

## > Chapter 1

# Kinematics: describing motion

### CHAPTER OUTLINE

- define and use distance, displacement, speed and velocity
- draw and interpret displacement–time graphs
- describe laboratory methods for determining speed
- understand the differences between scalar and vector quantities, and give examples of each
- use vector addition to add and subtract vector quantities that are in the same plane

### KEY EQUATIONS

$$\text{average speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

$$\text{average speed} = \frac{\Delta d}{\Delta t}$$

$$\text{velocity} = \frac{\text{change in displacement}}{\text{time taken}}$$

$$\text{velocity} = \frac{\Delta s}{\Delta t}$$

## Exercise 1.1 Speed calculations

These questions will help you to revise calculations involving speed, distance and time. You will also practise converting units. The SI unit of time is the second (s). It is usually best to work in seconds and convert to minutes or hours as the last step in a calculation. The correct scientific notation for metres per second is  $\text{m s}^{-1}$ .

- 1 A train travels 4000 m in 125 s. The measurement of the time is not exact and the uncertainty in the time is  $\pm 1$  s. The uncertainty in the distance is negligible.
  - a Calculate the average speed of the train.
  - b Calculate the percentage uncertainty in the time.
  - c Using the time as  $125 - 1 = 124$  s, calculate the maximum value of the average speed given by these values. Give your answer to a sensible number of significant figures.
  - d Using your answers to parts c and a, calculate the percentage uncertainty in the average speed of the train.

### TIP

When multiplying or dividing quantities, the percentage uncertainty in the final result is found by adding together the percentage uncertainty in each of the quantities.

This means your answer to **d** should be the same as the answer to **b** to one significant figure.

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- 2 A spacecraft is orbiting the Earth with a constant speed of  $8100 \text{ m s}^{-1}$ . The radius of its orbit is 6750 km.
- Explain what is meant by the term *constant speed*.
  - Calculate how far it will travel in 1.0 hour.
  - Calculate how long it will take to complete one orbit of the Earth. Give your answer in minutes.
- 3 A police patrol driver sees a car that seems to be travelling too fast on a motorway (freeway). He times the car over a distance of 3.0 km. The car takes 96 s to travel this distance.
- The speed limit on the motorway is  $120 \text{ km h}^{-1}$ . Calculate the distance a car would travel at  $120 \text{ km h}^{-1}$  in one minute.
  - Calculate the distance a car would travel at  $120 \text{ km h}^{-1}$  in 1 s.
  - Calculate the average speed of the car, in  $\text{m s}^{-1}$ .
  - Compare the car's actual speed with the speed limit. Was the car travelling above or below the speed limit?
- 4 It is useful to be able to compare the speeds of different objects. To do this, the speeds must all be given in the same units.
- Calculate the speed, in  $\text{m s}^{-1}$ , of the objects in each scenario, i–vi. Give your answers in standard form (also known as *scientific notation*), with one figure before the decimal point.
    - Light travels at  $300\,000\,000 \text{ m s}^{-1}$  in empty space.
    - A spacecraft travelling to the Moon moves at  $11 \text{ km s}^{-1}$ .
    - An athlete runs 100 m in 10.41 s.
    - An alpha-particle travels 5.0 cm in  $0.043 \times 10^{-6} \text{ s}$ .
    - The Earth's speed in its orbit around the Sun is  $107\,000 \text{ km h}^{-1}$ .
    - A truck travels 150 km along a motorway in 1.75 h.
  - List the objects in order, from slowest to fastest.

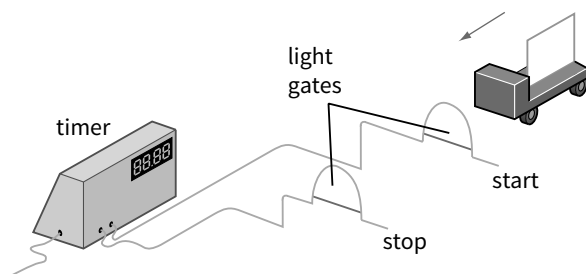
## Exercise 1.2 Measuring speed in the laboratory

You can measure the speed of a moving trolley in the laboratory using a ruler and a stopwatch. However, you are likely to get better results using light gates and an electronic timer. In this exercise, you will compare data from these different methods and practise analysing data.

- 1 A student used a stopwatch to measure the time taken by a trolley to travel a measured distance of 1.0 m.
- Explain why it can be difficult to obtain an accurate measurement of time in this way.
  - Explain why the problem is more likely to be greater if the trolley is moving more quickly.

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- 2 This diagram shows how the speed of a trolley can be measured using two light gates connected to an electronic timer. An interrupt card is fixed to the trolley:



**Figure 1.1:** For Question 2. Determining acceleration using two light gates.

- Describe what happens as the trolley passes through the light gates.
  - Name the quantity shown on the timer.
  - What other measurement must be made to determine the trolley's speed? Describe how you would make this measurement.
  - Explain how you would calculate the trolley's speed from these measurements.
  - Explain why this method gives the trolley's *average* speed.
- 3 It is possible to determine the average speed of a trolley using a single light gate.
- Draw a diagram to show how you would do this.
  - Describe what happens as the trolley passes through the light gate.
  - Explain how you would find the trolley's average speed using this arrangement.
- 4 A ticker-timer can be used to record the movement of a trolley. The ticker-timer makes marks (dots) on paper tape at equal intervals of time.
- Sketch the pattern of dots you would expect to see for a trolley travelling at constant speed.
  - A ticker-timer makes 50 dots each second on a paper tape. State the time interval between consecutive dots.
  - A student measures a section of tape. The distance from the first dot to the sixth dot is 12 cm. Calculate the trolley's average speed in this time interval. Give your answer in  $\text{m s}^{-1}$ .

## TIP

When using ticker-timers, think about whether to count the dots or the spaces between the dots.

## KEY WORD

**displacement:** the distance travelled in a particular direction

## TIP

Remember to label your graph axes with the correct quantities.

## Exercise 1.3 Displacement–time graphs

A **displacement–time** graph is used to represent an object's motion. The gradient of the graph is the object's velocity. These questions provide practice in drawing, interpreting and using data from displacement–time graphs.

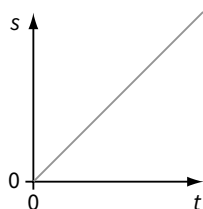
- 1 Velocity is defined by the equation:

$$\text{velocity} = \frac{\Delta s}{\Delta t}$$

- State what the symbols  $s$  and  $t$  stand for.
- State what the symbols  $\Delta s$  and  $\Delta t$  stand for.
- Sketch a straight-line displacement–time graph and indicate how you would find  $\Delta s$  and  $\Delta t$  from this graph.

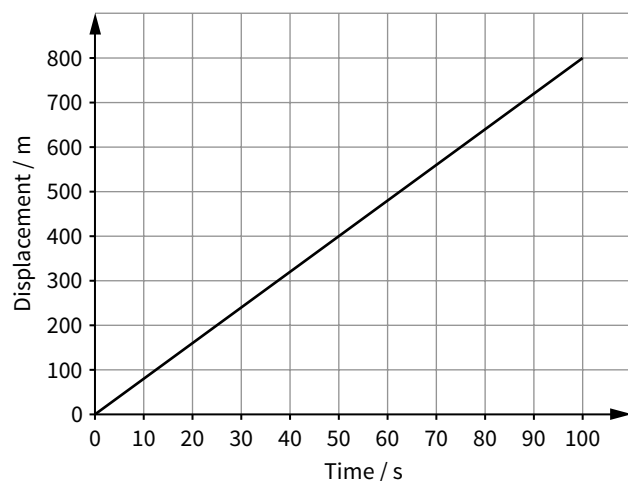
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- 2 This sketch graph represents the motion of a car:



**Figure 1.2:** For Question 2. Distance–time graph of a car in motion.

- Explain how you can tell that the car was moving with constant velocity.
  - Copy the sketch graph and add a second line to the graph representing the motion of a car moving with a higher constant velocity. Label this ‘faster’.
  - On your graph, add a third line representing the motion of a car which is stationary. Label this ‘not moving’.
- 3 This graph represents the motion of a runner in a race along a long, straight road:



**Figure 1.3:** For Question 3. Displacement–time graph for a runner.

Use the graph to deduce:

- the displacement of the runner after 75 s
  - the time taken by the runner to complete the first 200 m of the race
  - the runner’s velocity.
- 4 This table gives values of displacement and time during a short cycle journey:

Displacement / m	0	80	240	400	560	680
Time / s	0	10	20	30	40	50

**Table 1.1:** Data for a cyclist.

- Draw a displacement–time graph for the journey.
- From your graph, deduce the cyclist’s greatest speed during the journey.

## Exercise 1.4 Adding and subtracting vectors

These questions involve thinking about displacement and velocity. These are vector quantities – they have direction as well as magnitude. Every quantity in physics can be classified as either a **scalar** or a **vector** quantity. A vector quantity can be represented by an arrow.

### KEY WORDS

**scalar:** a quantity with magnitude only

**vector:** a quantity with both magnitude and direction

- 1 A scalar quantity has magnitude only.
  - a Name the scalar quantity that corresponds to displacement.
  - b Name the scalar quantity that corresponds to velocity.
  - c For each of the following quantities, state whether it is a scalar or a vector quantity: mass, force, acceleration, density, energy, weight.
- 2 This drawing shows a piece of squared paper. Each square measures  $1\text{ cm} \times 1\text{ cm}$ . The track shows the movement of a spider that ran around on the paper for a short while:

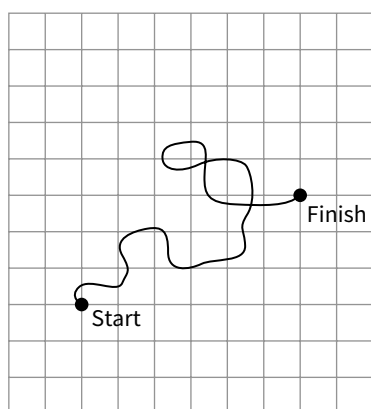


Figure 1.4: For Question 2. Movement of a spider.

- a How many squares did the spider move *to the right*, from start to finish?
  - b How many squares did the spider move *up the paper*?
  - c Calculate the spider's displacement between start and finish.  
 Make sure that you give the distance (in cm) and the angle of its displacement relative to the horizontal.
  - d Estimate the distance travelled by the spider. Describe your method.
- 3 A yacht sails 20 km due north. It then turns  $45^\circ$  to the west and travels a further 12 km.
    - a Calculate the distance, in km, travelled by the yacht.
    - b Draw a scale diagram of the yacht's journey. Include a note of the scale you are using.
    - c By measuring the diagram, determine the yacht's displacement relative to its starting point.

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- 4 A passenger jet aircraft can fly at  $950 \text{ km h}^{-1}$  relative to the air it is flying through. In still air it will therefore fly at  $950 \text{ km h}^{-1}$  relative to the ground.
- A wind of speed  $100 \text{ km h}^{-1}$  blows head-on to the aircraft, slowing it down. What will its speed relative to the ground be?
  - If the aircraft was flying in the opposite direction, what would its speed be relative to the ground?
  - The aircraft flies in a direction such that the wind is blowing at it sideways (in other words, at  $90^\circ$ ).
    - Draw a diagram to show how these two velocities add together to give the resultant velocity of the aircraft.
    - Calculate the aircraft's speed relative to the ground.
- 5 Subtract a displacement of  $5.0 \text{ m}$  in a direction  $030^\circ$  (N $30^\circ$ E) from a displacement of  $10 \text{ m}$  in a northerly direction.

### TIP

To subtract a vector, add on a vector equal in size but in the opposite direction, i.e. add on a  $5.0 \text{ m}$  vector at  $210^\circ$ .

### EXAM-STYLE QUESTIONS

- 1 a **Define** speed. [1]

This diagram shows a laboratory trolley with an interrupt card mounted on it. The trolley will pass through a single light gate:

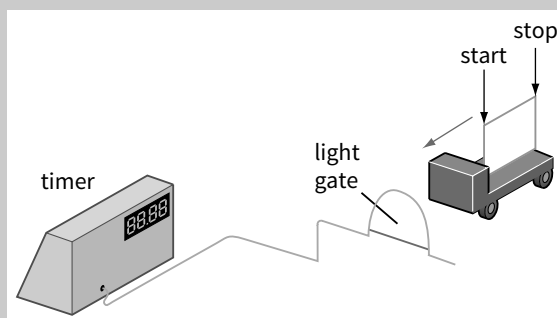


Figure 1.5

- Explain** how the card causes the timer to start and stop. [3]
  - The card is  $10 \text{ cm}$  wide. The timer indicates a time of  $0.76 \text{ s}$ . **Calculate** the average speed of the trolley. [2]
  - Explain why the speed you calculated in c is the trolley's average speed. [1]
- [Total: 7]
- 2 A slow goods train is travelling at a speed of  $50 \text{ km h}^{-1}$  along a track. A passenger express train that travels at  $120 \text{ km h}^{-1}$  sets off along the same track two hours after the goods train.
- Draw a displacement–time graph to represent the motion of the two trains. [4]
  - Use your graph to **determine** the time at which the express train will catch up with the goods train. [1]
- [Total: 5]

### COMMAND WORDS

**Define:** give precise meaning

**Explain:** set out purpose or reasons / make the relationships between things evident / provide why and/or how and support with relevant evidence

**Calculate:** work out from given facts, figures or information

**Determine:** establish an answer using the information available

## CONTINUED

3 This graph represents the motion of a car along a straight road:

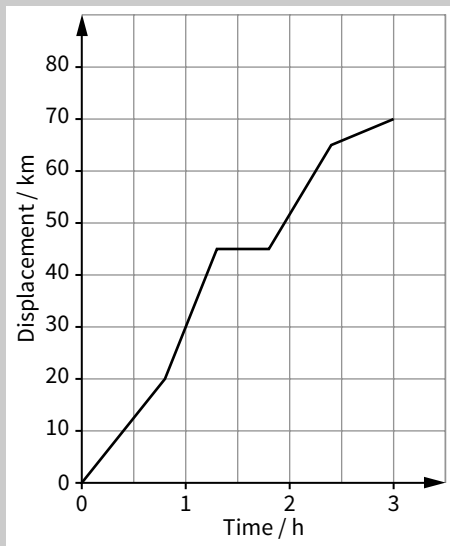


Figure 1.6

From the graph, deduce the following:

- a the time taken for the car's journey [1]  
 b the distance travelled by the car during its journey [1]  
 c the car's average speed during its journey [1]  
 d the car's greatest speed during its journey [1]  
 e the amount of time the car spent travelling at the speed you calculated in **d** [1]  
 f the distance it travelled at this speed. [1]
- [Total: 6]
- 4 A physical quantity can be described as either 'scalar' or 'vector'.
- a **State** the difference between a *scalar quantity* and a *vector quantity*. [2]  
 b Define *displacement*. [1]
- A light aircraft flies due east at  $80 \text{ km h}^{-1}$  for 1.5 h. It then flies due north at  $90 \text{ km h}^{-1}$  for 0.8 h.
- c Calculate the distance travelled by the aircraft in each stage of its journey. [2]  
 d Draw a scale diagram to represent the aircraft's journey. [2]  
 e Use your diagram to determine the aircraft's final displacement relative to its starting point. [2]
- [Total: 9]

## COMMAND WORD

**State:** express in clear terms