PHYSICS

Yr. 11 into Yr. 12

Name:______________________________

Task:

1. Answer all the questions from this booklet.
2. Return your answers to Miss. A.Jones or Mr. A.Doig in your first 'A' level Physics lesson in September.

Thank you.

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7	Distance, time, speed 1-10	
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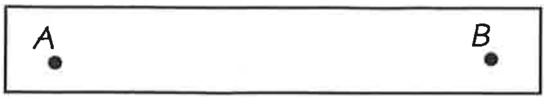
Distance, Time and Speed

Distance, Time and Speed

Consider the points A and B below. They are separated by a distance which we measure in metres. Now imagine a spider walking from A to B — we can measure the time it takes, in seconds, for it to travel this distance.



We can then work out the average speed of the spider between these two points using the following simple equation:

$$\text{speed } (ms^{-1}) = \text{distance travelled } (m) \ / \ \text{time taken } (s)$$

This is a very useful equation, but it does have a couple of limitations:

1) *It only tells you the average speed. The spider could have varied its speed from fast to slow and even gone backwards. So long as it got from A to B in the same time we get the same answer. The average speed is the speed which, if maintained for the whole journey, would take you the given distance in the given time.*
2) *We assume that the spider takes the shortest possible path between the two points (a straight line), rather than meandering around.*

Look at these examples:

It is important to remember that you should always convert distances to metres, times to seconds and speeds to metres per second when doing calculations involving this equation!

E.g. A time of 12 minutes is 12 x 60 s = 720 s.
A distance of 30km is 30 x 1000m = 30 000 m.
A speed of 10kms^{-1} is 10 x 1000ms^{-1} = 10 000ms^{-1}.
A speed of 10 metres per minute is 10 / 60ms^{-1} = 0.17ms^{-1}

1) *A car travels 100 metres in 5 seconds. What is its average speed?*
   speed = distance/time, so speed = 100m/5s = 20ms^{-1}

2) *A train travelling at an average speed of 50ms^{-1} takes 30 minutes to travel between stations. How far apart are the two stations?*
   speed = distance/time, multiplying both sides by time gives speed x time = distance.
   30 minutes = 30 x 60s = 1800s.
   So, distance = speed x time, distance = 50ms^{-1} x 1800s = 90 000 m.

3) *A spider walks away from you in a straight line. It starts at a point 10cm away, and finishes 50cm away from you. It walks at an average speed of 0.1ms^{-1}. How long does it take?*
   Distance travelled = 50cm – 10cm = 40cm = 0.4m.
   From example 2, distance = speed x time, dividing both sides by speed gives:
   distance/speed = time. So time = 0.4m/(0.1ms^{-1}) = 4s.

Distance, Time and Speed

Now have a go at these questions:

1) A cricket ball is thrown 40m at a speed of $18ms^{-1}$. How long does it take?
2) A sprinter runs the 100m in a time of 10.5s, what is his average speed?
3) A walker travels at an average speed of $0.5ms^{-1}$ for half an hour, how far do they walk?
4) A cyclist travels 10km at an average speed of $8ms^{-1}$. How long does it take her?
5) A ferry crosses a 250m wide river in 2 minutes. What is its average speed?
6) The speed of light is $3 \times 10^8 ms^{-1}$. If it takes light from the sun about 8 minutes to reach us, what is the approximate distance from the earth to the sun?
7) A bird flies 15m between trees in 5s. What is its average speed?
8) How long will it take a horse to gallop 300m across a field at an average speed of $15ms^{-1}$?
9) A spaceship flies 3000km in 1 minute. What is its average speed?
10) (difficult!) A blade of grass grows at an average speed of 1 metre per year. How far does it grow in one week?

Displacement

Displacement — a Vector Quantity

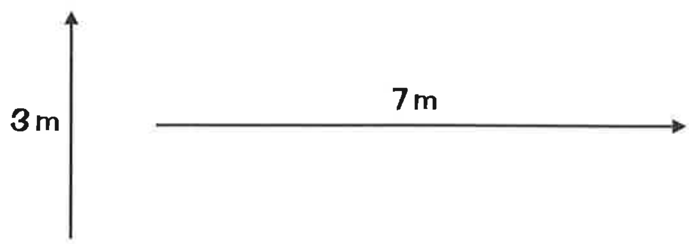
In order to get from point A to point B, knowing the distance you need to travel is not enough, you must also know the direction you need to travel in. This information, distance plus direction, is known as the displacement from A to B and has the symbol, s. It is a vector quantity since all vectors have both a size and a direction.

Representing Displacement — Scale Drawings

The simplest way to draw a displacement is to draw an arrow — the length of the arrow tells you the distance, and the way the arrow points shows you the direction.

We can do this even for very large displacements so long as we scale down.

For example, a displacement of 3 metres upwards could be represented by an arrow of length 3 centimetres. Using this same scale (1 cm to 1 m) a displacement of 7 metres to the right would be an arrow of length 7 centimetres.

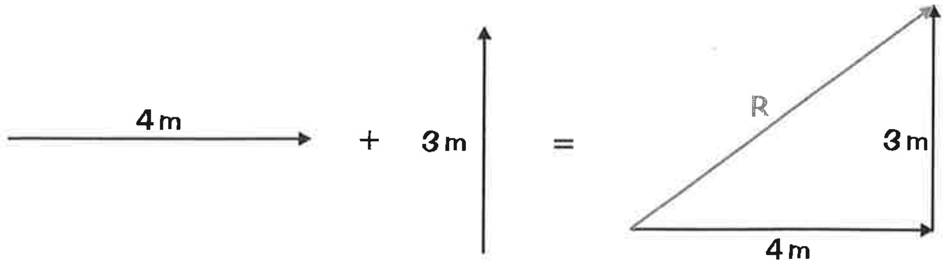


Addition of Two Displacements

We can't simply add together the two distances as this does not account for the different directions of the displacements. What we do is:

1) *Draw arrows representing the two vectors.*
2) *Place the arrows one after the other "tip-to-tail".*
3) *Draw a third arrow from start to finish. This is your total displacement.*

For example, consider adding a displacement of 4 metres to the right to one of 3 metres upwards (using a scale of 1cm to 1m):



R is called the resultant, it is the sum of the two displacements. You can find the size of R either by measuring the arrow and scaling up or by using Pythagoras. In this case it is 5m in length.

Displacement

Have a go at these questions:

1) *Draw arrows representing the following displacements to the given scale.*
   - (a) 3 miles upwards (1cm to 1 mile)
   - (b) 12m to the right (1cm to 2m)
   - (c) 4mm downwards (1cm to 1mm)
   - (d) 3.5km northeast (1cm to 1km)
   - (e) 5cm southwest (1cm to 1cm)
   - (f) 24m at a bearing of 030° (1cm to 5m)
   - (g) 110 miles at a bearing of 210° (1cm to 20 miles)
   - (h) 9mm at a bearing of 330° (1cm to 2mm)
   - (i) 18km northwest (1 cm to 5km)
   - (j) 9 miles to the left (1cm to 2 miles)

2) *Find the lengths of the following displacements by drawing the arrows "tip-to-tail"*
   - (a) 5m right and 12m up
   - (b) 8m up and 4m left
   - (c) 6cm right and 8cm left
   - (d) 15 miles down and 20 miles left
   - (e) 3mm left and 12mm right
   - (f) 7.5cm up and 9.5cm right
   - (g) 7km down and 24km right
   - (h) 20m left and 30m down
   - (i) 40 miles left and 50 miles right
   - (j) 60mm up and 20mm right

Velocity

Another quantity that you will have to get used to using is velocity, symbol v.

The Relationship Between Displacement and Velocity

The velocity of an object is given by the following equation:

velocity (ms^{-1}) = displacement (m) / time taken (t)

Or, in symbols: $v = s / t$

This equation is very similar to the one relating speed and distance (page 6), except that it includes information about the direction of motion.

Consider these examples:

1) An object is displaced 100 metres to the right in a time of 4 seconds. What is its velocity?

   $v = s/t$, so $v = 100m/4s = 25ms^{-1}$ to the right.
   Note that we must quote the direction as well as the speed.

2) An object has a velocity of 3 metres per second downwards. What is its displacement after 12 seconds?

   $v = s/t$, multiplying both sides by t gives, $v \times t = s$,
   i.e. $s = v \times t$, so $s = 3ms^{-1} \times 12s = 36m$ downwards.

Now have a go at these questions:

1) An object has a velocity of 3 ms^{-1} to the west. What is its displacement after one minute?
2) An object undergoes a displacement of 0.2 metres to the left in 5 seconds. What is its velocity?
3) How long does it take an object travelling with a velocity of 50 ms^{-1} north to travel 1km?
4) If someone has a velocity of 7.5 ms^{-1} south, what is their displacement after 15 seconds?

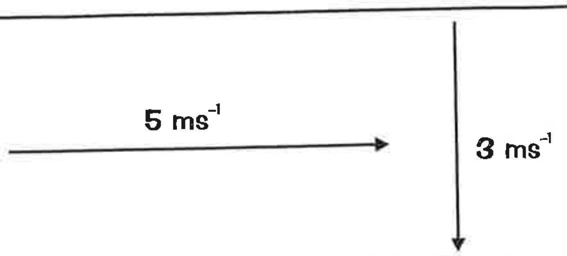
Velocity

Velocity is Another Vector Quantity

Just as displacement is distance and direction, so velocity is the speed of an object and the direction it is travelling in.

Again, we can represent velocities with arrows, but now the longer the arrow the greater the speed of the object. A typical scale might be 1cm to $1ms^{-1}$.

For example, the two velocities of 5 metres per second to the right and 3 metres per second downwards might be drawn (with a scale of 1cm to $1ms^{-1}$):

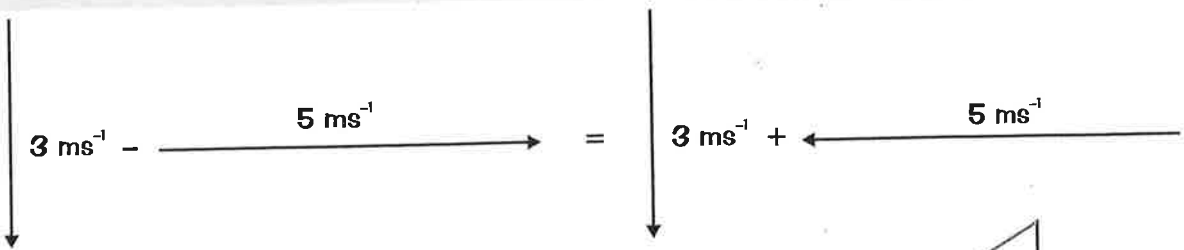


Changes in Velocity

change in velocity (ms^{-1}) = final velocity (ms^{-1}) – initial velocity (ms^{-1})

This is not quite as simple as it looks. We cannot just take one speed from the other, we have to account for the directions of the two velocities.

Consider the example of: an initial velocity = $5ms^{-1}$ to the right, and a final velocity = $3ms^{-1}$ down.



Δv is the change in velocity.

We found Δv by reversing the arrow for the initial velocity and adding this new arrow to the final velocity.

$\Delta v = 5.8ms^{-1}$ diagonally down and left.

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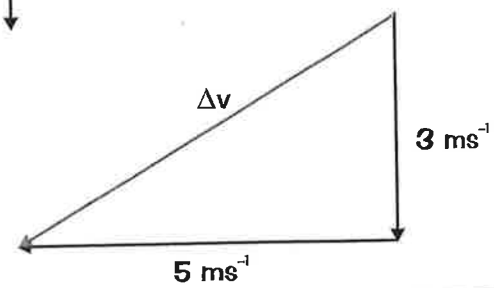


Have a go at finding the changes in velocity in these cases:

1) *initial velocity = $10ms^{-1}$ right; final velocity = $5ms^{-1}$ left.*
2) *initial velocity = $4ms^{-1}$ up; final velocity = $4ms^{-1}$ right.*
3) *initial velocity = $3ms^{-1}$ down; final velocity = $4ms^{-1}$ left.*

Acceleration

Acceleration — the Change in Velocity Every Second

$$\text{Acceleration (in metres per second}^2) = \frac{\text{change in velocity of an object (in metres per second)}}{\text{time taken (seconds)}}$$

So,

$$\text{Acceleration (ms}^{-2}) = \frac{\text{final velocity (ms}^{-1}) - \text{initial velocity (ms}^{-1})}{\text{time taken (s)}}$$

Or in symbols:

$$a = \frac{v - u}{t} = \frac{\Delta v}{t}$$

For simplicity we will only worry about velocities in one dimension, say left to right.

This has the advantage that we don't need to bother drawing out all the arrows for the velocities.

But we still need to worry about the difference between velocities from right to left and velocities from left to right.

We must choose a direction to be positive — let's say right. All velocities in this direction will from now on be positive, and all those in the opposite direction (left) will be negative.

Look at these examples to see how this works:

1) A car starts off moving to the right at 10 metres per second. After 20 seconds it is moving to the left at 5 metres per second. What was its acceleration during this time?
   $u = 10ms^{-1}$ to the right $= +10ms^{-1}$
   $v = 5ms^{-1}$ to the left $= -5ms^{-1}$
   So, $a = (v - u)/t = (-5ms^{-1} - 10ms^{-1})/20s = (-15ms^{-1})/20s = -0.75ms^{-2}$.
   The acceleration is negative so it is to the left.

2) An object accelerates from rest at $5ms^{-2}$ to the right. If its final velocity is $20ms^{-1}$ to the right, how long has it been accelerating for?
   $u = 0$
   $v = 20ms^{-1}$ to the right $= +20ms^{-1}$
   $a = (v - u)/t$, multiplying both sides by t gives $t \times a = v - u$, dividing both sides by a gives $t = (v - u)/a$.
   So, $t = (20ms^{-1} - 0)/(5ms^{-2}) = 4s$.

Have a go at these questions:

1) A train has an initial velocity of $12\ ms^{-1}$ to the left. After 20 seconds it is moving to the right at $18\ ms^{-1}$. What was its acceleration during this time?
2) A ship accelerates at a uniform rate of $0.1\ ms^{-2}$ to the right. If its initial velocity is $1.5\ ms^{-1}$ to the right and its final velocity is $4\ ms^{-1}$ in the same direction, how long has it been accelerating for?
3) True or false? Acceleration is a vector.

Acceleration

Falling — the Acceleration Due to Gravity

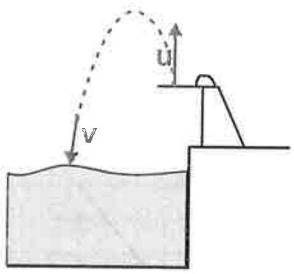
When an object is dropped it accelerates downwards at a constant rate of roughly $10\ ms^{-2}$. This is the acceleration due to gravity.

It seems sensible to take the upward direction as positive and down as negative, making the acceleration due to gravity $-10ms^{-2}$.

Look at the following examples:

1) What is the vertical velocity of a skydiver 5 seconds after jumping out of a plane? (Ignore the skydiver's horizontal motion)

$u = 0$
$a = -10ms^{-2}$
Example 2 on page 12 gives $t \times a = v - u$,
so adding u to each side gives $v = u + (t \times a)$.
So $v = 0 + (5s \times -10ms^{-2}) = 0 - 50ms^{-1}$
$= -50ms^{-1} = 50ms^{-1}$ down.



2) A diver jumps upwards off a springboard. After 2 seconds he hits the water travelling downwards at $18ms^{-1}$. What was his initial velocity?

$v = 18ms^{-1}$ down $= -18ms^{-1}$
$a = -10ms^{-2}$
From example 1, $v = u + (t \times a)$, subtracting $(t \times a)$ from each side gives $v - (t \times a) = u$.
So, $u = -18ms^{-1} - (2s \times -10ms^{-2}) = -18ms^{-1} - (-20ms^{-1})$
$= -18ms^{-1} + 20ms^{-1} = 2ms^{-1} = 2ms^{-1}$ upwards.

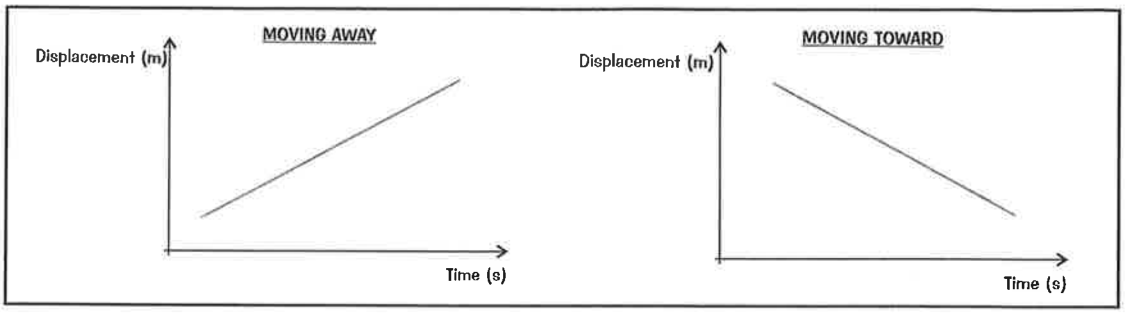
Try these. (Hint: it is often useful to draw a little diagram of what is going on in these questions)

1) An apple falls from a tree and hits the ground at $2\ ms^{-1}$. For how long has it been falling?
2) A pea dropped from the top of a tall building falls for 3 seconds. Ignoring air resistance, with what velocity does it hit the ground?
3) A stone is thrown downwards. It hits the ground at $15\ ms^{-1}$ after 0.7 seconds. With what velocity was it thrown?
4) A package is dropped from a stationary helicopter. Ignoring air resistance, with what velocity does it hit the ground 10 seconds later?
5) A sandbag is dropped from a stationary hot air balloon and it hits the ground at a velocity of 50 metres per second downwards. How long has it been falling for?
6) A ball is thrown upwards. After 2 seconds it is caught moving downwards at $10\ ms^{-1}$. With what velocity was it thrown upwards?

Displacement-Time Graphs

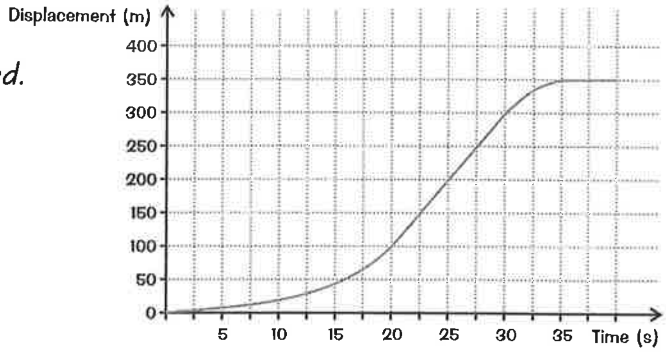
Drawing Graphs to Show How Far Something Has Travelled

A graph of displacement against time tells you how far an object is from a given point, in a given direction, as time goes on. As it moves away from that point the displacement on the graph goes up and as it moves towards it the displacement goes down:



Importantly, these graphs only tell you about motion in one dimension, so for example, they can tell you how far up a ball has been thrown, but not how far it has moved horizontally.
We can also use these graphs to calculate the velocity of an object (in the given direction).

Consider the example below, it shows the displacement-time graph for a car accelerating to a constant speed and then braking suddenly.



We can read the following directly off the graph:

1) It took 20 seconds to accelerate to full speed.
2) It travelled 100 metres in that time.
3) It travelled at constant velocity for the next 10 seconds.
4) It travelled 200 metres in that time.
5) It took 5 seconds to stop fully.
6) It travelled 50 metres in that time.
7) It remained stationary at a displacement of 350 metres from its starting point.

We can work out three more details of the car's journey:

1) The value of the constant velocity it had between 20 and 30 seconds.
2) Its average velocity for the whole journey.
3) Its average speed for the whole journey.

When an object is travelling at a steady velocity its displacement-time graph is a straight line, with a gradient equal to the velocity.

$$\text{velocity } (ms^{-1}) = \text{gradient} = \frac{\text{change in distance travelled (m)}}{\text{change in time (s)}} = \frac{300m - 100m}{30s - 20s} = \frac{200m}{10s} = \boxed{20ms^{-1}}$$

To calculate the average speed for the whole journey we use the formula:

$$\text{average velocity } (ms^{-1}) = \frac{\text{total displacement (m)}}{\text{total time taken (s)}} = \frac{350m}{35s} = \boxed{10ms^{-1}}$$

$$\text{and, average speed } (ms^{-1}) = \frac{\text{total distance travelled (m)}}{\text{total time taken (s)}} = \frac{350m}{35s} = \boxed{10ms^{-1}}$$

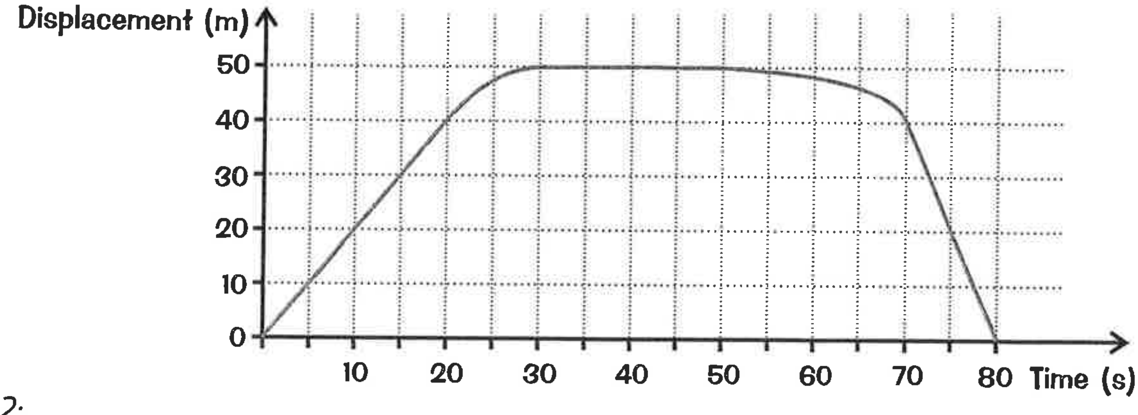
In this case, the average speed is the same as the average velocity, because the car doesn't change direction. The total distance is the +ve displacement plus the -ve displacement.

Displacement-Time Graphs

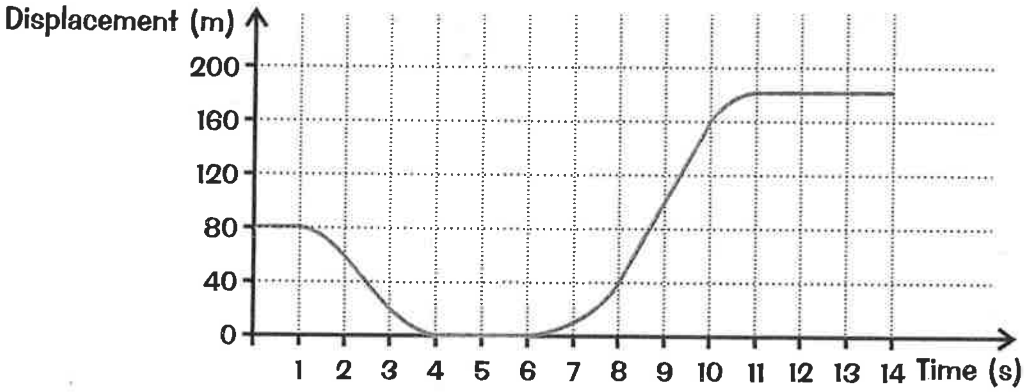
Have a go at analysing these graphs:

Write down as much as you can about the motion of the objects represented by the following graphs. Work out any steady velocities, the average velocity and average speed for the journey.

Graph 1:



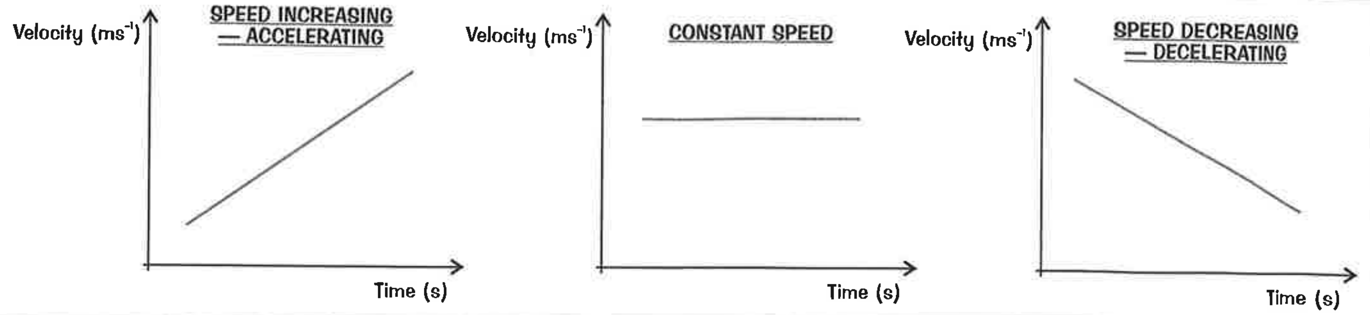
Graph 2:



Velocity-Time Graphs

Drawing Graphs to Show the Speed of an Object

Clearly, we can also draw graphs that show the velocity of an object moving in one dimension.



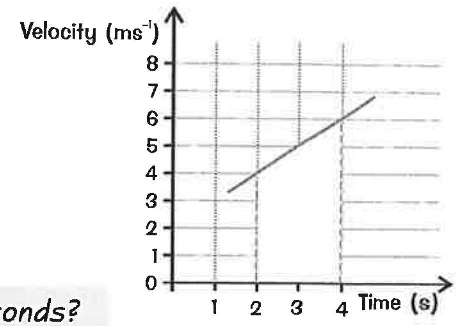
We can use a velocity-time graph to calculate two things:

1) *The distance the object has moved.*
2) *The acceleration.*

Calculating the Distance Travelled

To find the distance an object travels between two times:

1) *Draw vertical lines up from the horizontal axis at the two times as shown.*
2) *Work out the "area" of the shape formed by these lines.*
3) *Remember that although we call it an area we are actually multiplying time (the horizontal length) by average speed (the average vertical length) so the result is a distance.*



E.g. What is the distance travelled between 2 seconds and 4 seconds?

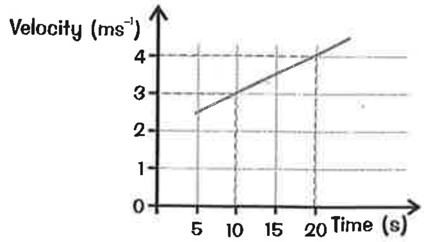
The shape is a trapezium, so the area = $\frac{1}{2}(a + b) \times h = \frac{1}{2}(4 + 6) \times 2 = 5ms^{-1} \times 2s = 10m$.

Calculating the Acceleration

The acceleration of an object travelling in one dimension is given (see page 12) by:

$$\text{Acceleration } (ms^{-2}) = \frac{\text{change in velocity } (ms^{-1})}{\text{time taken } (s)}$$

This is just the gradient of the velocity-time graph.

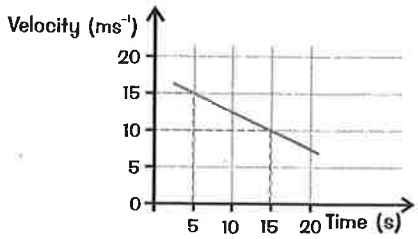


E.g. What is the acceleration between 10 and 20 seconds?

Acceleration = $(4ms^{-1} - 3ms^{-1})/(20s - 10s)$

$= 1ms^{-1} / 10s = 0.1ms^{-2}$

When an object is slowing down, we say it is decelerating.
Its acceleration is negative, as is the gradient of the graph.



E.g. What is the acceleration between 5 and 15 seconds?

Acceleration (in ms^{-2}*) =* $(10ms^{-1} - 15ms^{-1})/(15s - 5s)$

$= -5ms^{-1} / 10s = -0.5ms^{-2}$

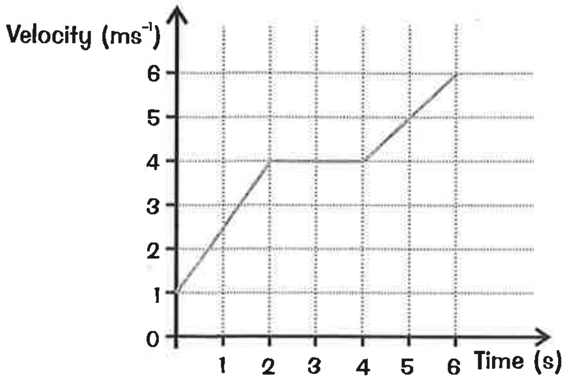
or a deceleration of $0.5ms^{-2}$

Velocity-Time Graphs

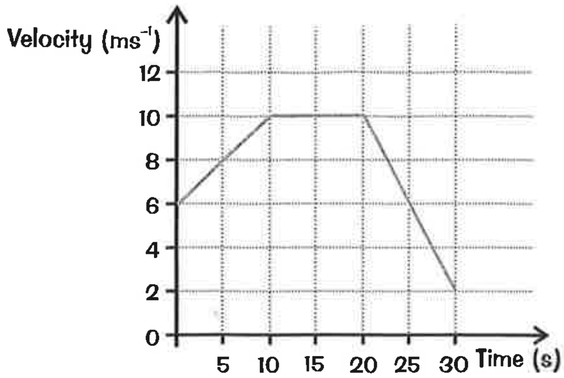
Try these:

1) *Calculate the accelerations in each of the three sections of each graph.*
2) *Calculate the distances travelled in each of the three sections of each graph and calculate the total distance travelled in each case.*

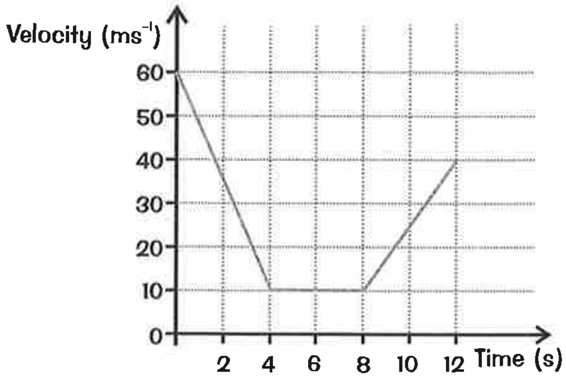
a)



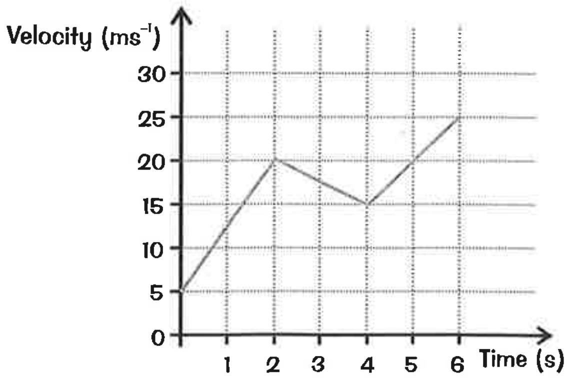
b)



c)



d)



Forces

Newton's Second Law

It is difficult to explain precisely what a "force" is, so instead we talk about what forces do. Forces stretch things, forces squash things, forces twist things, but most importantly, forces make things go faster (or slower or change what direction they are moving in).

When a force acts on an object it changes the velocity of the object.

In other words, applying a force to an object makes it accelerate.
This acceleration is directly proportional to the force. This just means that, for the same object, if you double the force applied, you double its acceleration.

We can write down this equation:

Force (N) = mass of object (kg) × acceleration of object (ms^{-2})

Or, in symbols:

$$F = m \times a$$

This is Newton's second law of motion.

Have a look at this example:

a) A car of mass 1000kg accelerates from rest ($0ms^{-1}$) to $15ms^{-1}$ in 20s. What is the force accelerating it?

b) The same car then stops suddenly in 5s. What is the braking force?

a) $v = 15ms^{-1}$
$u = 0ms^{-1}$
$t = 20s$
$a = (v - u)/t$, so $a = (15ms^{-1} - 0)/20s = 0.75ms^{-2}$.
Then $F = m \times a = 1000kg \times 0.75ms^{-2} = 750N$.

b) $v = 0ms^{-1}$
$u = 15ms^{-1}$
$t = 5s$
Again $a = (v - u)/t$, so $a = (0 - 15ms^{-1})/5s = -3ms^{-2}$
(the acceleration is negative because the car is slowing down)
Then $F = m \times a = 1000kg \times (-3ms^{-2}) = -3000N$
(the force is negative because it is slowing the car down)

Forces

Finding the Force When Given the Mass and the Acceleration

Try these (they are like the example on page 18):

1) *A bus of mass 10 000kg accelerates at $0.25ms^{-2}$. What is the force acting on it?*
2) *A car pulls a caravan of mass 800kg. If it accelerates at $0.4ms^{-2}$, what force must the caravan experience?*
3) *An apple of mass 0.1kg falls with acceleration of $10ms^{-2}$. What is the gravitational force pulling it down (its weight)?*

Finding the Acceleration When Given the Force and the Mass

Consider this example:

What would be the acceleration of a 500g mass if a force of 10N acted on it?

$F = m \times a$, dividing both sides by m gives $F/m = a$, so $a = F/m = 10N/0.5kg = 20ms^{-2}$.

Now try these questions:

4) *What would be the acceleration of an arrow of mass 0.3kg if the force from the strings in the bow is 200N?*
5) *What would be the acceleration of a train of mass 10 000 kg if the force from the engine is 8000N?*
6) *What would be the acceleration of a bullet in a rifle if the bullet has a mass of 0.008kg and the force accelerating it is 2000N?*

Finding the Mass When Given the Acceleration and the Force

Consider this example:

What is the mass of an object if a force of 250N produces an acceleration of $2ms^{-2}$?

$F = m \times a$, dividing both sides by a gives $F/a = m$, so $m = F/a = 250N/(2ms^{-2}) = 125kg$

Now try these questions:

7) *What is the mass of a sailing boat if a force of 120N produces an acceleration of $0.5\ ms^{-2}$?*
8) *What is the mass of a ship if a force of 50 000N produces an acceleration of $0.2ms^{-2}$?*
9) *What is the mass of a box if a force of 50N produces an acceleration of $8ms^{-2}$?*

Forces

Balanced and Unbalanced Forces

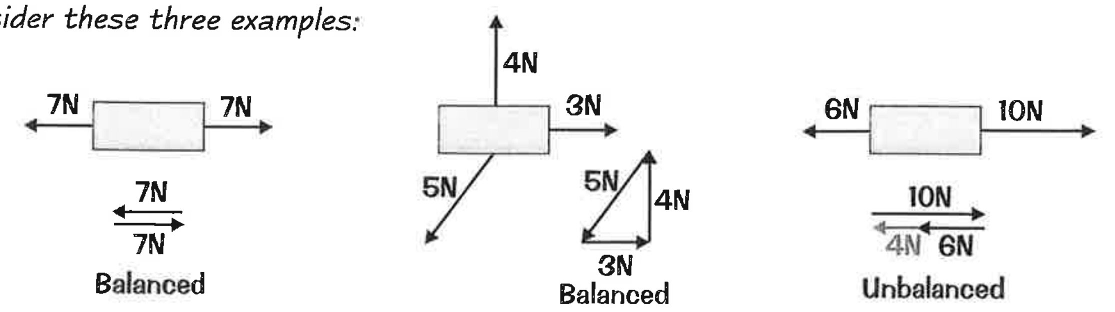
Force is a vector, just like displacement or velocity.

When more than one force acts on a body, we have to add them together in just the same way as we add displacements or velocities.

We find the resultant force by putting the arrows "tip-to-tail".

If the resultant force is zero we say that the forces are balanced.

Consider these three examples:



If there is a resultant force then the forces are unbalanced.

We say there is a net force on the object.

Example:

A force of 10 newtons to the right and a force of 6 newtons to the left result in a net force of 4 newtons to the right. If these forces acted on an object of mass 5 kilograms it would produce an acceleration given by:

$$a = F/m = 4N/5kg = 0.8ms^{-2}$$

Have a go at these:

Work out the net forces on these objects and calculate the acceleration they would cause: