2 SPEED, VELOCITY AND ACCELERATION

Videos & questions on the CD ROM

We have all been in a car travelling at 90 kilometres per hour. This, of course, means that the car (if it kept travelling at this speed for one hour) would travel 90 km. During one second of its journey this car travels 25 metres, so its speed can also be described as 25 metres per second. Scientists prefer to measure time in seconds, and distance in metres. So they prefer to measure speed in metres per second, often written as m/s.

The **speed** of an object can be calculated using the following formula:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

$$v = \frac{s}{t}$$

v = speed in m/s
s = distance in m
t = time in s

Most objects speed up and slow down as they travel. An object's 'average speed' can be calculated by dividing the total distance travelled by the total time taken.

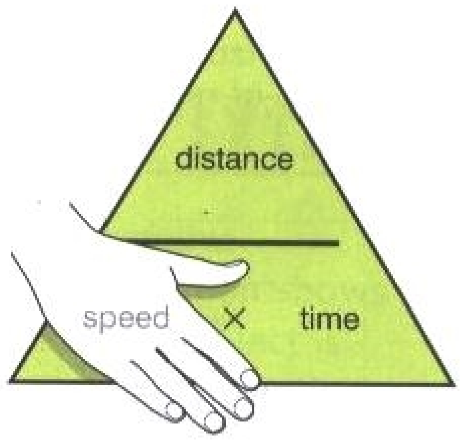
WORKED EXAMPLES

1 Calculate the average speed of a motor car that travels 500 m in 20 seconds.

Write down the formula:	$v = \frac{s}{t}$
Substitute the values for s and t:	$v = \frac{500}{20}$
Work out the answer and write down the units:	$v = 25$ m/s

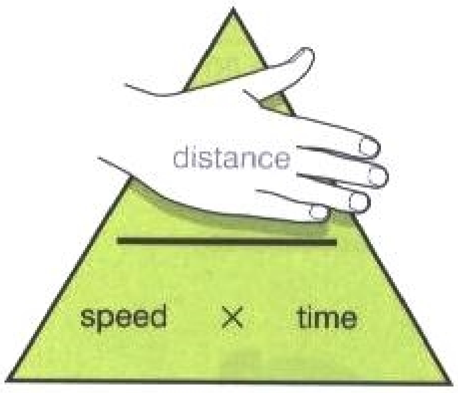
2 A horse canters at an average speed of 5 m/s for 2 minutes. Calculate the distance it travels.

Write down the formula in terms of s:	$s = v \times t$
Substitute the values for v and t:	$s = 5 \times 2 \times 60$
Work out the answer and write down the units:	$s = 600$ m



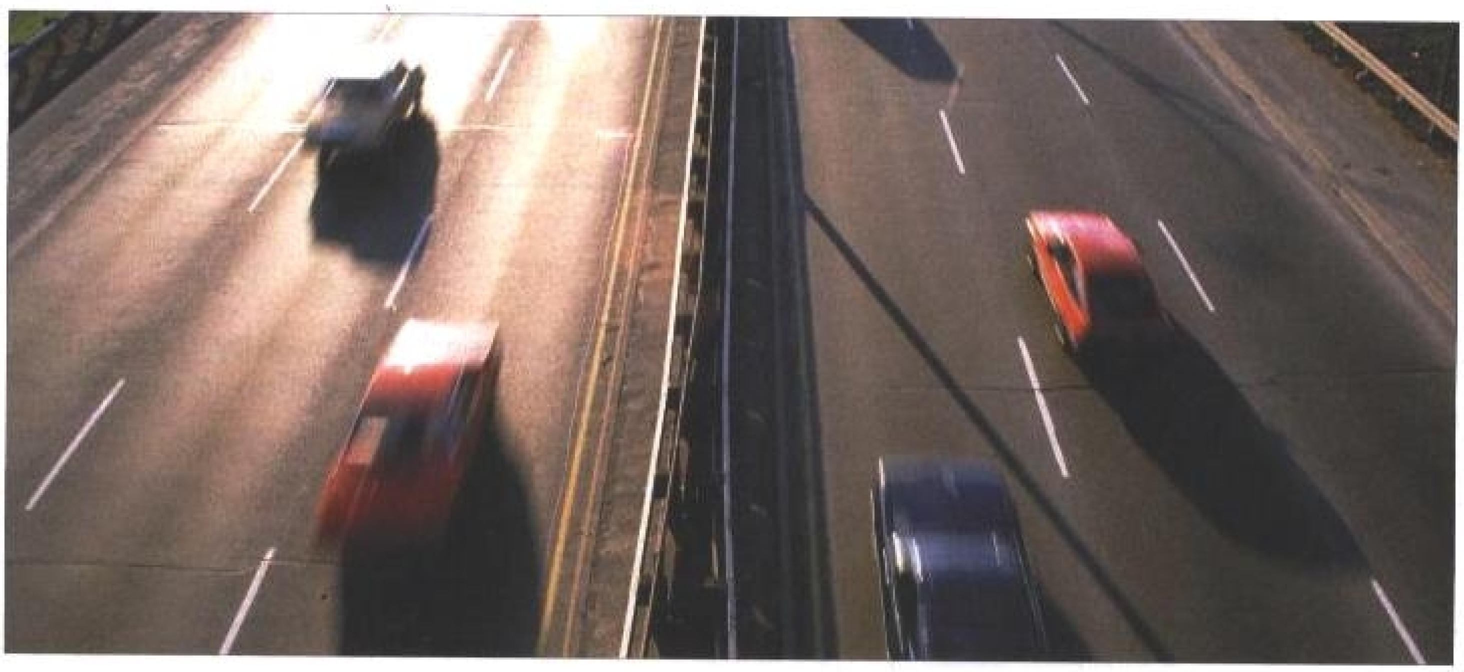
Cover speed to find that

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

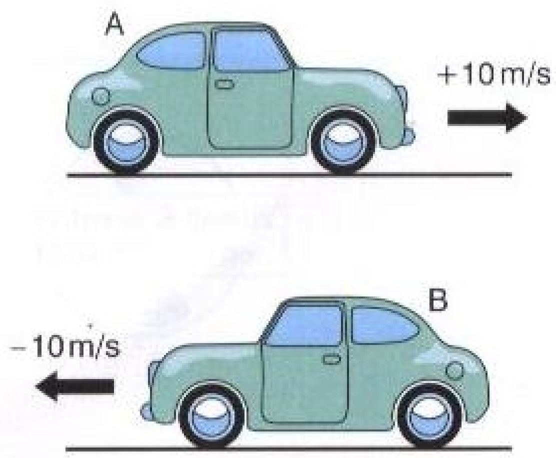


Cover distance to find that

distance = speed × time



Each car's average speed can be calculated by dividing the distance it has travelled by the time it has taken.



Both cars have the same speed. Car A has a velocity of +10 m/s, car B has a velocity of −10 m/s.

ARE SPEED AND VELOCITY THE SAME?

We often want to know the direction in which an object is travelling. For example, when a space rocket is launched, it is likely to reach a speed of 1000 km/h after about 30 seconds. However, it is extremely important to know whether this speed is upwards or downwards. You want to know the speed *and* the direction of the rocket. The velocity of an object is one piece of information, but it consists of two parts: the speed and the direction. In this case, the velocity of the rocket is 278 m/s (its speed) upwards (its direction).

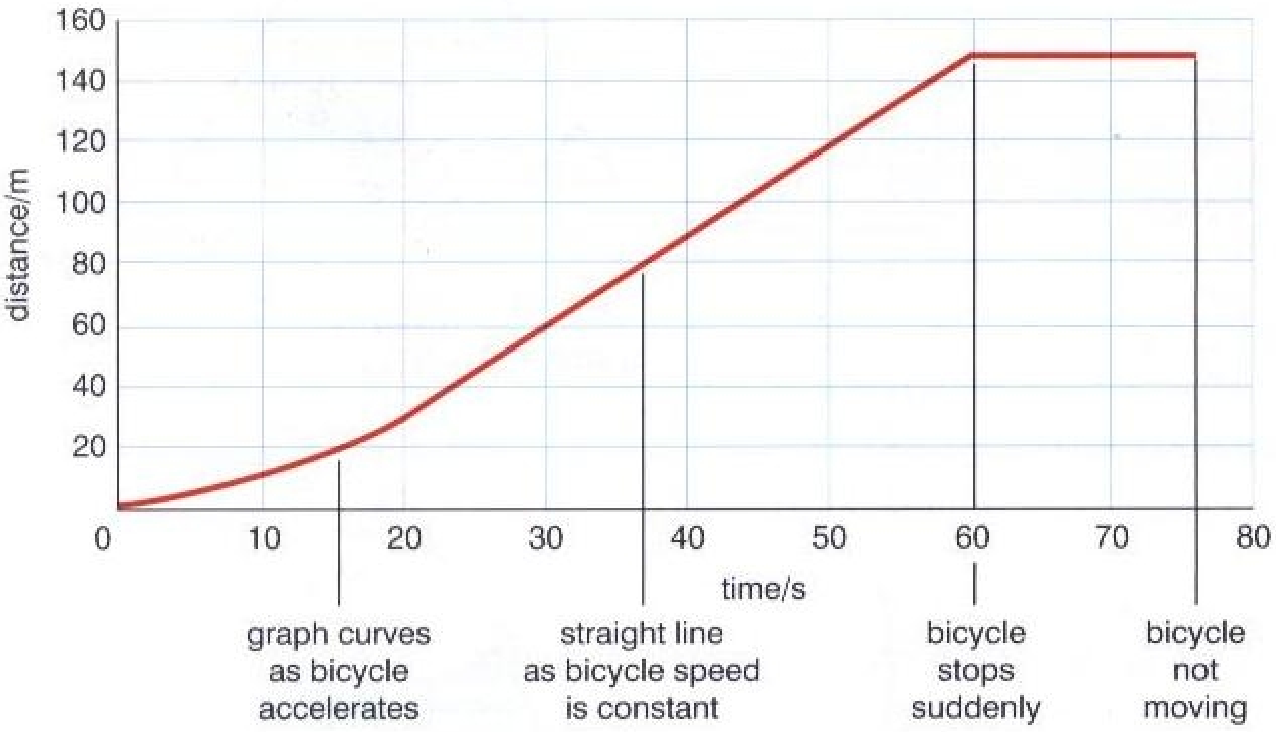
A velocity can have a minus sign. This tells you that the object is travelling in the opposite direction. So a velocity of -278 m/s upwards is actually a velocity of 278 m/s downwards.

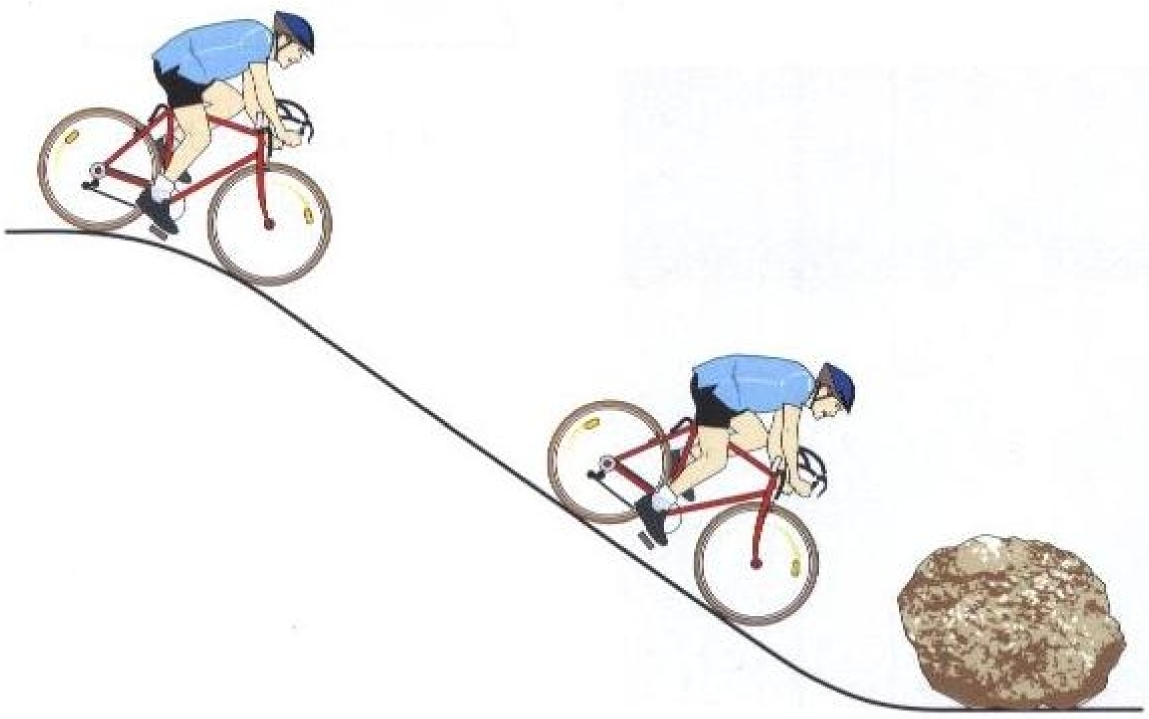
USING GRAPHS TO STUDY MOTION

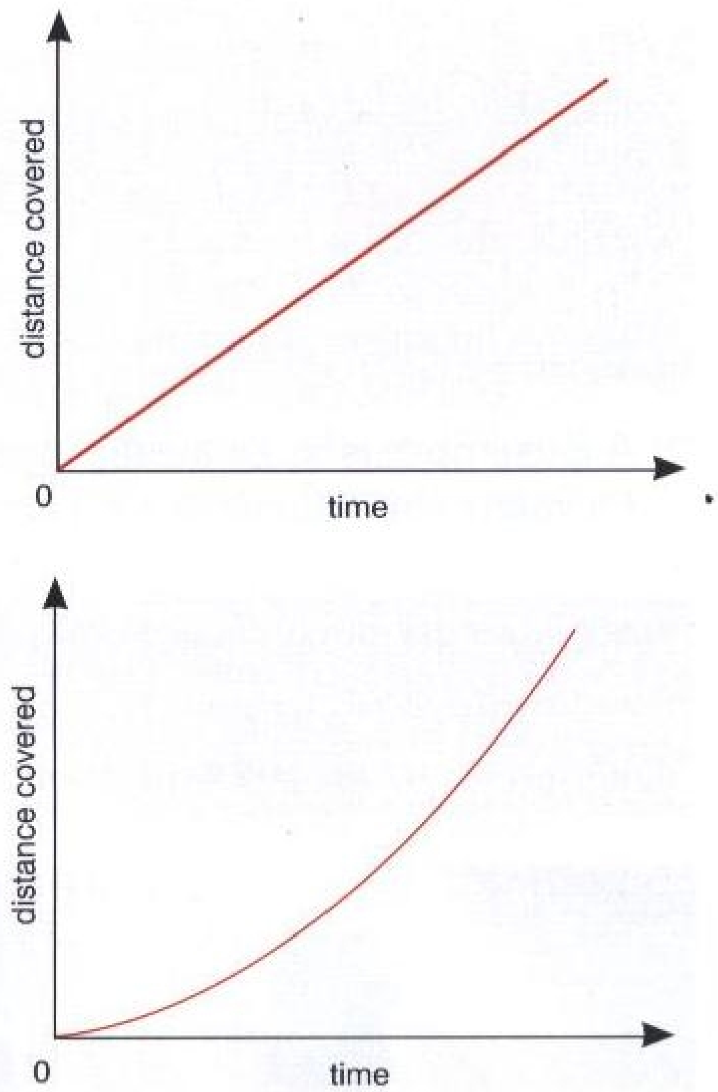
Journeys can be summarised using **graphs.** The simplest type is a **distance-time graph** where the distance travelled is plotted against the time of the journey.

At the beginning of an experiment, time is usually given as 0 s, and the position of the object 0 m. If the object is not moving, then time increases, but distance does not. This gives a horizontal line. If the object is travelling at a steady speed, then both time and distance increase steadily, which gives a straight line. If the speed is varying, then the line will not be straight.

A distance–time graph for a bicycle travelling down a hill. The graph slopes when the bicycle is moving. The slope gets steeper when the bicycle goes faster. The slope is straight (has a constant gradient) when the bicycle's speed is constant. The line is horizontal when the bicycle is at rest.







Steady speed is shown by a straight line. Steady acceleration is shown by a smooth curve.

WHAT IS ACCELERATION?

If the speedometer of a car displays 50 km/h, and then a few seconds later it displays 70 km/h, then the car is accelerating. If the car is slowing down, this is called negative acceleration, or deceleration. Acceleration is a change in speed or velocity.

Let us imagine that the car is initially travelling at 15 m/s, and that one second later it has reached 17 m/s, and that its speed increases by 2 m/s each second after that. Each second its speed increases by 2 metres per second. We can say that its speed is increasing at '2 metres per second *per second*'. This can be written, much more conveniently, as an acceleration of 2 m/s^2.

Our planet Earth attracts all objects towards its centre with the force of gravity. The strength of the force decreases slowly with distance from the surface of the Earth, but for objects within a few km of the surface, all objects that are falling freely will have the same constant acceleration of just under 10 m/s^2. If a coconut falls from a tree, then after 1 s it will be falling at 10 m/s (though it will only have travelled 5 m because, of course, it started with zero velocity). After 2 s it will be falling at 20 m/s, if it does not hit the ground first.

How much an object's **speed or velocity changes** in a certain time is its **acceleration**. Acceleration can be calculated using the following formula:

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

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

a = acceleration

v = final velocity in m/s

u = starting velocity in m/s

t = time in s

A* EXTRA

- A negative acceleration shows that the object is slowing down.

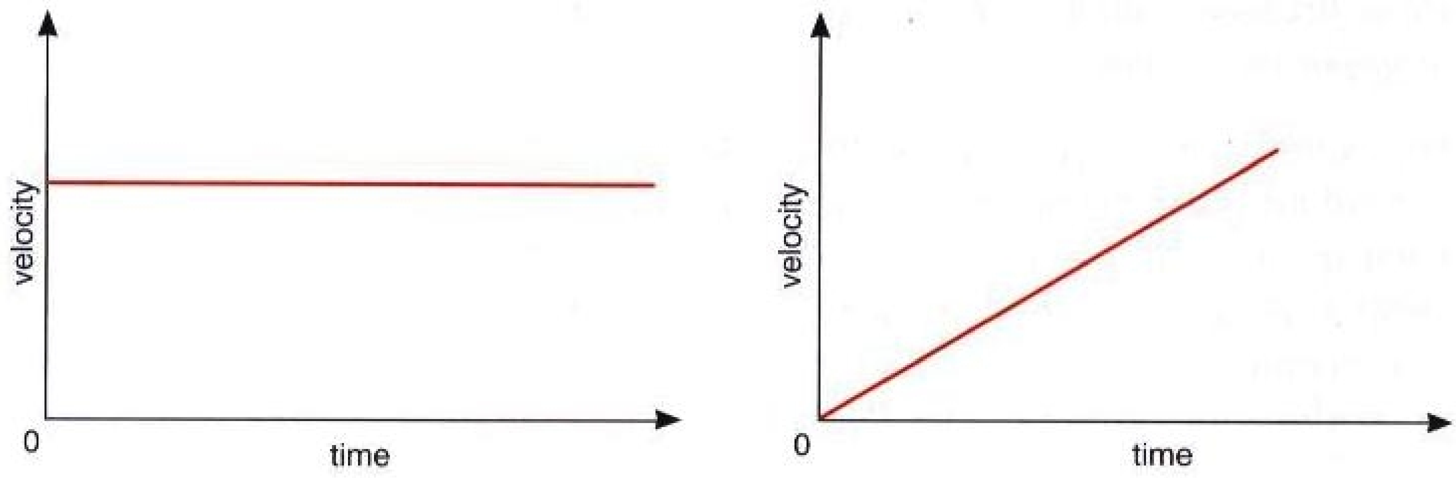
WORKED EXAMPLE

Calculate the acceleration of a car that travels from 0 m/s to 28 m/s in 10 seconds.

Write down the formula:	$a = \frac{(v - u)}{t}$
Substitute the values for v, u and t:	$a = \frac{(28 - 0)}{10}$
Work out the answer and write down the units:	$a = 2.8\ m/s^2$

A **velocity–time graph** provides information on speed or velocity, acceleration and distance travelled.

Steady velocity is shown by a horizontal line. Steady acceleration is shown by a line sloping up.



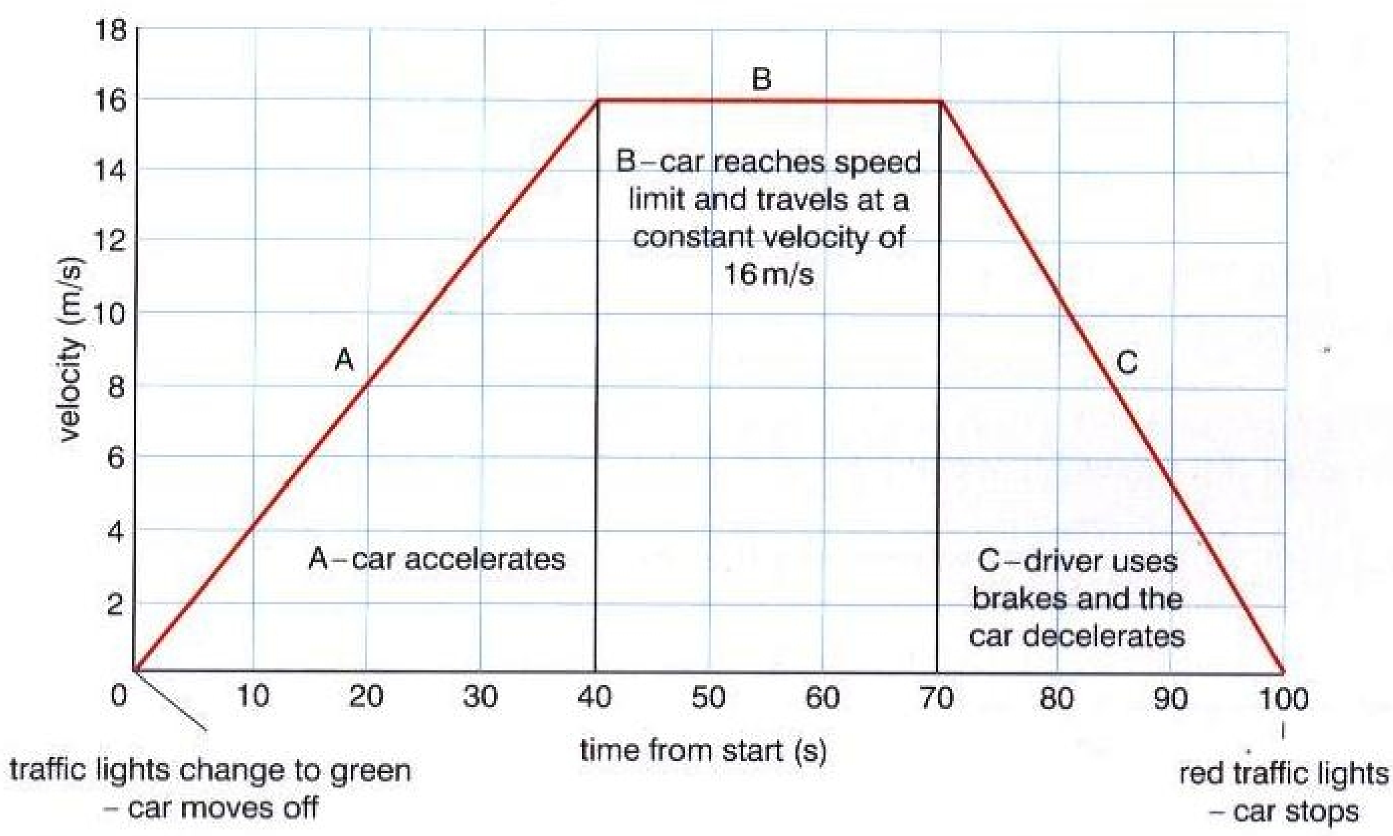
In the graph above left, the object is already moving when the graph begins. If the object starts with a velocity of zero, then the line starts from the origin as shown in the graph above right.

Note that the object may not move to begin with. In this case the line will start by going along the *x*-axis, showing that the velocity stays at zero for a while.

MEASURING AREA UNDER A GRAPH

The area under a velocity-time graph gives you the distance travelled, because distance = velocity × time. Always make sure the units are consistent, so if the velocity is in km/h, you must use time in hours too.

The graph below shows how the velocity of a car varies as it travels between two sets of traffic lights. The graph can be divided into three regions.



A velocity-time graph for a car travelling between two sets of traffic lights.

In region A, the car has constant **acceleration** (the line has a constant positive gradient). The distance travelled by the car can be calculated:

average velocity = $\frac{(16 + 0)}{2}$ = 8 m/s

time = 40 s

so distance = $v \times t = 8 \times 40 = 320$ m

This can also be calculated from the area under the line ($\frac{1}{2}$ base × height = $\frac{1}{2} \times 40 \times 16 = 320$ m).

In region B, the car is travelling at a **constant velocity** (the line has a gradient of zero). The distance travelled by the car can be calculated:

velocity = 16 m/s

time = 30 s

so, distance = $v \times t = 16 \times 30 = 480$ m

This can also be calculated from the area under the line (base × height = $30 \times 16 = 480$ m).

In region C, the car is **decelerating at a constant rate** (the line has a constant negative gradient). The distance travelled by the car can be calculated:

average velocity = $\frac{(16 + 0)}{2}$ = 8 m/s

time = 30 s

so, distance = $v \times t = 8 \times 30 = 240$ m

This can also be calculated from the area under the line ($\frac{1}{2}$ base × height = $\frac{1}{2} \times 30 \times 16 = 240$ m).

In the above example, the acceleration and deceleration were constant, and the lines in regions A and C were straight. This is very often not the case. You will probably have noticed that a car will have a larger acceleration when it is travelling at 30 km/h than when it is travelling at 120 km/h.

A man-carrying space rocket does exactly the opposite, and if you watch one being launched you can see that it has a small acceleration. As it is burning several tonnes of fuel per second, it quickly becomes less massive and starts to have a larger acceleration.

REVIEW QUESTIONS

Q1 An aeroplane takes off from an airfield and travels north for 20 minutes and the pilot finds herself 200 km north of her starting point. She finds that she has gone too far, and she travels south for 10 minutes at 300 km/h to reach the airfield that is her destination.

a What is the plane's average speed for the first part of its journey?

b What is the plane's average speed for the whole journey?

c How far apart are the two airfields?

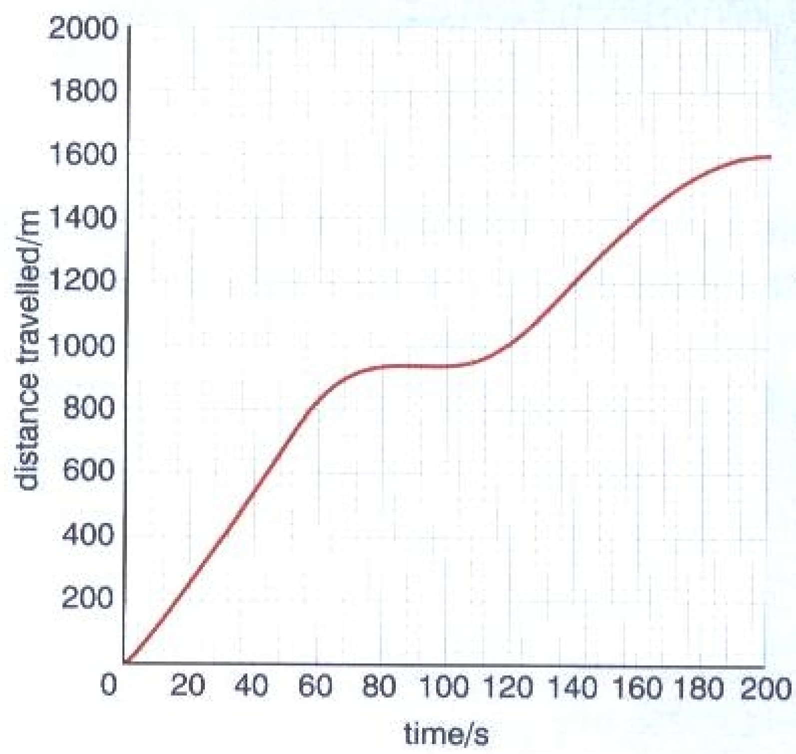
Q2 The graph shows a distance–time graph for a journey.

a What does the graph tell us about the speed of the car between 20 and 60 seconds?

b How far did the car travel between 20 and 60 seconds?

c Calculate the speed of the car between 20 and 60 seconds.

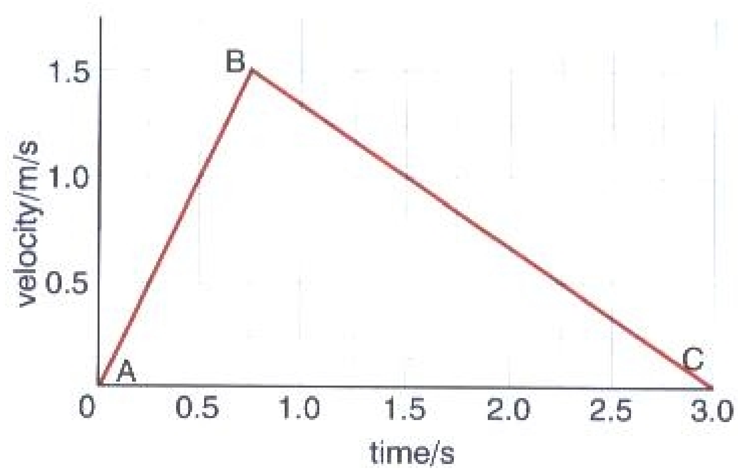
d What happened to the car between 80 and 100 seconds?



Q3 Look at the velocity–time graph for a toy tractor.

a Calculate the acceleration of the tractor from A to B.

b Calculate the total distance travelled by the tractor from A to C.



More questions on the CD ROM

Examination questions are on page 50.