Physics Intro & Kinematics

- •Quantities
- •Units
- •Vectors
- •Displacement
- •Velocity
- •Acceleration
- •Kinematics
- •Graphing Motion in 1-D

Some Physics Quantities

Vector - quantity with both magnitude (size) and direction

Scalar - quantity with magnitude only

<u>Vectors</u>:
- Displacement
- Velocity
- Acceleration
- Momentum
- Force

<u>Scalars:</u>
- Distance
- Speed
- Time
- Mass
- Energy

Mass vs. Weight

<u>Mass</u>
- Scalar (no direction)
- Measures the amount of matter in an object

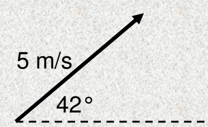
<u>Weight</u>
- Vector (points toward center of Earth)
- Force of gravity on an object

On the moon, your mass would be the same, but the magnitude of your weight would be less.

Vectors

Vectors are represented with arrows

- The length of the arrow represents the magnitude (how far, how fast, how strong, etc, depending on the type of vector).
- The arrow points in the directions of the force, motion, displacement, etc. It is often specified by an angle.



Units

Units are not the same as quantities!

<u>Quantity . . . Unit (symbol)</u>
- Displacement & Distance . . . meter (m)
- Time . . . second (s)
- Velocity & Speed . . . (m/s)
- Acceleration . . . (m/s^2)
- Mass . . . kilogram (kg)
- Momentum . . . (kg·m/s)
- Force . . .Newton (N)
- Energy . . . Joule (J)

SI Prefixes

Little Guys

pico	p	10^{-12}
nano	n	10^{-9}
micro	μ	10^{-6}
milli	m	10^{-3}
centi	c	10^{-2}

Big Guys

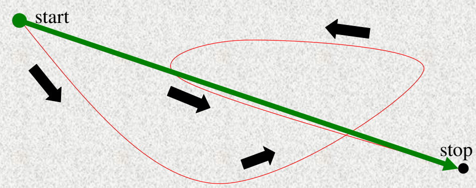
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}
tera	T	10^{12}

Kinematics definitions

- Kinematics – branch of physics; study of motion
- Position (***x***) – where you are located
- Distance (*d*) – how far you have traveled, regardless of direction
- Displacement (Δ***x***) – where you are in relation to where you started

Distance vs. Displacement

- You drive the path, and your odometer goes up by 8 miles (your distance).
- Your displacement is the shorter directed distance from start to stop (green arrow).
- What if you drove in a circle?



Speed, Velocity, & Acceleration

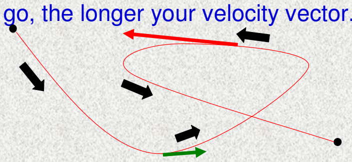
- Speed (*v*) – how fast you go
- Velocity (***v***) – how fast and which way; the rate at which position changes
- Average speed ($\bar{v}$) – distance/time
- Acceleration (***a***) – how fast you speed up, slow down, or change direction; the rate at which velocity changes

Speed vs. Velocity

- Speed is a scalar (how fast something is moving regardless of its direction). Ex: *v* = 20 mph
- Speed is the magnitude of velocity.
- Velocity is a combination of speed and direction. Ex: ***v*** = 20 mph at 15° south of west
- The symbol for speed is *v*.
- The symbol for velocity is type written in bold: ***v*** or hand written with an arrow: $\vec{v}$

Speed vs. Velocity

- During your 8 mi. trip, which took 15 min., your speedometer displays your instantaneous speed, which varies throughout the trip.
- Your average speed is 32 mi/hr.
- Your average velocity is 32 mi/hr in a SE direction.
- At any point in time, your velocity vector points tangent to your path.
- The faster you go, the longer your velocity vector.



Acceleration

Acceleration – how fast you speed up, slow down, or change direction; it's the rate at which velocity changes. Two examples:

t (s)	*v* (mph)
0	55
1	57
2	59
3	61

$a = +2 \text{ mph/s}$

t (s)	*v* (m/s)
0	34
1	31
2	28
3	25

$a = -3 \frac{\text{m/s}}{\text{s}} = -3 \text{ m/s}^2$

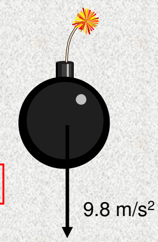
Velocity & Acceleration Sign Chart

	VELOCITY: +	VELOCITY: -
ACCELERATION: +	Moving forward; Speeding up	Moving backward; Slowing down
ACCELERATION: -	Moving forward; Slowing down	Moving backward; Speeding up

Acceleration due to Gravity

Near the surface of the Earth, all objects accelerate at the same rate (ignoring air resistance).

$\boxed{a = -g = -9.8 \text{ m/s}^2}$



This acceleration vector is the same on the way up, at the top, and on the way down!

Interpretation: Velocity decreases by 9.8 m/s each second, meaning velocity is becoming less positive or more negative. Less positive means slowing down while going up. More negative means speeding up while going down.

Kinematics Formula Summary

For 1-D motion with *constant* acceleration:

- $v_f = v_0 + a t$
- $\overline{v} = (v_0 + v_f)/2$
- $\Delta x = v_0 t + \frac{1}{2} a t^2$
- $v_f^2 - v_0^2 = 2 a \Delta x$

(derivations to follow)

Kinematics Derivations

$a = \Delta v / \Delta t$ (by definition)

$a = (v_f - v_0)/t$

$\Rightarrow \quad v_f = v_0 + a t$

$\overline{v} = (v_0 + v_f)/2$ will be proven when we do graphing.

$\Delta x = \overline{v} t = ½ (v_0 + v_f)\, t = ½ (v_0 + v_0 + a t)\, t$

$\Rightarrow \Delta x = v_0 t + \frac{1}{2} a t^2$

(cont.)

Kinematics Derivations (cont.)

$v_f = v_0 + a t \quad \Rightarrow \quad t = (v_f - v_0)/a$

$\Delta x = v_0 t + \frac{1}{2} a t^2 \quad \Rightarrow$

$\Delta x = v_0 [(v_f - v_0)/a] + \frac{1}{2} a [(v_f - v_0)/a]^2$

$\Rightarrow \quad v_f^2 - v_0^2 = 2 a \Delta x$

Note that the top equation is solved for t and that expression for t is substituted twice (in red) into the Δx equation. You should work out the algebra to prove the final result on the last line.

Sample Problems

1. You're riding a unicorn at 25 m/s and come to a uniform stop at a red light 20 m away. What's your acceleration?
2. A brick is dropped from 100 m up. Find its impact velocity and air time.
3. An arrow is shot straight up from a pit 12 m below ground at 38 m/s.
   a. Find its max height above ground.
   b. At what times is it at ground level?

Multi-step Problems

1. How fast should you throw a kumquat straight down from 40 m up so that its impact speed would be the same as a mango's dropped from 60 m?

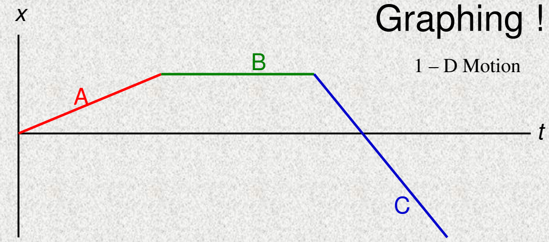
   Answer: 19.8 m/s

2. A dune buggy accelerates uniformly at 1.5 m/s^2 from rest to 22 m/s. Then the brakes are applied and it stops 2.5 s later. Find the total distance traveled.

   Answer: 188.83 m

Graphing !

1 – D Motion

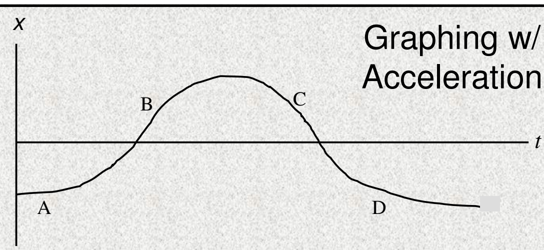


A … Starts at home (origin) and goes forward slowly

B … Not moving (position remains constant as time progresses)

C … Turns around and goes in the other direction quickly, passing up home

Graphing w/ Acceleration



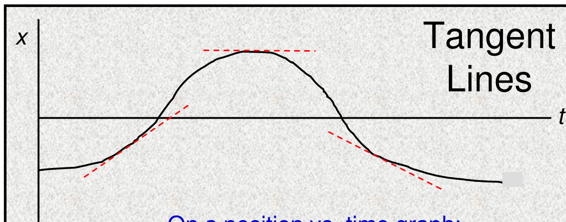
A … Start from rest south of home; increase speed gradually

B … Pass home; gradually slow to a stop (still moving north)

C … Turn around; gradually speed back up again heading south

D … Continue heading south; gradually slow to a stop near the starting point

Tangent Lines

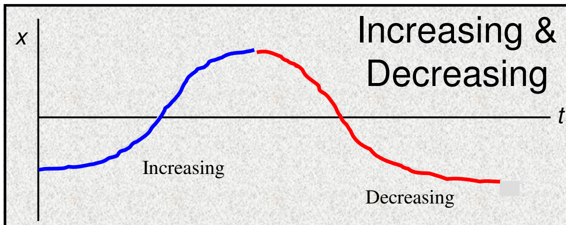


On a position vs. time graph:

SLOPE	VELOCITY
Positive	Positive
Negative	Negative
Zero	Zero

SLOPE	SPEED
Steep	Fast
Gentle	Slow
Flat	Zero

Increasing & Decreasing

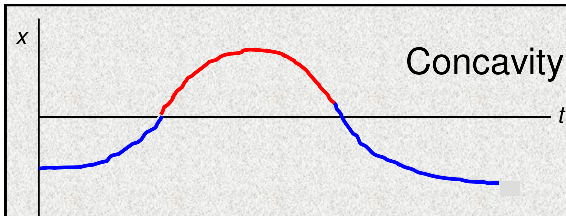


On a position vs. time graph:

Increasing means moving forward (positive direction).

Decreasing means moving backwards (negative direction).

Concavity

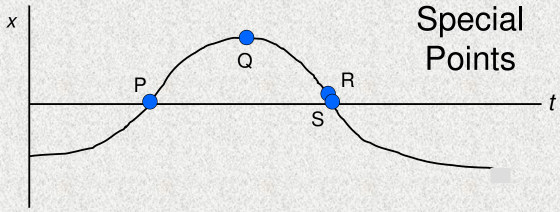


On a position vs. time graph:

Concave up means positive acceleration.

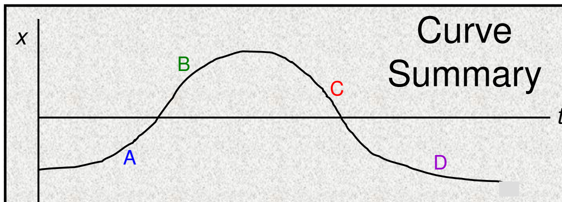
Concave down means negative acceleration.

Special Points



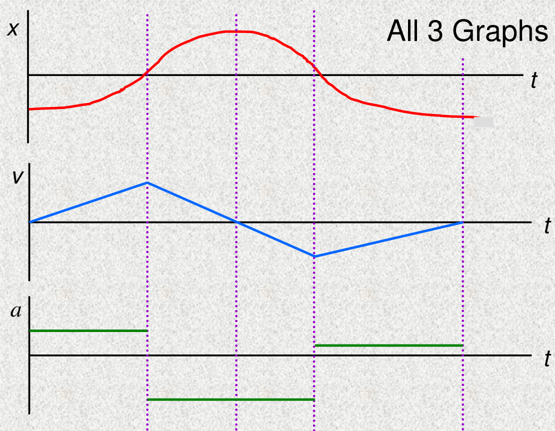
Inflection Pt.	P, R	Change of concavity
Peak or Valley	Q	Turning point
Time Axis Intercept	P, S	Times when you are at "home"

Curve Summary



	Concave Up	Concave Down
Increasing	$v > 0$ $a > 0$ (A)	$v > 0$ $a < 0$ (B)
Decreasing	$v < 0$ $a > 0$ (D)	$v < 0$ $a < 0$ (C)

All 3 Graphs

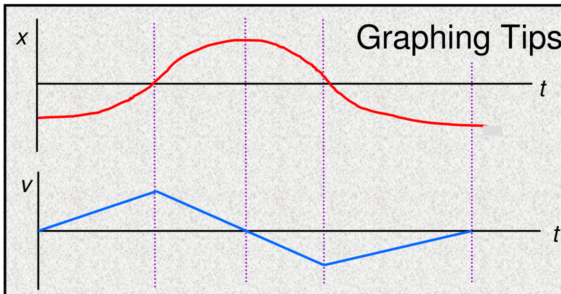


Graphing Animation Link

This website will allow you to set the initial velocity and acceleration of a car. As the car moves, all three graphs are generated.

Car Animation

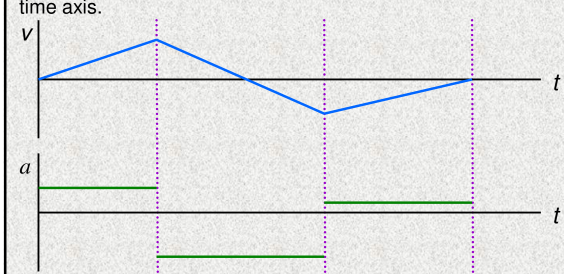
Graphing Tips



- Line up the graphs vertically.
- Draw vertical dashed lines at special points except intercepts.
- Map the slopes of the position graph onto the velocity graph.
- A red peak or valley means a blue time intercept.

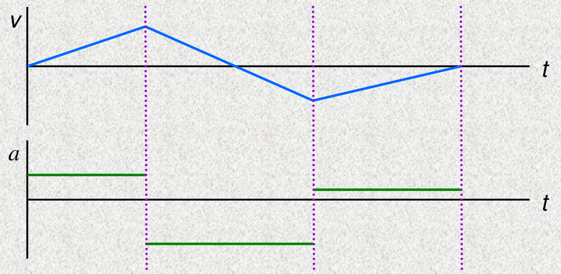
Graphing Tips

The same rules apply in making an acceleration graph from a velocity graph. Just graph the slopes! Note: a positive constant slope in blue means a positive constant green segment. The steeper the blue slope, the farther the green segment is from the time axis.

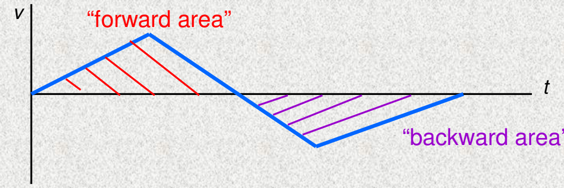


Real life

Note how the *v* graph is pointy and the *a* graph skips. In real life, the blue points would be smooth curves and the green segments would be connected. In our class, however, we'll mainly deal with constant acceleration.



Area under a velocity graph



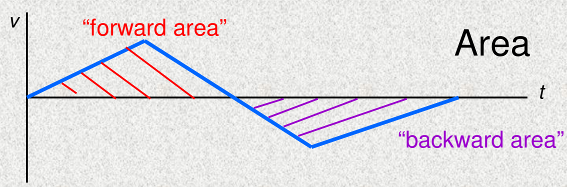
Area above the time axis = forward (positive) displacement.

Area below the time axis = backward (negative) displacement.

Net area (above - below) = net displacement.

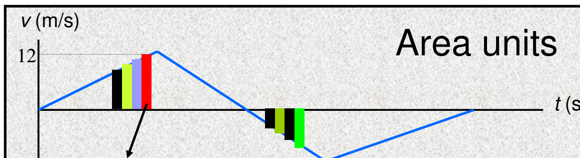
Total area (above + below) = total distance traveled.

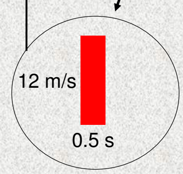
Area



The areas above and below are about equal, so even though a significant distance may have been covered, the displacement is about zero, meaning the stopping point was near the starting point. The position graph shows this too.

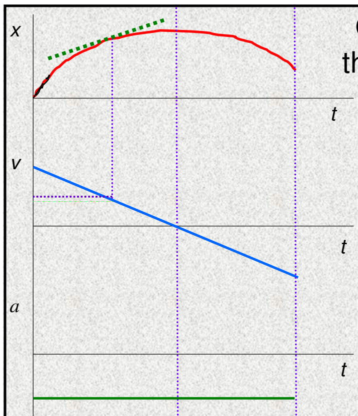
Area units





- Imagine approximating the area under the curve with very thin rectangles.
- Each has area of height × width.
- The height is in m/s; width is in seconds.
- Therefore, area is in meters!
- The rectangles under the time axis have negative heights, corresponding to negative displacement.

Graphs of a ball thrown straight up



The ball is thrown from the ground, and it lands on a ledge.

The position graph is parabolic.

The ball peaks at the parabola's vertex.

The *v* graph has a slope of -9.8 m/s^2.

Map out the slopes!

There is more "positive area" than negative on the *v* graph.

Graph Practice

Try making all three graphs for the following scenario:

1. Schmedrick starts out north of home. At time zero he's driving a cement mixer south very fast at a constant speed.

2. He accidentally runs over an innocent moose crossing the road, so he slows to a stop to check on the poor moose.

3. He pauses for a while until he determines the moose is squashed flat and deader than a doornail.

4. Fleeing the scene of the crime, Schmedrick takes off again in the same direction, speeding up quickly.

5. When his conscience gets the better of him, he slows, turns around, and returns to the crash site.

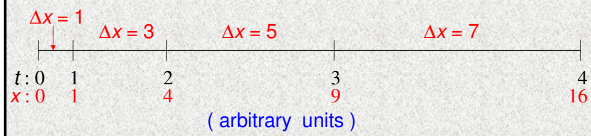
Kinematics Practice

A catcher catches a 90 mph fast ball. His glove compresses 4.5 cm. How long does it take to come to a complete stop? Be mindful of your units!

2.24 ms

Answer

Uniform Acceleration



When object starts from rest and undergoes constant acceleration:

- Position is proportional to the square of time.
- Position changes result in the sequence of odd numbers.
- Falling bodies exhibit this type of motion (since *g* is constant).

Spreadsheet Problem

- We're analyzing position as a function of time, initial velocity, and constant acceleration.
- x, Δx, and the ratio depend on t, v_0, and a.
- Δx is how much position changes each second.
- The ratio (1, 3, 5, 7) is the ratio of the Δx's.

- Make a spreadsheet like this and determine what must be true about v_0 and/or a in order to get this ratio of odd numbers.
- Explain your answer mathematically.

t (s)	x (m)	delta x (m)	ratio	v_0 (m/s)	a (m/s^2)
0	0			0	17.3
		8.66	1		
1	8.66				
		25.98	3		
2	34.64				
		43.30	5		
3	77.94				
		60.62	7		
4	138.56				

Relationships

Let's use the kinematics equations to answer these:

1. A mango is dropped from a height *h*.
   a. If dropped from a height of 2 *h*, would the impact speed double?
   b. Would the air time double when dropped from a height of 2 *h* ?
2. A mango is thrown down at a speed *v*.
   a. If thrown down at 2 *v* from the same height, would the impact speed double?
   b. Would the air time double in this case?

3. A rubber chicken is launched straight up at speed *v* from ground level. Find each of the following if the launch speed is tripled (in terms of any constants and *v*).

a. max height	$9v^2/2g$
b. hang time	$6v/g$
c. impact speed	$3v$

Answers