Distance, Displacement, Speed and Velocity

To understand the difference between distance and displacement, or speed and velocity, you've got to know the difference between a scalar quantity and a vector quantity. Then you can race through this page.

Vectors Have Magnitude and Direction

1) Vector quantities have a magnitude (size) and a direction.
2) Lots of physical quantities are vector quantities:

   Vector quantities: force, velocity, displacement, weight, acceleration, momentum, etc.

3) Some physical quantities only have magnitude and no direction. These are called scalar quantities:

   Scalar quantities: speed, distance, mass, energy, temperature, time, etc.

Velocity is a vector, but speed is a scalar quantity.
Both bikes are travelling at the same speed, v.
They have different velocities because they are travelling in different directions.

Distance is Scalar, Displacement is a Vector

1) Distance is just how far an object has moved. It's a scalar quantity so it doesn't involve direction.
2) Displacement is a vector quantity. It measures the distance and direction in a straight line from an object's starting point to its finishing point — e.g. the plane flew 5 metres north. The direction could be relative to a point, e.g. towards the school, or a bearing (a three-digit angle from north, e.g. 035°).
3) If you walk 5 m north, then 5 m south, your displacement is 0 m but the distance travelled is 10 m.

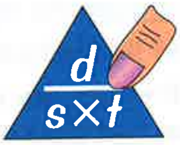
Speed and Velocity are Both How Fast You're Going

1) Speed and velocity both measure how fast you're going, but speed is a scalar and velocity is a vector:

   Speed is just how fast you're going (e.g. 30 mph or 20 m/s) with no regard to the direction.
   Velocity is speed in a given direction, e.g. 30 mph north or 20 m/s, 060°.

2) This means you can have objects travelling at a constant speed with a changing velocity. This happens when the object is changing direction whilst staying at the same speed.
3) For an object travelling at a constant speed, distance, (average) speed and time are related by the formula:

   distance travelled (m) = (average) speed (m/s) × time (s)



4) Objects rarely travel at a constant speed. E.g. when you walk, run or travel in a car, your speed is always changing. Make sure you have an idea of the typical speeds for different transport methods:

   1) Walking — 1.4 m/s (5 km/h)
   2) Running — 3 m/s (11 km/h)
   3) Cycling — 5.5 m/s (20 km/h)
   4) Cars in a built-up area — 13 m/s (47 km/h)
   5) Aeroplanes — 250 m/s (900 km/h)
   6) Cars on a motorway — 31 m/s (112 km/h)
   7) Trains — up to 55 m/s (200 km/h)
   8) Wind speed — 5 – 20 m/s
   9) Speed of sound in air — 340 m/s
   10) Ferries — 15 m/s (54 km/h)

My life's feeling pretty scalar — I've no idea where I'm headed...

This all seems pretty basic, but it's vital you understand it if you want to make it through the rest of this topic.

Q1 Name two examples of: a) a scalar quantity b) a vector quantity [4 marks]

Q2 A sprinter runs 200 m in 25 s. Calculate his average speed. [2 marks]

Acceleration

Uniform acceleration sounds fancy, but it's just speeding up (or slowing down) at a constant rate.

Acceleration is How Quickly You're Speeding Up

1) Acceleration is definitely not the same as velocity or speed.
2) Acceleration is the change in velocity in a certain amount of time.
3) You can find the average acceleration of an object using:

$$a = \frac{(v - u)}{t}$$

Acceleration (m/s²) — a

Change in velocity (m/s) — $(v - u)$, where u is the initial velocity in m/s and v is the final velocity in m/s

Time (s) — t

Initial velocity is just the starting velocity of the object.

4) Deceleration is just negative acceleration (if something slows down, the change in velocity is negative).

You Need to be Able to Estimate Accelerations

You might have to estimate the acceleration (or deceleration) of an object:

EXAMPLE: A car is travelling at 15 m/s, when it collides with a tree and comes to a stop. Estimate the deceleration of the car.

1) Estimate how long it would take the car to stop. — The car comes to a stop in ~1 s.
2) Put these numbers into the acceleration equation. — $a = (v - u) \div t$ $= (0 - 15) \div 1$ $= -15\ m/s^2$
3) As the car has slowed down, the change in velocity and so the acceleration is negative — the car is decelerating. — So the deceleration is about 15 m/s²

The ~ symbol just means it's an approximate value (or answer).

From the deceleration, you can estimate the forces involved too — more about that on page 16.

Uniform Acceleration Means a Constant Acceleration

1) Constant acceleration is sometimes called uniform acceleration.
2) Acceleration due to gravity (g) is uniform for objects in free fall. It's roughly equal to 10 m/s² near the Earth's surface and has the same value as gravitational field strength (p.17).
3) You can use this equation for uniform acceleration:

$$v^2 - u^2 = 2 \times a \times x$$

Final velocity (m/s) — v; Initial velocity (m/s) — u; Acceleration (m/s²) — a; Distance (m) — x

EXAMPLE: A van travelling at 23 m/s starts decelerating uniformly at 2.0 m/s² as it heads towards a built-up area 112 m away. What will its speed be when it reaches the built-up area?

1) First, rearrange the equation so v^2 is on one side. — $v^2 = u^2 + (2 \times a \times x)$
2) Now put the numbers in — remember a is negative because it's a deceleration. — $v^2 = 23^2 + (2 \times -2.0 \times 112)$ $= 81$
3) Finally, square root the whole thing. — $v = \sqrt{81} = 9$ m/s

Uniform problems — get a clip-on tie or use the equation above...

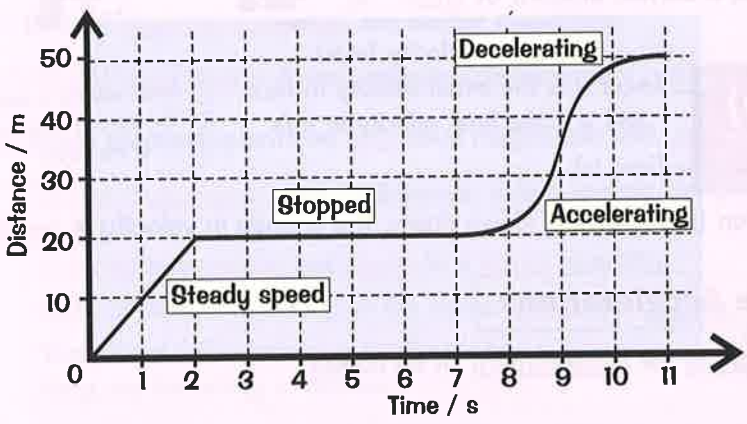
You might not be told what equation to use in the exam, so make sure you can spot when to use the equation for uniform acceleration. Make a list of the information you're given to help you see what to do.

Q1 A ball is dropped from a height, h, above the ground. The speed of the ball just before it hits the ground is 5 m/s. Calculate the height the ball is dropped from. (acceleration due to gravity ≈ 10 m/s²) [2 marks]

Distance/Time Graphs

A graph speaks a thousand words, so it's much better than writing 'An object starts from rest and moves at a steady speed of 10 m/s for 2 s until it has reaches a distance of 20 m, then remains stationary for 5 s before increasing its velocity with a constant acceleration for 2.5 s.'

Distance/Time Graphs Tell You How Far Something has Travelled



The different parts of a distance/time graph describe the motion of an object:

- The gradient (slope) at any point gives the speed of the object.
- Flat sections are where it's stopped.
- A steeper graph means it's going faster.
- Curves represent acceleration.
- A curve getting steeper means it's speeding up (increasing gradient).
- A levelling off curve means it's slowing down (decreasing gradient).

The Speed of an Object can be Found From a Distance/Time Graph

You can find the speed at any time on a distance/time graph:

1) If the graph is a straight line, the speed at any point along that line is equal to the gradient of the line.

For example, in the graph above, the speed at any time between 0 s and 2 s is:

$$\text{Speed} = \text{gradient} = \frac{\text{change in the vertical}}{\text{change in the horizontal}} = \frac{20}{2} = 10 \text{ m/s}$$

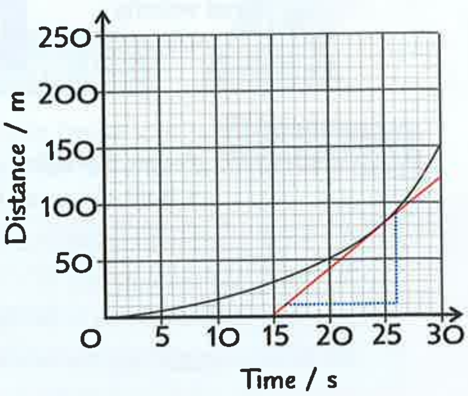
A tangent is a line that is parallel to the curve at that point.

2) If the graph is curved, to find the speed at a certain time you need to draw a tangent to the curve at that point, and then find the gradient of the tangent.

3) You can also calculate the average speed of an object when it has non-uniform motion (i.e. it's accelerating) by dividing the total distance travelled by the time it takes to travel that distance.

EXAMPLE:

The graph shows the distance/time graph for a cyclist on his bike.
Calculate:
a) the speed of the bike 25 s into the journey.
b) the average speed of the cyclist from 0 to 30 s.



a) Draw the tangent to the curve at 25 s (red line).
Then calculate the gradient of the tangent (blue lines).

$$\text{gradient} = \frac{\text{change in the vertical}}{\text{change in the horizontal}} = \frac{80}{10} = 8 \text{ m/s}$$

b) Use the formula from page 12 to find the average speed of the bike.

average speed = distance ÷ time = 150 ÷ 30 = 5 m/s

Tangent — a man who's just come back from holiday...

For practice, try sketching distance/time graphs for different scenarios. Like walking home or running from a bear.

Q1 Sketch a distance/time graph for an object that initially accelerates, then travels at a constant speed, then decelerates to a stop. [2 marks]

Velocity/Time Graphs

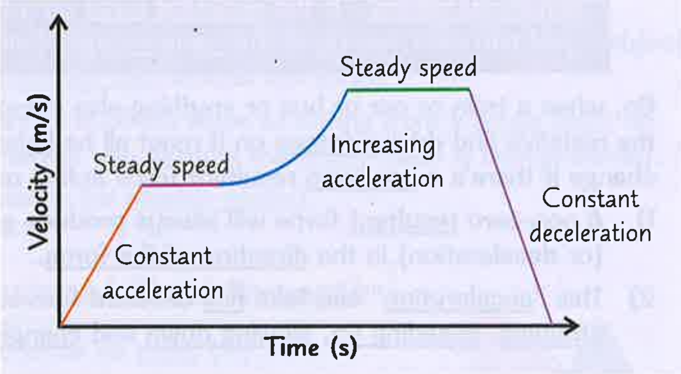
Huzzah, more graphs — velocity/time graphs this time. These look a lot like the distance/time graphs on page 14, so make sure you check the labels on the axes really carefully. You don't want to mix them up.

Velocity/Time Graphs can have a Positive or Negative Gradient

How an object's velocity changes over time can be plotted on a velocity/time (or v/t) graph.

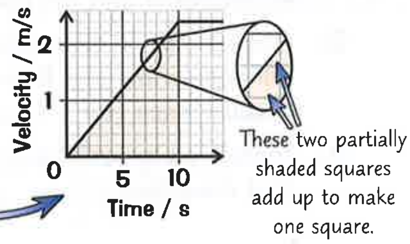
1) Gradient = acceleration, since acceleration = change in velocity ÷ time.
2) Flat sections represent a steady speed.
3) The steeper the graph, the greater the acceleration or deceleration.
4) Uphill sections (/) are acceleration.
5) Downhill sections (\) are deceleration.
6) A curve means changing acceleration.

If the graph is curved, you can use a tangent to the curve (p.14) at a point to find the acceleration at that point.



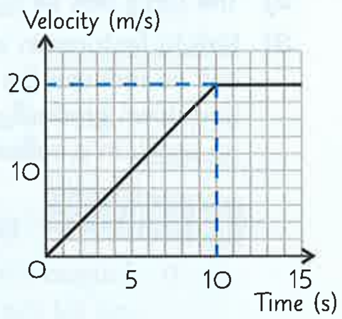
The Distance Travelled is the Area Under the Graph

1) The area under any section of the graph (or all of it) is equal to the distance travelled in that time interval.
2) For bits of the graph where the acceleration's constant, you can split the area into rectangles and triangles to work it out.
3) You can also find the area under the graph by counting the squares under the line and multiplying the number by the value of one square.



EXAMPLE:

The velocity/time graph of a car's journey is plotted.
a) Calculate the acceleration of the car over the first 10 s.
b) How far does the car travel in the first 15 s of the journey?



a) This is just the gradient of the line: $a = (v - u) \div t$
$= (20 - 0) \div 10 = 2\ m/s^2$

b) Split the area into a triangle and a rectangle, then add together their areas — remember the area of a triangle is ½ × base × height.
Area = (½ × 10 × 20) + (5 × 20)
= 200 m

Or find the value of one square, count the total number of squares under the line, and then multiply these two values together.
1 square = 2 m/s × 1 s = 2 m
Area = 100 squares
= 100 × 2 = 200 m

Understanding motion graphs — it can be a real uphill struggle...

Make sure you know the differences between distance/time and velocity/time graphs, and how to interpret them.

Q1 A stationary car starts accelerating increasingly for 10 s until it reaches a speed of 20 m/s.
It travels at this speed for 20 s until the driver sees a hazard and brakes.
He decelerates uniformly, coming to a stop 4 s after braking.
a) Draw the velocity/time graph for this journey. [3 marks]
b) Using the graph, calculate the deceleration of the car when it brakes. [2 marks]