Topic 1

Distance and speed

Introduction

This topic deals with speed and distance. It also introduces you to some important skills and techniques in science, including using your calculator, deciding on how to present an answer and drawing a graph.

You will probably need 2 hours to complete this topic.

Objectives

When you have completed this topic you should be able to:

- explain the relationship between average speed, distance moved and time taken
- plot and interpret distance–time graphs.

For this topic you will need graph paper and a calculator (we suggest you don't use your phone for this). Graph paper can be obtained free from the internet. Try using a search engine with the term 'printable graph paper'.

Speed

Speed and velocity

You can probably think of two words that describe how fast things move: speed and velocity. In everyday life we tend to use these terms interchangeably, but in Physics these have distinct meanings.

Speed is the distance travelled divided by the time taken; it is measure in units of distance per unit time. This could be:

- metres per second (m/s)
- centimetres per second (cm/s)

- kilometres per hour (km/h).

Velocity not only describes the speed (distance divided by time), but also defines the direction of motion. An object travelling at 1 m/s going north has a different velocity from an object travelling 1 m/s going east (even though they have the same speed).

Converting between units

To convert between units:

100 cm = 1 m

1000 m = 1 km

60 s = 1 min

60 min = 1 h

Note that units are never given a plural form, so kms, hrs, hs, mins, etc. are not used. In everyday life you will often see 'secs' for seconds, but this is not correct – please use s.

Standard form

Scientists frequently handle both large and small numbers. For example, the speed of light is 300 000 000 m/s and the average diameter of a human hair is 0.0001 m.

To make it easier to handle these numbers we can use **standard form**. This consists of a number between 1 and 9, with any decimal fraction, followed by a power of 10, which is called the **exponent**.

The following is 6789 expressed as standard form: 6.789×10^3

10^3 stands for 10 × 10 × 10. The number given as a superscript (3 in this case) is the number of times you multiply by 10.

The pattern of exponents is:

$10^3 = 10 \times 10 \times 10$ (= 1000)

$10^2 = 10 \times 10$ (= 100)

$10^1 = 10$

$10^0 = 1$

$10^{-1} = 1/10^1 = 0.1$

$10^{-2} = 1/10^2 = 0.01$

$10^{-3} = 1/10^3 = 0.001$

And so on.

Don't worry if you are not familiar with this – practice will help.

Entering these numbers into your calculator can be tricky. You would enter 6.789×10^3 as follows:

6	.	7	8	9	EXP	3	=

Casio scientific calculators now have a $\times 10^x$ key, rather than EXP.

Note in particular that entering 10EXP3 (or 10 $\times 10^x$ 3) returns the number 10000 and not 1000. To obtain 1000 you enter 1EXP3 (or 1 $\times 10^x$ 3).

For entering a small number such as 6.789×10^{-3}, this is required:

6	.	7	8	9	EXP	–	3	=

Or 6.789 $\times 10^x$ (–) 3.

Make sure you become familiar with your own calculator as soon as possible.

A word of caution

Many students start to use their phone as a calculator, but unfortunately you are not permitted to have your phone in an exam situation, so please don't start to use it for your GCSE studies, except in emergencies. Get to know your calculator!

Precision

Calculators will often give you answers with lots of figures in the window. These are not usually justified. For example, if you measured the width of your dinner table to be 1382 mm to the nearest millimetre and its length to be 2460 mm to the nearest millimetre, then we could work out the area to be 1382 × 2460 mm^2. A calculator gives this as 3399720.

Since you only measured the table to four-figure accuracy, you should round off your final answer to that level. The fifth figure in this number is 7, so it causes the one to the left to be rounded up, and the result is: 3400000.

When rounding to four figures you look at the next (fifth) figure. If it is 5 or more, the fourth figure is rounded up. If it is 4 or less, the fourth figure stays the same.

Don't worry that 3400000 appears to only have two significant figures. When using standard form the precise number of significant figures can be indicated thus:

3.400×10^6

The two zeros after the decimal point indicate that these figures were significant.

Activity 1

(Allow 10 minutes)

1 Round the following numbers to the stated number of figures:

(a) 3.142 (to 2 significant figures)

(b) 6.789 (to 3 significant figures)

(c) 6.789 (to 1 significant figure)

(d) 6.719 (to 2 significant figures).

2 The national speed limit on dual carriageways is 70 miles per hour, which converts to 112.7 km/h. Convert this to m/s. Express this in standard form.

3 Convert 100 m/s to (a) cm/s and (b) km/h. Express both of your answers in standard form to two significant figures.

1 (a) 3.1; (b) 6.79; (c) 7; (d) 6.7.

2 112.7 km is 112.7 × 1000 m. There are 3600 s in 1 h, so the speed becomes: 112.7 × 1000 /3600 = 31.3 m/s. This is 3.13 × 101 m/s.

3 (a) 100 m/s is 100 × 100 cm/s, which is 1.0 × 104 cm/s.

(b) 100 m is 100/1000 km. There are 3600 s in 1 h, so this converts to (100/1000) × 3600 = 360 km/h. This is 3.60×10^2 km/h. Lastly, you were asked to round to two significant figures, which is 3.6×10^2 km/h.

If some of this maths is new to you, we suggest you access Maths Help 1 in this section of the course, which will give you some more practice in this. You can go back to that document later at any time if you need a refresher.

Average speed

The **average speed** of an object is the total distance travelled divided by the time taken.

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

Speed, in general, is distance divided by time:

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

Exam hint

You need to remember the equation for average speed; it will not be given to you in the examination.

To save having to write a lot of words scientists usually use abbreviations in their formulae and equations.

We might use symbols *u* or *v* for the speed, *s* for the distance and *t* for time. This would then become:

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

You may be given problems where you have to work out the speed of individual sections of a journey, and also an overall average speed. Be sure to read the question carefully to distinguish between them.

Average speed may bear little relation to the actual speed for most of a journey. For instance, it may take four hours to drive from Cambridge to Bournemouth via London, a distance of about 260 km. The average speed is therefore 260/4 = 65 km/h. Much of the route is along motorways, along which you can average about 100 km/h, but the journey time is lengthened by a lot of stop-start driving in congested areas.

Activity 2

(Allow 10 minutes)

1 Calculate the speed of something that travels:

(a) 8 m in 2 s, expressing your answer in m/s

(b) 1 m in 4 s, expressing your answer in cm/s

(c) 12 km in 20 min, expressing your answer in km/h.

2 A car is travelling at a constant14 m/s. How long will it take to travel 100 km? Express your answer in seconds, to two significant figures.

1 (a) 8/2 = 4 m/s; (b) 1/4 = 0.25 m/s, which is 25 cm/s; (c) 12 × 60/20 = 36 km/h.

2 Speed = distance/time. Hence time = distance/speed = 100 × 1000/14 = 7100 s. Did you remember to convert km to m?

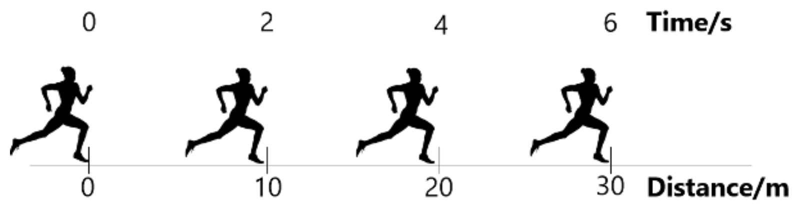
Drawing a distance–time graph

We often express data in graphical form in the sciences, because this enables us to get more useful information from our data, and to identify patterns that may not be evident from the data alone.

While you can use a computer package such as Excel to draw graphs, it is very important to practise drawing graphs by hand. In the exam you won't be able to use a computer package, unless your examination arrangements include this. Plotting graphs takes a lot of practice, so please start now!

Imagine you're watching a runner and photograph her position every two seconds. Your sequence of pictures might look like Figure 1.1.

Figure 1.1 A runner



Activity 3

(Allow 10 minutes)

Using Figure 1.1, measure the distance the runner has travelled at 0, 2, 4 and 6 s, and fill in the table.

Table 1.1 Timings for the runner

Time/s	Distance/m
0	
2	
4	
6	

You should get:

Table 1.2 Completed table

Time/s	Distance/m
0	0
2	10
4	20
6	30

We are now going to draw a graph using these data.

Setting up your axes and scales

This is the most difficult part of drawing graphs! Start by drawing two axes, near to the edge of the left-hand side and the bottom of the graph paper.

The convention is to put time on the horizontal axis and the distance on the vertical axis. We will revisit the convention for choosing which quantity to put on which axis later in the course.

You need to give your graph a title, for instance 'Distance–time graph for a runner', and label the axes with the quantity and the units. It is conventional to use a 'slash' before the units of measurement, so we have:

Distance/ m

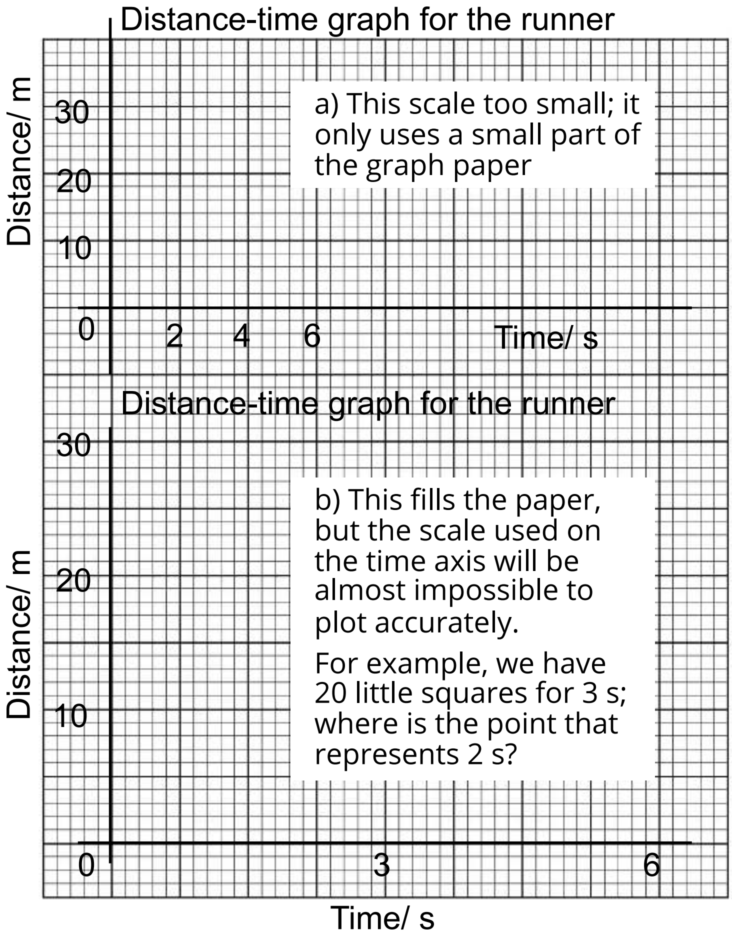
Time/ s

Note that there are alternatives, and 'distance (m)' is acceptable.

You now need to choose a scale for our graph. It needs to fill the graph paper, if possible, because a graph that is too small is difficult to read and any calculations from it are likely to contain errors. If the scale is too big you may run out of room on the graph paper. Generally, your graph line should occupy as much of the graph paper as possible, while using sensible scales on each axis.

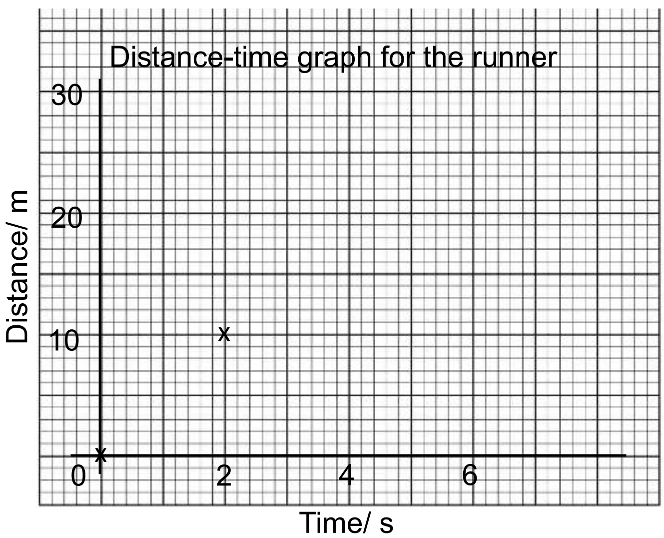
There are also problems with some scales. Choosing one square to represent 3, 6, 7 or 9, makes it very difficult to plot the points accurately. You will lose marks in the IGCSE if you choose one of these scales. Multiples of 2, 5 and 10 are usually good choices. Figure 1.2 shows some of the pitfalls in choosing a scale.

Figure 1.2 Poor scales for a graph



Once you have your scales you can start to plot the points. Use a sharp pencil, and draw a small cross to indicate where the point is. See Figure 1.3.

Figure 1.3 Starting the plot



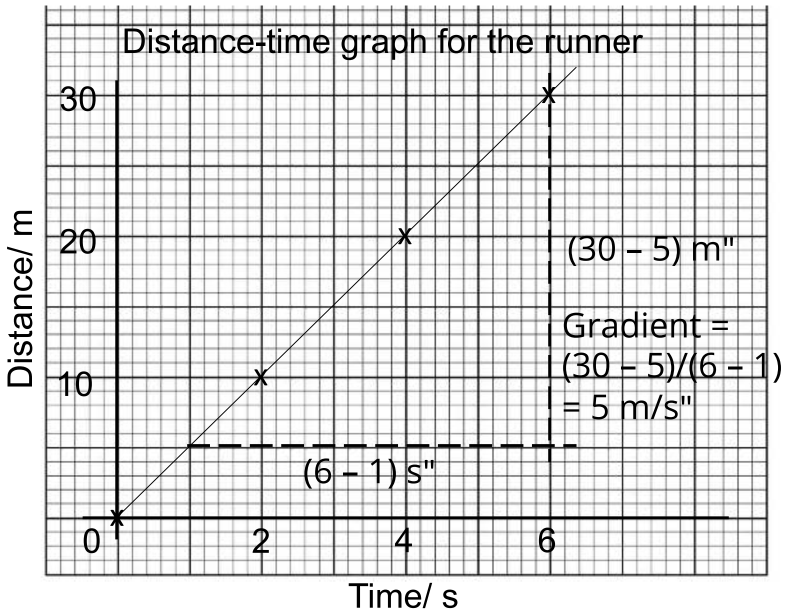
Now try to plot the data (i.e. the figures) from Table 1.2 on a piece of graph paper.

When you have plotted your data, lay a ruler against them. You should notice that they all line up in a straight line. This is the kind of distance–time graph you get when the speed is constant, i.e. when an object travels equal distances in equal times.

The speed is calculated from distance divided by time. You can get this from the graph by measuring the gradient (slope) of the line. You measure this by drawing a triangle on the line, and measuring its height and width (or 'rise and run'). Divide the vertical height of the triangle by the width to get the speed in m/s.

Figure 1.4 shows how this is done.

Figure 1.4 Calculating the gradient



The gradient of the graph is (30 – 5)/(6 – 1) = 5 m/s. This is the speed of our runner. As a check we can also calculate this from the data in Table 1.2, shown below in Table 1.3.

Table 1.3 Calculating the speed

Time/s	Distance/m	Speed m/s (= distance/time)
0	0	
2	10	10/2 = 5
4	20	20/4 = 5
6	30	30/6 = 5

Activity 4 has a slightly more complex example. See if you can solve it.

Activity 4

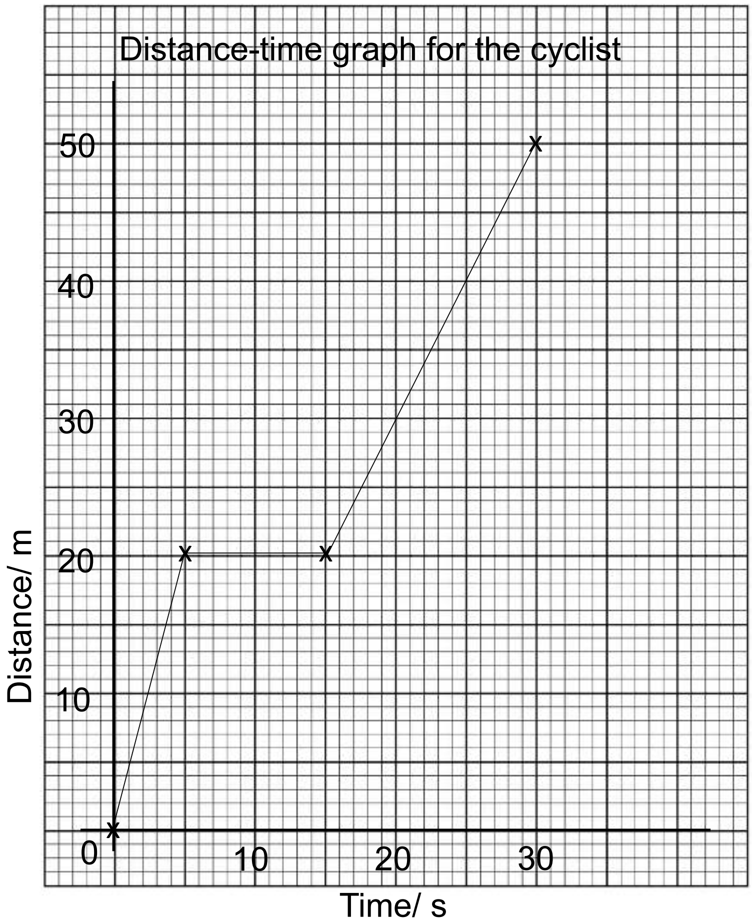
(Allow 20 minutes)

A cyclist emerges from a side street. He covers a distance of 20 m in five seconds before hitting the kerb and falling off. He takes 10 seconds to get up and then he continues on foot for the next 30 m, which takes a time of 15 seconds. Assume he travels with constant speed whenever he is moving.

1. Plot a distance–time graph for this journey.
2. From the graph, find his speed (a) when cycling, and (b) when walking.
3. Calculate his overall average speed.

1 This is our graph:

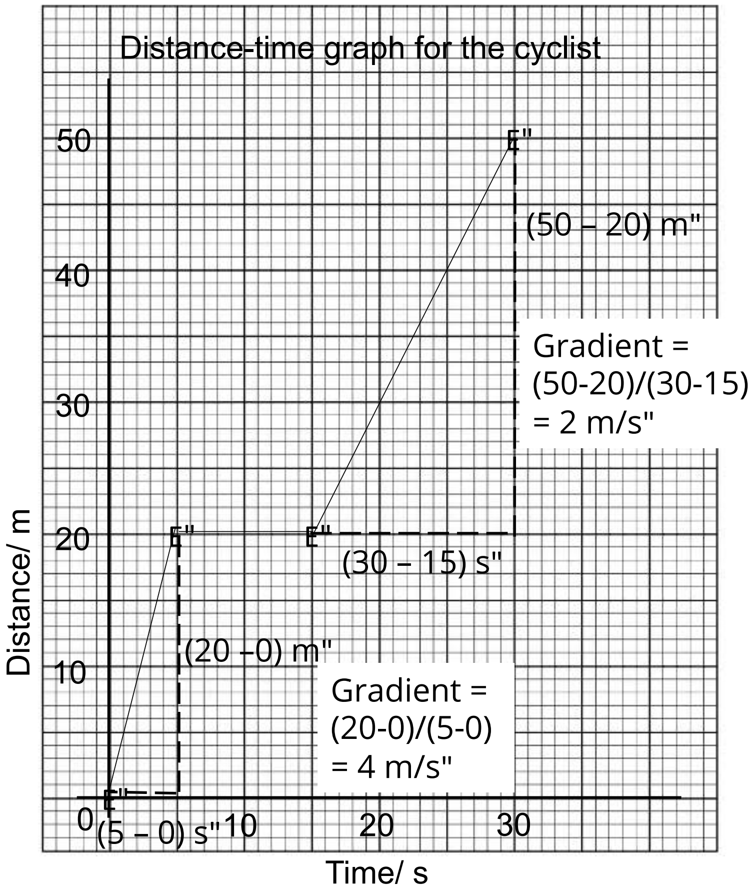
Figure 1.5 The cyclist's distance–time graph



Notice the horizontal section between 5 s and 15 s when he did not move forward, so his distance from the start remained the same.

2 The gradients are marked on the graph in Figure 1.6. (a) In the first five seconds his speed was 4 m/s. (b) In the time when he was walking his speed was 2 m/s.

Figure 1.6 Finding the speeds from the graph



Notice that the line is perceptibly steeper in the first section of the graph than the final section. A steeper gradient indicates a larger speed.

3 The total distance travelled was 50 m. He took a total of (5 + 10 + 15) = 30 s. Therefore, his average speed was 50/30 = 1.7 m/s. Note that we rounded this result to two significant figures, to be consistent with the data used. Note also that you could not get to this figure by taking the average of the two answers in question 2. There are two reasons for this: he did not travel for equal times in the walking and cycling sections, and there was a period when he was not moving. Always work out the total distance and the total time!

Traffic speed cameras

There are several types of speed camera. One type monitors the traffic moving away from it and if triggered takes two photographs of the vehicle as it passes over a grid painted on the road. A camera of this type is shown in Figure 1.7

Figure 1.7 A 'Gatso' speed camera

Another type, becoming popular on motorways and dual carriageways, is an average speed camera. This has automatic number plate recognition and times vehicles as they pass between successive cameras, calculating an average speed. The advantage of this type is that it deters drivers who speed until they see a camera, and then brake while they pass the camera.

Figure 1.8 An average speed camera

Self check

(Allow 10 minutes)

1 A marathon runner in training runs 40 km in 4 hours. What is the runner's average speed in m/s.

2 What are the correct abbreviations for minutes, hours, seconds and kilometres?

You will find feedback to self-checks at the end of the section.

Summary

You can now calculate average speed, plot a distance–time graph and find gradients from straight-line graphs. You also now know how to use standard form numbers and round off your answers.

Key terms

average speed: total distance travelled divided by the total time taken

exponent: the part 10^6 in the number expressed as 3.24×10^6

speed: distance travelled divided by time taken

standard form: a number expressed in the form in which there is a number between 1 and 9, with a decimal part if appropriate, and a power of 10, e.g. 3.24×10^6

velocity: a speed with a specified direction

References

Figures 1.1 – 1.6: Author's own work, with human silhouette from Pixabay; https://pixabay.com/

Figure 1.7: Arpingstone [Public domain], from Wikimedia Commons

Figure 1.8: Ross [CC BY-SA 2.0 (https://creativecommons.org/licenses/by-sa/2.0)], via Wikimedia Commons

What next?

We hope this sample has helped you to decide whether this course is right for you.

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