)\left(\frac{63.546\text{ g}}{1\text{ mol}}\right)\left(\frac{1\text{ cm}^3}{8.92\text{ g}}\right)$$

$$= 1.18\times10^4\text{ cm} = 118\text{ m}$$

4. At 400.0 K, germanium has 1.13×10^{15} free electrons/cm^3. How many free electrons per Ge atom are there at this temperature?

$$\frac{\text{free e}^-}{\text{atom}} = \left(\frac{1}{N_A}\right)(M)\left(\frac{1}{\rho}\right)(\text{free e}^-/\text{cm}^3 \text{ for Ge})$$

Substitute: $N_A = 6.02\times10^{23}$ **atoms/mol,**

$M = 72.63$ **g/mol,** $\rho = 5.23$ **g/cm^3,**

free e$^-$/cm^3 for Ge = 1.13×10^{15} free e$^-$/cm^3

$$\frac{\text{free e}^-}{\text{atom}} = \left(\frac{1 \text{ mol}}{6.02\times10^{23} \text{ atoms}}\right)\left(\frac{72.63 \text{ g}}{1 \text{ mol}}\right)\left(\frac{1 \text{ cm}^3}{5.23 \text{ g}}\right)\left(\frac{1.13\times10^{15} \text{ free e}^-}{\text{cm}^3}\right)$$

free e$^-$/atom of Ge at 400.0 K = 2.61×10^{-8}

5. At 400.0 K, silicon has 4.54×10^{12} free electrons/cm^3. How many free electrons per Si atom are there at this temperature?

$$\frac{\text{free e}^-}{\text{atom}} = \left(\frac{1}{N_A}\right)(M)\left(\frac{1}{\rho}\right)(4.54\times10^{12} \text{ free e}^-/\text{cm}^3 \text{ for Si})$$

Substitute: $N_A = 6.02\times10^{23}$ **atoms/mol,** $M = 28.09$ **g/mol,** $\rho = 2.33$ **g/cm^3,**

free e$^-$/cm^3 for Si = 4.54×10^{12} free e$^-$/cm^3 at 400.0 K

$$\frac{\text{free e}^-}{\text{atom}} = \left(\frac{1 \text{ mol}}{6.02\times10^{23} \text{ atoms}}\right)\left(\frac{28.09 \text{ g}}{1 \text{ mol}}\right)\left(\frac{1 \text{ cm}^3}{2.33 \text{ g}}\right)\left(\frac{4.54\times10^{12} \text{ free e}^-}{\text{cm}^3}\right)$$

free e$^-$/atom of Si at 400.0 K = 9.09×10^{-11}

6. At 200.0 K, silicon has 3.79×10^{-18} free electrons per atom. How many free electrons/cm^3 are there in silicon at this temperature?

$$\frac{\text{free e}^-}{\text{cm}^3} = \left(\frac{\text{free e}^-}{\text{atom}}\right)(N_A)\left(\frac{1}{M}\right)(\rho)$$

Substitute: free e$^-$/atom = 3.79×10^{-18} free e$^-$/1 atom,

$N_A = 6.02\times10^{23}$ **atoms/mol,** $M = 28.09$ **g/mol,** $\rho = 2.33$ **g/cm^3**

$$\frac{\text{free e}^-}{\text{cm}^3} = \left(\frac{3.79\times10^{-18} \text{ e}^-}{1 \text{ atom}}\right)\left(\frac{6.02\times10^{23} \text{ atoms}}{1 \text{ mol}}\right)\left(\frac{1 \text{ mol}}{28.09 \text{ g}}\right)\left(\frac{2.33 \text{ g}}{1 \text{ cm}^3}\right)$$

$$= 1.89\times10^{5} \text{ free e}^-/\text{cm}^3 \text{ in silicon at 200 K}$$

7. Silicon has 1.45×10^{10} free electrons/cm^3 at room temperature. If you wanted to have 3×10^6 as many electrons from arsenic doping as thermal free electrons from silicon at room temperature, how many arsenic atoms should there be for each silicon atom? Each arsenic atom provides 1 free electron. Use Appendix D for physical constants.

$$\frac{\text{As atoms}}{\text{Si atoms}} = \left(\frac{\text{number As atoms}}{\text{As e}^-}\right)\left(\frac{\text{number of As e}^-}{\text{thermal e}^-}\right)$$

$$\left(\frac{\text{number of thermal e}^-}{\text{cm}^3}\right)(M)\left(\frac{1}{N_A}\right)\left(\frac{1}{\rho}\right)$$

Substitute: $M = 28.09$ **g/mol,** $N_A = 6.02\times10^{23}$ **atoms/mol,** $\rho = 2.33$ **g/cm^3,**

1 As atom = 1 As e$^-$, 3×10^6 As e$^-$/thermal e$^-$,

number of thermal e$^-$/cm^3 = 1.45×10^{10} e$^-$/cm^3

$$\frac{\text{As atoms}}{\text{Si atoms}} = \left(\frac{\text{1 As atoms}}{\text{1 As e}^-}\right)\left(\frac{3\times10^6 \text{ As e}^-}{\text{thermal e}^-}\right)\left(\frac{1.45\times10^{10}\text{ thermal e}^-}{\text{cm}^3}\right)\left(\frac{28.09\text{ g}}{\text{mol}}\right)$$
$$\left(\frac{\text{mol}}{6.02\times10^{23}\text{ Si atoms}}\right)\left(\frac{\text{cm}^3}{2.33\text{ g}}\right)$$
$$= 8.71\times10^{-7}$$

8. At 200.0 K, germanium has 1.16×10^{10} thermally liberated charge carriers/cm^3. If it is doped with 1 As atom to 525,000 Ge atoms, what is the ratio of doped carriers to thermal carriers at this temperature? See Appendix D for physical constants.

$$\frac{\text{doped carriers}}{\text{thermal carriers}} = \left(\frac{\text{doped carriers}}{5.25\times10^5\text{ atoms}}\right)(N_A)\left(\frac{1}{M}\right)(\rho)\left(\frac{1}{\text{thermal carriers}}\right)$$

Substitute: $M = 72.6$ **g/mol,**

$N_A = 6.02\times10^{23}$ **atoms/mol,** $\rho = 5.23$ **g/cm**^{3}

thermal carriers $= 1.16\times10^{10}$ **thermal carriers/cm**^{3}

$$\frac{\text{doped carriers}}{\text{thermal carriers}} = \left(\frac{\text{1 doped carrier}}{5.25\times10^5\text{ atoms}}\right)\left(\frac{6.02\times10^{23}\text{ atoms}}{\text{mol}}\right)\left(\frac{\text{mol}}{72.6\text{ g}}\right)\left(\frac{5.23\text{ g}}{\text{cm}^3}\right)$$
$$\left(\frac{\text{cm}^3}{1.16\times10^{10}\text{ thermal carriers}}\right)$$
$$= 7.12\times10^6$$

9. At 200.0 K, silicon has 1.89×10^5 thermally liberated charge carriers/cm^3. If it is doped with 1 As atom to 3.75 million Si atoms, what is the ratio of doped carriers to thermal carriers at this temperature? See Appendix D for physical constants.

$$\frac{\text{doped carriers}}{\text{thermal carriers}} = \left(\frac{\text{doped carriers}}{3.75\times10^6\text{ atoms}}\right)(N_A)\left(\frac{1}{M}\right)(\rho)\left(\frac{1}{\text{thermal carriers}}\right)$$

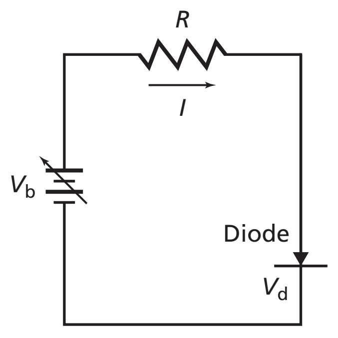
Substitute: $M = 28.09$ **g/mol,**

$N_A = 6.02\times10^{23}$ **atoms/mol,** $\rho = 2.33$ **g/cm**^{3}

thermal carriers $= 1.89\times10^5$ **thermal carriers/cm**^{3}

$$\frac{\text{doped carriers}}{\text{thermal carriers}} = \left(\frac{\text{1 doped carrier}}{3.75\times10^6\text{ atoms}}\right)\left(\frac{6.02\times10^{23}\text{ atoms}}{\text{mol}}\right)\left(\frac{\text{mol}}{28.09\text{ g}}\right)\left(\frac{2.33\text{ g}}{\text{cm}^3}\right)$$
$$\left(\frac{\text{cm}^3}{1.89\times10^5\text{ thermal carriers}}\right)$$
$$= 7.05\times10^{10}$$

10. The diode shown below has a voltage drop, V_d, of 0.45 V when I = 11 mA. If a 680-Ω resistor, R, is connected in series, what power supply voltage, V_b is needed?



$$V_b = IR + V_d = (0.011\text{ A})(680\ \Omega) + 0.45\text{ V}$$
$$= 7.9\text{ V}$$

11. A diode in a circuit similar to the one in Figure 29-26 has a voltage drop, V_d, of 0.95 V when $I = 18$ mA. If a 390-Ω resistor, R, is connected in series, what power supply voltage, V_b is needed?

$V_b = IR + V_d$

$= (0.018 \text{ A})(390\ \Omega) + 0.95 \text{ V}$

$= 8.0 \text{ V}$

12. What power supply voltage would be needed to produce a current of 27 mA in the circuit in problem 10? Assume the diode voltage is uncharged.

$V_b = IR + V_d$

$= (0.027 \text{ A})(680\ \Omega) + 0.45 \text{ V}$

$= 19 \text{ V}$

Chapter 30

pages 888–889

1. Carbon-14, or ^{14}C, is an isotope of the common $^{12}_{6}C$, and is used in dating ancient artifacts. What is the composition of its nucleus?

six protons (equal to *Z*) and eight neutrons (equal to *A* − *Z*)

2. An isotope of iodine ($Z = 53$) is used to treat thyroid conditions. Its mass number is 131. How many neutrons are in its nucleus?

131 − 53 = 78 neutrons

3. The only nonradioactive isotope of fluorine has nine protons and ten neutrons.

a. What is its mass number?

mass number (*A*) = 19

b. The atomic mass unit, *u*, is equal to 1.66×10^{-27} kg. What is fluorine-19's approximate mass in kilograms?

$(19 \text{ nucleons})(1.66\times10^{-27} \text{ kg/nucleon})$

$= 3.15\times10^{-26} \text{ kg}$

c. Write the full symbol of this atom.

$^{19}_{9}F$

4. The magnesium isotope $^{25}_{12}Mg$ has a mass of 24.985840 u.

a. Calculate its mass defect.

mass defect = (isotope mass) − (mass of protons and electrons) − (mass of neutrons)

$= 24.985840 \text{ u} - (12)(1.007825 \text{ u}) - (13)(1.008665 \text{ u})$

$= -0.220705 \text{ u}$

b. Calculate its binding energy in MeV.

binding energy = (mass defect)(binding energy of 1 u)

$= (-0.220705 \text{ u})(931.49 \text{ MeV/u})$

$= -205.58 \text{ MeV}$

5. The isotope $^{10}_{5}B$ has a mass of 10.012939 u.

a. Calculate the mass defect.

mass defect = (isotope mass) − (mass of protons and electrons) − (mass of neutrons)

= 10.012939 u − (5)(1.007825 u) − (5)(1.008665 u)

= −0.069511 u

b. Calculate its binding energy in MeV.

binding energy = (mass defect) (binding energy of 1 u)

= (−0.069511 u)(931.49 MeV/u)

= −64.749 MeV

c. Calculate its binding energy per nucleon.

binding energy per nucleon is $\frac{-64.744 \text{ MeV}}{10 \text{ nucleons}} = -6.4749 \text{ MeV/nucleon}$

6. The most stable isotope of all is $^{56}_{26}Fe$. Its binding energy per nucleon is −8.75 MeV/nucleon.

a. What is the binding energy of this isotope?

(56 nucleons)(–8.75 MeV/nucleon) = –4.90×10^{2} MeV

b. What is the mass defect of this isotope?

$$\text{mass defect} = \frac{\text{binding energy}}{\text{binding energy of 1 u}} = \frac{-4.90\times10^{2} \text{ MeV}}{931.49 \text{ MeV/u}} = -0.526 \text{ u}$$

7. The isotope $^{239}_{94}Pu$ can be transmuted to an isotope of uranium, $^{235}_{92}U$.

a. Write the nuclear equation for this transmutation.

$^{239}_{94}\text{Pu} \rightarrow {}^{235}_{92}\text{U} + {}^{A}_{Z}\text{X}$

where $Z = 94 - 92 = 2$

$A = 239 - 235 = 4$

For $Z = 2$, the element must be helium. Thus the equation is

$^{239}_{94}\text{Pu} \rightarrow {}^{235}_{92}\text{U} + {}^{4}_{2}\text{He}$

b. Identify the particle that is ejected.

an α particle

8. The radioisotope $^{222}_{84}Po$ undergoes alpha decay to form an isotope of lead (lead has atomic number 82). Determine what the mass number of that isotope must be by writing a nuclear equation.

$^{222}_{84}\text{Po} \rightarrow {}^{A}_{Z}\text{Pb} + {}^{4}_{2}\text{He}$

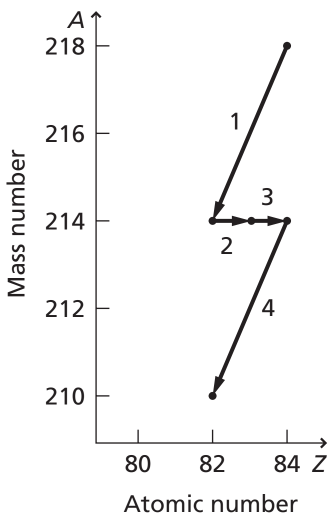
where $Z = 84 - 2 = 82$

$A = 222 - 4 = 218$

Thus the equation is $^{222}_{84}\text{Po} \rightarrow {}^{218}_{82}\text{Pb} + {}^{4}_{2}\text{He}$

The mass number is 218.

9. The graph below shows a sequence of alpha and beta decays, labeled *1*, *2*, *3*, and *4*. Consult Table 30-1 as needed.



a. Which represent alpha decays, and which represent beta decays?

alpha decays: 1 and 4, in which mass number decreases by 4 and atomic number by 2; beta decays: 2 and 3, in which atomic number increases by 1 and mass number stays the same

b. What is the overall change in mass in the sequence? In the number of neutrons?

Overall change in mass is 218 u − 210 u = 8 u lower. Overall change in *Z* is 84 – 82 = 2 lower. Thus, overall change in the number of neutrons is 6 lower (8 nucleons less, 2 protons less, so 6 neutrons less).

10. Use Appendix D to complete the two nuclear equations. Include correct subscripts and superscripts for each of the particles.

a. ${}^{32}_{15}P \rightarrow ? + \beta +$ antineutrino

$${}^{32}_{15}\mathbf{P} \rightarrow {}^{A}_{Z}\mathbf{X} + {}^{0}_{-1}\mathbf{e} + {}^{0}_{0}\bar{\nu}$$

where $Z = 15 - (-1) - 0 = 16$

$A = 32 - 0 - 0 = 32$

For $Z = 16$, the element must be sulfur. Thus, the equation is

$${}^{32}_{15}\mathbf{P} \rightarrow {}^{32}_{16}\mathbf{S} + {}^{0}_{-1}\mathbf{e} + {}^{0}_{0}\bar{\nu}$$

b. ${}^{235}_{92}U \rightarrow ? + \alpha$

$${}^{235}_{92}\mathbf{U} \rightarrow {}^{A}_{Z}\mathbf{X} + {}^{4}_{2}\mathbf{He}$$

where $Z = 92 - 2 = 90$

$A = 235 - 4 = 231$

For $Z = 90$, the element must be thorium. Thus, the equation is

$${}^{235}_{92}\mathbf{U} \rightarrow {}^{231}_{90}\mathbf{Th} + {}^{4}_{2}\mathbf{He}$$

11. Write the complete nuclear equation for the beta decay of ${}^{34}_{16}S$.

$${}^{34}_{16}\mathbf{S} \rightarrow {}^{A}_{Z}\mathbf{X} + {}^{0}_{-1}\mathbf{e} + {}^{0}_{0}\bar{\nu}$$

where $Z = 16 - (-1) - 0 = 17$

$A = 34 - 0 - 0 = 34$

For $Z = 17$, the element must be chlorine. Thus, the equation is

$${}^{34}_{16}\mathbf{S} \rightarrow {}^{34}_{17}\mathbf{Cl} + {}^{0}_{+1}\mathbf{e} + {}^{0}_{0}\bar{\nu}$$

12. A positron is identical to a beta particle, except that its charge is +1 instead of −1. ${}^{37}_{19}K$ undergoes spontaneous positron decay to form an isotope of argon. Identify the isotope of argon by writing a nuclear equation.

$${}^{37}_{19}\mathbf{K} \rightarrow {}^{A}_{Z}\mathbf{Ar} + {}^{0}_{+1}\mathbf{e} + {}^{0}_{0}\bar{\nu}$$

where $Z = 19 - 1 - 0 = 18$

$A = 37 - 0 - 0 = 37$

Thus the equation is

$${}^{37}_{19}\mathbf{K} \rightarrow {}^{37}_{18}\mathbf{Ar} + {}^{0}_{+1}\mathbf{e} + {}^{0}_{0}\bar{\nu}$$

The isotope is argon −37.

13. Iodine-131 has a half-life of 8.0 days. If there are 60.0 mg of this isotope at time zero, how much remains 24 days later?

$$\frac{24\text{ days}}{8.0\text{ days/half-life}} = 3.0\text{ half-lives}$$

$$\text{remaining} = \text{original}\left(\frac{1}{2}\right)^{t}$$

$$= (60.0\text{ mg})\left(\frac{1}{2}\right)^{3.0}$$

$$= 7.5\text{ mg}$$

14. Refer to Table 30-2. Given a sample of cobalt-60,

a. how long a time is needed for it to go through four half-lives?

(4)(30 years) = 120 years

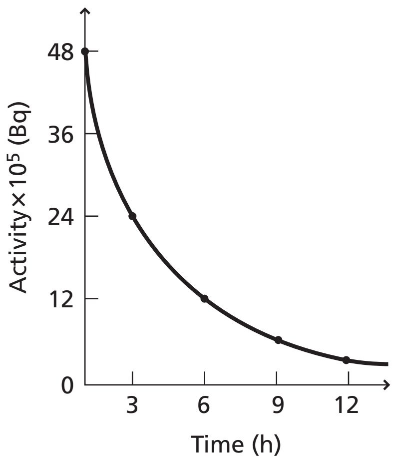
b. what fraction remains at the end of that time?

$$\text{remaining} = \text{original}\left(\frac{1}{2}\right)^{t}$$

$$= \text{original}\left(\frac{1}{2}\right)^{4}$$

$$= \left(\frac{1}{16}\right)\text{original}$$

15. The graph shows the activity of a certain radioisotope over time. Deduce its half-life from this data.



Every 3.0 h the activity is half of the previous activity, so the half-life is 3.0 h.

16. The mass of a proton and of an antiproton is 1.00728 u. Recall that the conversion of exactly 1 u into energy yields 931.5 MeV.

a. Calculate the mass used up when a proton and an antiproton annihilate one another.

(2)(1.00728 u) = 2.01456 u

b. Calculate the energy released here.

(2.01456 u)(931.5 MeV/u) = 1876.5 MeV

17. One source of a star's energy is the fusion of two deuterons to form an alpha particle plus a gamma ray.

Particle	Mass in u
$^{2}_{1}H$	2.0136
$^{4}_{2}He$	4.0026
$^{0}_{0}\gamma$	0.0000

a. Write the nuclear equation for this fusion.

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{4}_{2}He + ^{0}_{0}\gamma$$

b. Calculate the mass "lost" in this process.

mass before − mass after

= 2(2.0136 u) − 4.0026 u

= 0.0246 u

c. Calculate the energy released in MeV.

(0.0246 u)(931.49 MeV/u) = 22.9 MeV

18. When 1 mol (235 g) of uranium-235 undergoes fission, about 2.0×10^{10} kJ of energy are released. When 4.0 g of hydrogen undergoes fusion, about 2.0×10^{9} kJ are released.

a. For each, calculate the energy yield per gram of fuel.

$$\frac{2.0\times10^{9}\ \text{kJ}}{4.0\ \text{g}} = 5.0\times10^{8}$$

kJ/g for fusion of hydrogen;

$$\frac{2.0\times10^{10}\ \text{kJ}}{235\ \text{g}} = 8.5\times10^{7}$$

kJ/g for fission of uranium

b. Which process produces more energy per gram of fuel?

Fusion releases about six times as much energy per gram of fuel as fission.