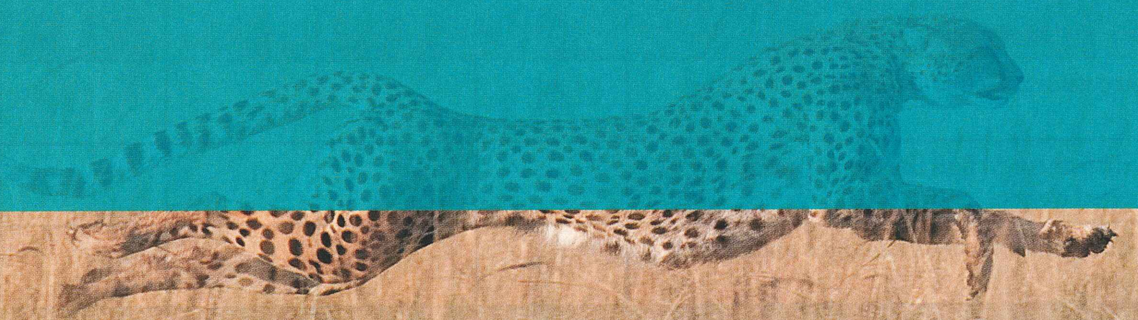
› Chapter 2

# Describing motion



IN THIS CHAPTER YOU WILL:

- define speed and calculate average speed
- plot and interpret distance–time and speed–time graphs
- work out the distance travelled from the area under a speed–time graph
- understand that acceleration is a change in speed and the gradient of a speed–time graph

› distinguish between speed and velocity

› define and calculate acceleration; understand deceleration as a negative acceleration

› use the gradient of a distance–time graph to calculate speed and the gradient of a speed–time graph to calculate acceleration.

## GETTING STARTED

Work in pairs.

On your own, quickly sketch a distance–time graph, perhaps based on your journey to school. Then ask your partner to write a description of it on a separate sheet of paper. Discuss each other's answers.

Sketch a speed–time graph for a sprinter running the 100 m in a time of 9.58 s. Label it with as much information as you know. Show how your graph could be used to work out the sprinter's acceleration at the start of the race and the distance he travelled. Compare your sketch with your partner's and add to or correct your own work. Be prepared to share your thoughts with the class.

## AROUND THE WORLD IN 80 DAYS

The first known circumnavigation (trip around the world) was completed by a Spanish ship on 8 September 1522. It took more than three years. The French writer Jules Verne wrote the book *Le tour du monde en quatre-vingts jours* (which means *Around the World in Eighty Days*) in 1873. In honour of the writer, the Jules Verne Trophy is a prize for the fastest circumnavigation by a yacht, now held by the yacht IDEC Sport, which did it in just under 41 days in 2017. In 2002, the American Steve Fossett was the first to make a solo circumnavigation in a balloon, without stopping, taking just over 13 days. In 2006, he flew the Virgin Atlantic GlobalFlyer (Figure 2.1), the first fixed-wing aircraft to go around the world without stopping or refuelling. It took him just under three days. Hypersonic jets are being developed that could fly at 1.7 km per second so they could circumnavigate the globe in an incredible six and a half hours.


**Figure 2.1:** The Virgin Atlantic GlobalFlyer passes over the Atlas Mountains.

Sometimes these epic adventures inspire those who do them to campaign for a better world. The British sailor Ellen MacArthur (Figure 2.2) is just such a person. She held the world record for the fastest solo circumnavigation, achieved on 7 February 2005. However, she retired from competitive sailing to set up the Ellen MacArthur Foundation, a charity that works with business and education to accelerate the transition to a circular economy. A circular economy would create less waste as things should be designed to last a long time and be easy to maintain, repair, reuse or recycle.

**Figure 2.2:** Ellen MacArthur celebrates after completing her record solo round the world journey on 7 February 2005 in Falmouth, England.

### Discussion questions

1 What were the speeds of the six journeys mentioned in the first paragraph? Assume that the Earth's circumference is 40 000 km.

2 How could the fastest boat not win a round-the-world yacht race?

# 2.1 Understanding speed

## Measuring speed

If you travel on a major highway or through a large city, the chances are that someone is watching you. Cameras by the side of the road and on overhead road signs keep an eye on traffic as it moves along. Some cameras are there to monitor the flow, so that traffic managers can take action when blockages develop, or when accidents occur. Other cameras are equipped with sensors to spot speeding motorists, or those who break the law at traffic lights. In some busy places, traffic police may observe the roads from helicopters.

In this chapter, we will look at ideas of motion and speed. In Chapter 3, we will look at how physicists came to understand the forces involved in motion, and how to control them to make our everyday travel possible.

## Distance, time and speed

There is more than one way to determine the **speed** of a moving object. Several methods to determine speed rely on making two measurements:

- the total distance travelled between two points
- the total time taken to travel between these two points.

We can then work out the **average speed** between the two points.

**KEY EQUATION**

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

**KEY WORDS**

**speed:** the distance travelled by an object per unit of time

**average speed:** the speed calculated from total distance travelled divided by total time taken

We can use the equation for speed in the definition when an object is travelling at a constant speed. If it travels 10 metres in 1 second, it will travel 20 metres in 2 seconds. Its speed is 10 m/s.

We cannot say whether it was travelling at a steady speed, or if its speed was changing. For example, you could use a stopwatch to time a friend cycling over a fixed distance, for example, 100 metres (see Figure 2.3). Dividing distance by time would tell you their average speed, but they might have been speeding up or slowing down along the way.

Table 2.1 shows the different units that may be used in calculations of speed. SI units are the standard units used in physics. The units m/s (metres per second) should remind you that you divide a distance (in metres, m) by a time (in seconds, s) to find speed. In practice, many other units are used. In US space programmes, heights above the Earth are often given in feet, while the spacecraft's speed is given in knots (nautical miles per hour). These awkward units did not prevent them from reaching the Moon!

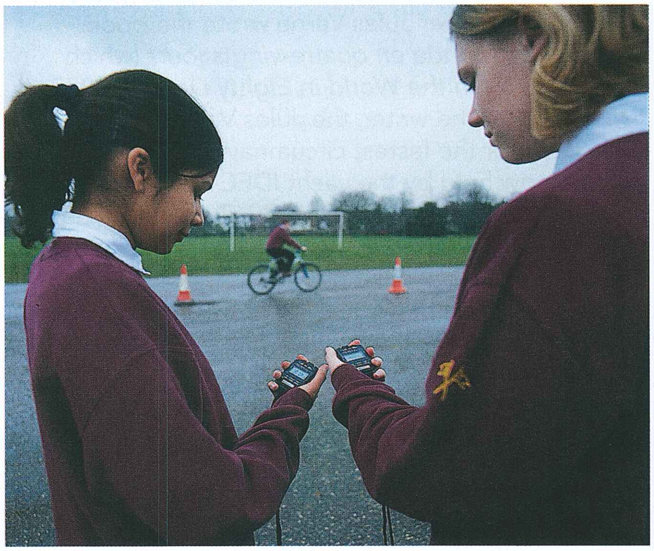


**Figure 2.3:** Timing a cyclist over a fixed distance. Using a stopwatch involves making judgements as to when the cyclist passes the starting and finishing lines. This can introduce an error into the measurements. An automatic timing system might be better.

| Quantity | SI unit | Other units |
|---|---|---|
| distance | metre, m | kilometre, km |
| time | second, s | hour, h |
| speed | metres per second, m/s | kilometres per hour, km/h |

**Table 2.1:** Quantities, symbols and units in measurements of speed.

## WORKED EXAMPLE 2.1

A cyclist completed a 1500 metre stage of a race in 37.5 s. What was her average speed?

**Step 1:** Start by writing down what you know, and what you want to know.

distance = 1500 m

time = 37.5 s

speed = ?

**Step 2:** Now write down the equation.

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

**Step 3:** Substitute the values of the quantities on the right-hand side.

$$\text{speed} = \frac{1500\ \text{m}}{37.5\ \text{s}}$$

**Step 4:** Calculate the answer.

speed = 40 m/s

**Answer**

The cyclist's average speed was 40 m/s.

## Questions

1 a What was Usain Bolt's average speed when he achieved his 100 m world record of 9.58 s in 2009?

b How do you know that his top speed must have been higher than this?

2 A cheetah runs 100 m in 3.11 s. What is its speed?

3 Information about three trains travelling between stations is shown in Table 2.2.

| Vehicle | Distance travelled / km | Time taken / minutes |
|---|---|---|
| train A | 250 | 120 |
| train B | 72 | 50 |
| train C | 400 | 150 |

Table 2.2

a Which train has the highest average speed?

b Which train has the lowest average speed?

## Determining speed in the laboratory

There are many experiments you can do in the laboratory if you can measure the speed of a moving trolley or toy car. Figure 2.4 shows how to do this using one or two **light gates** connected to an electronic timer (or to a computer). The light gate has a beam of (invisible) infrared radiation.

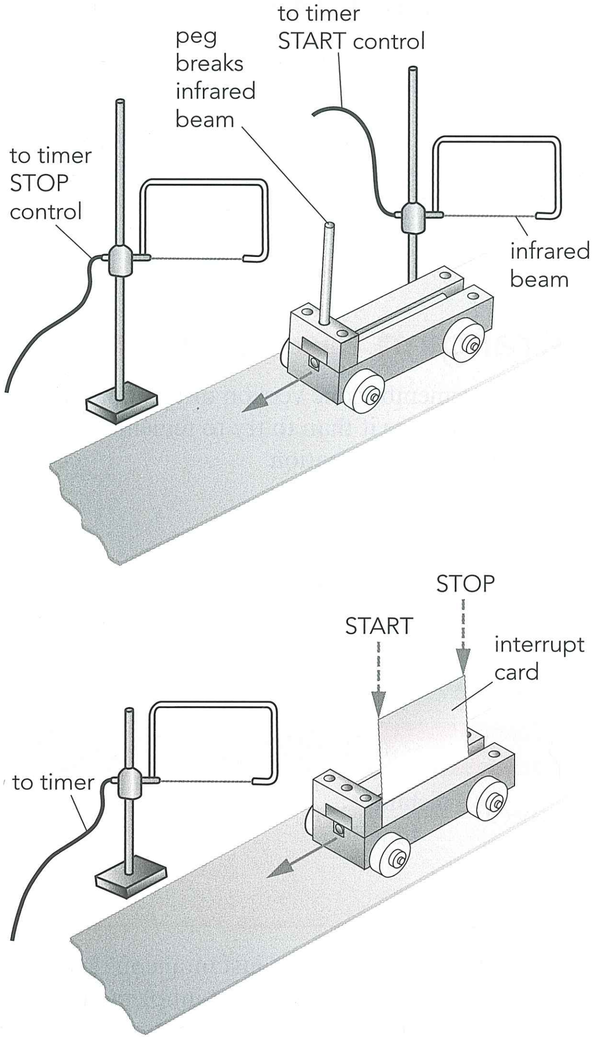



**Figure 2.4:** Using light gates to measure the speed of a moving trolley in the laboratory.

In the first part of Figure 2.4, the peg attached to the trolley breaks the beam of one light gate to start the timer. It breaks the second beam to stop the timer. The timer then shows the time taken to travel the distance between the two light gates.

In the second part of Figure 2.4, a piece of card, called an **interrupt card**, is mounted on the trolley. As the trolley passes through the gate, the leading edge of the interrupt card breaks the beam to start the timer. When the trailing edge passes the gate, the beam is no longer broken and the timer stops. The faster the trolley is moving, the shorter the time for which the beam is broken. Given the length of the interrupt card, the trolley's speed can be calculated.

### KEY WORDS

**light gates:** allow the speed of an object passing between them to be calculated electronically

**interrupt card:** allows the speed of an object passing through a light gate to be calculated; a timer starts when the card breaks the beam and stops when the beam is no longer broken

## Rearranging the equation

It is better to remember one version of an equation and how to rearrange it than to try to remember three different versions. The equation

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

allows us to calculate speed from measurements of distance and time. This equation can also be written in symbols:

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

### KEY EQUATION

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

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

This is sometimes known as the instantaneous speed, which is the speed at a particular instant or moment in time, whereas average speed is worked out over a longer time interval. Beware, $s$ in this equation means distance (or displacement) and not speed. We can rearrange the equation to allow us to calculate distance or time.

For example, a railway signaller might know how fast a train is moving, and needs to be able to predict where it will have reached after a certain length of time:

$$\text{distance} = \text{speed} \times \text{time} \quad \text{or} \quad s = vt$$

Similarly, the crew of an aircraft might want to know how long it will take for their aircraft to travel between two points on its flight path:

$$\text{time} = \frac{\text{distance}}{\text{speed}} \quad \text{or} \quad t = \frac{s}{v}$$

### WORKED EXAMPLE 2.2

A spacecraft is orbiting the Earth at a steady speed of 8.0 km/s (see Figure 2.5). How long will it take to complete a single orbit, a distance of 44 000 km?

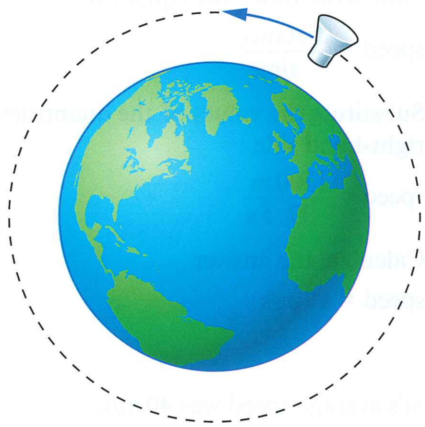


Figure 2.5

**Step 1:** Start by writing down what you know, and what you want to know.

speed ($v$) = 8.0 km/s

distance ($s$) = 40 000 km

time ($t$) = ?

**Step 2:** Choose the appropriate equation, with the unknown quantity, time, as the subject (on the left-hand side).

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

**Step 3:** Substitute values – it can help to include units.

$$t = \frac{40000\text{ km}}{8.0\text{ km/s}}$$

**Step 4:** Perform the calculation.

$t = 5000$ s

**Answer**

The time to complete a single orbit (44 000 km) is 5500 s. This is about 92 minutes (5500 ÷ 60 = 91.667). So, the spacecraft takes 92 minutes to orbit the Earth once.

Worked Example 2.2 illustrates the importance of looking at the units. Because speed is in km/s and distance is in km, we do not need to convert to m/s and metres. We would get the same answer if we did the conversion:

$$\text{time} = \frac{40\,000\,000\text{ m}}{8000\text{ m/s}}$$

$$= 5000\text{ s}$$

## Questions

4 An aircraft travels 900 metres in 3.0 seconds. What is its speed?

5 A car travels 400 km in 3.5 hours. What is the speed of the car in km/h and m/s?

6 The Voyager spacecraft is moving at 17 000 m/s. How far will it travel in one year? Give your answer in km.

7 Calculate how many minutes it takes sunlight to reach us from the Sun. Light travels at $3 \times 10^8$ m/s and the Sun is about 144 million km away.

8 A cheetah can maintain its top speed of 31 m/s over a distance of 100 metres while some breeds of gazelle, such as Thomson's gazelle, have a top speed of 25 m/s. This question considers how close the cheetah needs to be to catch the gazelle if they have both just reached top speed.

  a How long does it take a cheetah to cover 100 m?

  b What is the closing speed of the cheetah, that is, what is the difference in speed between the cheetah and the gazelle?

  c How far ahead of the cheetah would the gazelle need to be to escape? (Hint: you need the time you calculated in **a** and the closing speed you calculated in **b**.)

  d How long would it take the cheetah to catch the gazelle with the closing speed you calculated in **b** and the distance apart you calculated in **c**?

## ACTIVITY 2.1

### Running with the wind behind you

In 2011, Justin Gatlin ran 100 metres in 9.45 seconds (faster than Usain Bolt's world record by 0.13 seconds). However, he was pushed along by a 20 m/s tailwind generated by giant fans as part of a Japanese game show. A 100 m or 200 m sprint record can stand only if a tailwind does not exceed 2 m/s. Why does this rule not apply to longer events?

First, think about how you might approach this problem.

The day Roger Bannister ran a mile in four minutes (6 May 1954) he almost decided not to race because it was too windy. Imagine there is a tailwind along the final straight section of a 400 m track which speeds you up, and a headwind on the opposite straight section which slows you down. Why do the effects of the tailwind and headwind **not** cancel out? (Hint: you need to think about the time it would take you to run the straight sections.)

1 Imagine that you are a 400 m runner who can run the distance in 40 s (a new world record) at the same average speed of 10 m/s. Assume that the 400 m track is equally divided so that the straight sections and bends are each 100 m long.

Plot your time for the 400 m (*y*-axis) against wind speed (*x*-axis). When you are running against the wind on the straight section opposite the finish line, subtract the wind speed from your normal running speed. When you are running with the wind on the final straight section before the finish line, add the wind speed to your normal running speed.

For example, if there is a wind speed of 1 m/s, your speed along the straight opposite the finish line will be 9 m/s while it will be 11 m/s along the straight section before the finish line. Then you need to add the times for each straight section to the 20 s for the bends. Repeat this, increasing the wind speed by 1 m/s each time, until you reach 10 m/s.

2 Could you have reached the answer without plotting a graph?

3 Discuss whether it is realistic to add or subtract the wind speed to your normal running speed.

4 Design an experiment to test how wind speed affects running speed. You might need to include equipment that you do not have access to (such as the giant fans used on the Japanese game show).

## REFLECTION

Discuss your answers to the activity with the person sitting next to you. Have they thought of anything you haven't included in your answer? Would you add anything to your answers after your discussion?

# 2.2 Distance–time graphs

You can describe how something moves in words, 'The coach drove away from the bus stop. It travelled at a steady speed along the main road, leaving town. After five minutes, it reached the highway, where it was able to speed up. After ten minutes, it was forced to stop because of traffic.'

We can show the same information in the form of a distance–time graph, as shown in Figure 2.6a. This graph is in three sections, corresponding to the three sections of the coach's journey.

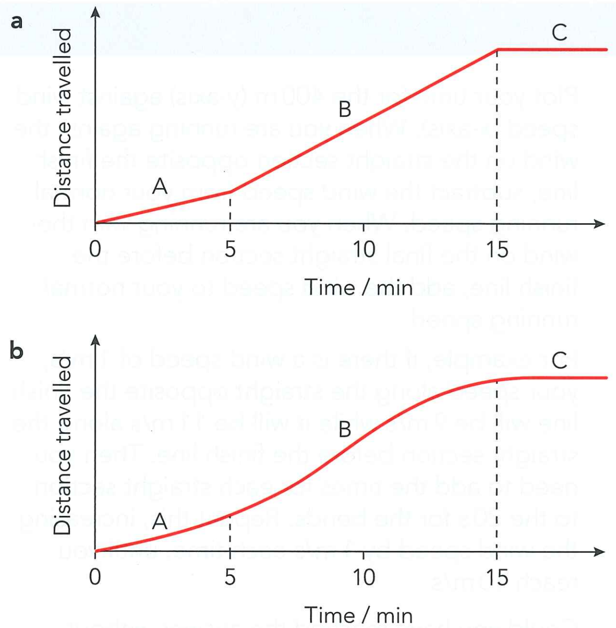



**Figure 2.6 a and b:** A graph to represent the motion of a coach, as described in the text. The slope of the graph tells us about the coach's speed.

In section A, the graph slopes up gently, showing that the coach was travelling at a slow speed.

In section B, the graph becomes steeper. The distance of the coach from its starting point is increasing more rapidly. It is moving faster.

In section C, the graph is flat (horizontal). The distance of the coach from its starting point is not changing. It is stationary.

The slope of the distance–time graph tells us how fast the coach is moving. The steeper the graph, the faster it is moving (the greater its speed). When the graph becomes horizontal, its slope is zero. This tells us that the coach's speed is zero in section C. It is not moving.

Figure 2.6a shows abrupt (instant) changes in speed between A, B and C. It would not be a very comfortable ride for the passengers! Instead of abrupt changes in speed, the speed would change more slowly in the real world and there would be smooth curves joining the sections (Figure 2.6b). The increasing gradient of the upward-sloping curve between A and B would show that the coach was speeding up (accelerating) and the decreasing gradient of the curve between B and C would show that the coach was slowing down (decelerating). However, we will only look at graphs with angled edges as in Figure 2.6a.

## Questions

**9** A car pulled away from the lights and travelled at a steady speed along an empty road. After 8 minutes it joined a main road, where it travelled at about twice the original speed for 12 minutes. The car then met a traffic jam and had to quickly slow down and stop. The traffic cleared after 5 minutes but then the car travelled slowly, at about half the original speed.

Sketch a distance–time graph to show the car's journey.

**10** Figure 2.7 shows the distance–time graph for a woman running a mountain marathon.

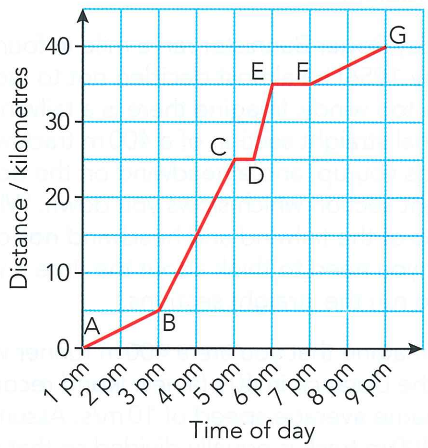



**Figure 2.7:** Distance–time graph

- **a** How far did she travel?
- **b** What was her average speed in km/h?
- **c** How many stops did she make?
- **d** The rules said she had to stop for half an hour for food. When did she take her break?
- **e** Later she stopped to help an injured runner. When did this happen?
- **f** What would her average speed have been if she had not stopped at all?
- **g** What was her highest speed and over what section did this happen?

## Express trains, slow buses

An express train is capable of reaching high speeds, perhaps more than 300 km/h. However, when it sets off on its journey, it may take several minutes to reach this top speed. Then it takes a long time to slow down when it approaches its destination. The French TGV trains (Figure 2.8) run on lines that are reserved solely for their operation, so that their high-speed journeys are not disrupted by slower, local trains.

A bus journey is full of accelerations and decelerations. The bus accelerates away from the stop. Ideally, the driver hopes to travel at a steady speed until the next stop. A steady speed means that you can sit comfortably in your seat. Then there is a rapid deceleration as the bus slows to a halt. A lot of accelerating and decelerating means that you are likely to be thrown about as the bus changes speed. The gentle acceleration of an express train will barely disturb the drink in your cup. The bus's rapid accelerations and decelerations would make it impossible to avoid spilling the drink (Figure 2.9).

**Figure 2.8:** France's high-speed trains, the TGVs (Trains à Grande Vitesse), run on dedicated tracks. Their speed has made it possible to travel 600 km from Marseille in the south to Paris in the north, attend a meeting, and return home again within a single day.

**Figure 2.9:** It can be uncomfortable on a packed bus as it accelerates and decelerates along its journey.

# 2.3 Understanding acceleration

Some cars, particularly high-performance ones, are advertised according to how rapidly they can accelerate. An advert may claim that a car goes 'from 0 to 100 km/h in 5 s'. This means that, if the car accelerates at a steady rate, it reaches 20 km/h after 1 s, 40 km/h after 2 s, and so on. We could say that it speeds up by 20 km/h every second. In other words, its acceleration is 20 km/h per second.

So, we say that an object accelerates if its speed increases. Its **acceleration** tells us the rate at which its speed is changing, that is, the change in speed per unit time.

When an object slows down, its speed is also changing. We say that it is decelerating. Instead of an acceleration, it has a deceleration.

## Speed and velocity, vectors and scalars

In physics, the words 'speed' and 'velocity' have different meanings, although they are closely related: **velocity** is an object's speed in a particular stated direction. So, we could say that an aircraft has a speed of 200 m/s but a velocity of 200 m/s due north. We must give the direction of the velocity or the information is incomplete.

Velocity is an example of a **vector quantity**. Vectors have both magnitude (size) and direction. Another example of a vector is weight – your weight is a force that acts downwards, towards the centre of the Earth.

Speed is an example of a **scalar quantity**. Scalars only have magnitude. Temperature is an example of another scalar quantity.

You will learn more about vectors and scalars in Chapter 3.

KEY WORDS

**acceleration:** the rate of change of an object's velocity

**velocity:** the speed of an object in a stated direction

**vector quantity:** has both magnitude (size) and direction

**scalar quantity:** is something that has magnitude but no direction

## Speed–time graphs

Just as we can represent the motion of a moving object by a distance–time graph, we can also represent it by a speed–time graph. A speed–time graph shows how the object's speed changes as it moves. Always check any graph by looking at the axes to see the labels. A speed–time graph has speed on the vertical axis and time on the horizontal axis.

Figure 2.10 shows a speed–time graph for a bus. The graph frequently drops to zero because the bus stops to let people on and off. Then the line slopes up, as the bus accelerates away from the stop. Towards the end of its journey, the bus is moving at a steady speed (horizontal graph), as it does not have to stop. Finally, the graph slopes downwards to zero again as the bus pulls into the terminus and stops.

The slope of the speed–time graph tells us about the bus's acceleration:

- the steeper the slope, the greater the acceleration
- a negative slope means a deceleration (slowing down)
- a horizontal graph (slope = 0) means a constant speed.

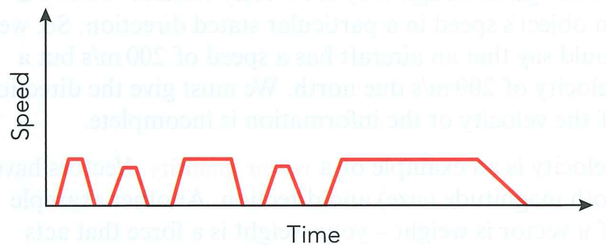



**Figure 2.10:** A speed–time graph for a bus on a busy route. At first, it has to halt frequently at bus stops. Towards the end of its journey, it maintains a steady speed.

## Graphs of different shapes

Speed–time graphs can show us a lot about an object's movement. Was it moving at a steady speed, or speeding up, or slowing down? Was it moving at all?

Figure 2.11 represents a train journey. The graph is in four sections. Each section illustrates a different point:

- A: sloping upwards, so the speed increases and the train is accelerating
- B: horizontal, so the speed is constant and the train is travelling at a steady speed
- C: sloping downwards, so the speed decreases and the train is decelerating
- D: horizontal, so the speed has decreased to zero and the train is stationary.

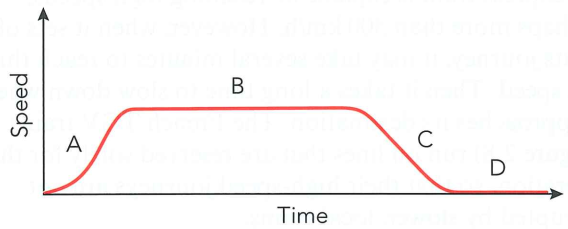



**Figure 2.11:** An example of a speed–time graph for a train during part of its journey.

The fact that the graph lines are curved in sections A and C tells us that the train's acceleration was changing. If its speed had changed at a steady rate, these lines would have been straight.

## Questions

**11** Two students live in the same apartment block in Hometown and attend the same school in Schooltown, as shown in Figure 2.12. For this question, work in km and hours.

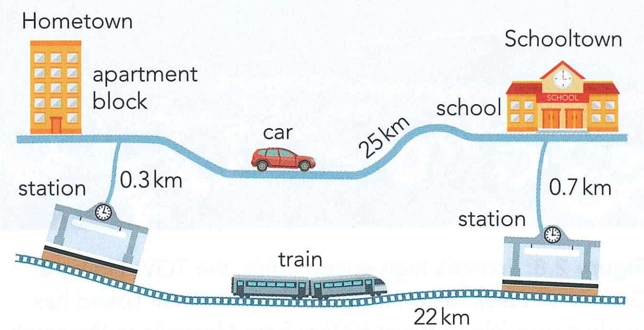



**Figure 2.12**

**a** Arun gets a lift to school in his mother's car. The traffic is heavy so the average speed for the journey is 40 km/h. How many minutes does it take Arun to get to school?

**b** Sofia leaves home at the same time as Arun but she walks the 0.3 km to Hometown station, waits 3 minutes (0.05 hour) for the train, travels on the train to Schooltown station (journey distance 22 km) and walks the 0.7 km from Schooltown station to the school. The train averages 88 km/h and Sofia walks at 5 km/h. How many minutes does it take Sofia to get to school?

**c** How many minutes shorter is Sofia's journey time than Arun's?

**d** Draw a speed–time graph for their journeys on the same axes but assume that any change in speed is instant (do not show the acceleration).

**12** Look at the speed–time graph in Figure 2.13.

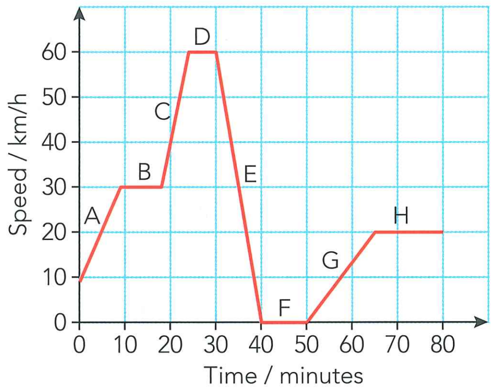



**Figure 2.13**

Name the sections that represent:

**a** steady speed

**b** speeding up (accelerating)

**c** being stationary

**d** slowing down (decelerating).

**13** A car is travelling at 20 m/s. The driver sees a hazard. After a reaction time of 0.7 s, she performs an emergency stop by applying the brakes. The car takes a further 3.3 s to come to a stop. Sketch a speed–time graph for her journey from the moment she sees the hazard to the moment she brings her car to a stop. Label the graph with as many details as you can.

**14** **a** Copy Table 2.3 and sketch the motion graphs for each motion described.

| Motion of body | Distance–time graph | Speed–time graph |
|---|---|---|
| at rest | | |
| moving at constant speed | | |
| constant acceleration (speeding up) | | |
| constant deceleration (slowing down) | | |

**Table 2.3**

**b** Copy Table 2.4 and sketch the speed–time graphs for each acceleration described.

| Motion of body | constant acceleration | increasing acceleration | decreasing accleration |
|---|---|---|---|
| accelerating | | | |
| decelerating | | | |

**Table 2.4**

## Finding distance travelled

A speed–time graph represents an object's movement. It tells us about how its speed changes. We can also use the graph to deduce (work out) how far the object travels. To do this, we have to make use of the equation:

distance = area under speed–time graph

The area under any straight-line graph can be broken down into rectangles and triangles. Then you can calculate the area using:

area of rectangle = width × height

area of a triangle = $\frac{1}{2}$ × base × height

To understand this equation, consider Worked Examples 2.3, 2.4 and 2.5.

## WORKED EXAMPLE 2.3

Calculate the distance you travel when you cycle for 20 s at a constant speed of 10 m/s (see Figure 2.14).

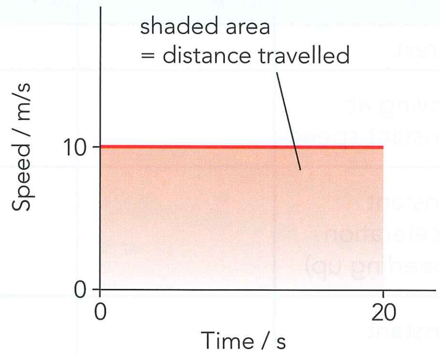



**Figure 2.14:** Speed–time graph for Worked Example 2.3.

**Step 1:** Distance travelled is the same as the shaded area under the graph. This rectangle is 20 s wide and 10 m/s high, so its area is 10 m/s × 20 s = 200 m.

**Step 2:** Check using the equation:

distance travelled = speed × time

= 10 m/s × 20 s = 200 m

**Answer**

You would travel 200 metres.

## WORKED EXAMPLE 2.4

You set off down a steep ski slope. Your initial speed is 0 m/s. After 10 s you are travelling at 30 m/s (see Figure 2.15). Calculate the distance you travel in this time.

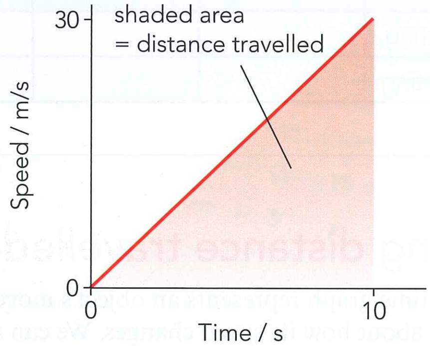



**Figure 2.15:** Speed–time graph for Worked Example 2.4.

**Step 1:** Distance travelled is the same as the shaded area under the graph. The shape is a triangle with a height of 30 m/s and base of 10 s.

$$\text{area of a triangle} = \frac{1}{2} \times \text{base} \times \text{height}$$

$$\frac{1}{2} \times 10\text{ s} \times 30\text{ m/s}$$

$$= 150\text{ m}$$

**Step 2:** Check using the equation:

$$\text{average speed} = \frac{\text{initial velocity} + \text{final velocity}}{2}$$

$$= \frac{0\text{ m/s} + 30\text{ m/s}}{2}$$

$$= 15\text{ m/s}$$

distance travelled = average speed × time

= 15 m/s × 10 s

= 150 m

**Answer**

You travel 150 metres.

## WORKED EXAMPLE 2.5

A train's motion is represented by the graph in Figure 2.16. Calculate the distance the train travels in 60 s.

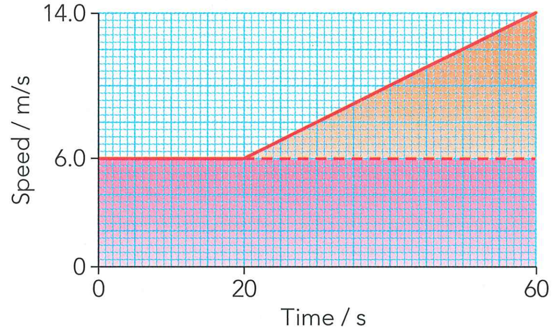



**Figure 2.16:** Speed–time graph for Worked Example 2.5.

**Step 1:** Distance travelled is the same as the shaded areas under the graph. This graph has two shaded areas: the pink rectangle and the orange triangle.

**Step 2:** Find the area of the pink rectangle.

It is 60 s wide and 6.0 m/s high, so its area = 60 s × 6.0 m/s = 360 m

(Note: this tells us how far the train would have travelled if it had maintained a constant speed of 6.0 m/s.)

**Step 3:** Find the area of the orange triangle. It has a base of 40 s and height of 14.0 m/s − 6.0 m/s = 8.0 m/s

$$\text{area of a triangle} = \frac{1}{2} \times \text{base} \times \text{height}$$
$$= \frac{1}{2} \times 40\,\text{s} \times 8.0\,\text{m/s}$$
$$= 160\,\text{m}$$

(Note: this tells us the extra distance travelled by the train because it was accelerating.)

**Step 4:** Add these two areas to find the total area and, therefore, the total distance travelled:

total distance travelled = 360 m + 160 m

= 520 m

**Step 5:** Check using the equation

distance travelled = average speed × time

The train travelled for 20 s at a steady speed of 6.0 m/s, and then for 40 s at an average speed of 10.0 m/s. So:

$$\text{distance travelled} = (6.0\,\text{m/s} \times 20\,\text{s}) + (10.0\,\text{m/s} \times 40\,\text{s})$$
$$= 120\,\text{m} \times 400\,\text{m}$$
$$= 520\,\text{m}$$

**Answer**

In 60 s, the train travelled 520 metres.

## Question

**15** **a** Draw a speed–time graph to show a car that accelerates uniformly from 6 m/s for 5 s then travels at a steady speed of 12 m/s for 5 s.

**b** On your graph, shade the area that shows the distance travelled by the car in 10 s.

**c** Calculate the distance travelled in this time.

## ACTIVITY 2.2

### The 4 × 100 metre relay

The purpose of this activity is to apply what you have learned about motion (and particularly sketching speed–time graphs) to a real problem. If you get the chance to take this activity out onto a running track, you will need to take time and distance measurements (something you learned about in Chapter 1).

Success in a 4 × 100 m relay race depends both on the speed of the runners and effective baton exchange between the runners. The baton must pass between runners within a 30 m changeover (or passing) zone, which includes a 10 m acceleration (or fly) zone. Figure 2.17 shows the first of these three passing zones.

CONTINUED

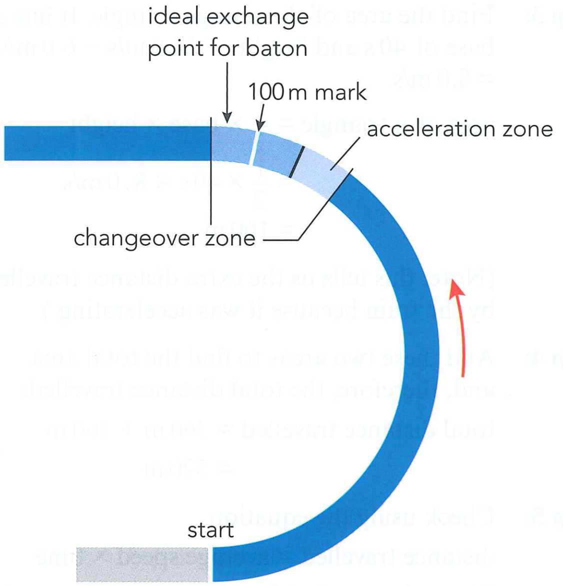



**Figure 2.17:** The first bend of a 400m athletics track.

Each athlete actually sprints for more than 100 m, as shown in Table 2.5. By planning for the baton to exchange between runners at the beginning or end of the changeover box, you can adjust the distance each runner runs. You might have a slightly shorter distance for a 60 m sprinter and a lengthened distance for a 100 m runner who also runs 200 m, which also makes them used to running bends. Usually, each runner keeps the baton in the same hand and passes it to the opposite hand of the next runner to exchange the baton. Usually, the first runner carries the baton in their right hand.

1 In what hand will runners receive and carry the baton on subsequent legs?

2 What are the advantages of passing the baton to the opposite hand?

Ideally, during the baton exchange the speeds of the runners should be the same. To achieve this the outgoing runner starts his run when the incoming runner reaches a check mark.

3 How would you work out where to place the check mark? (Hint: it might help if you sketch speed–time graphs on the same axes for both runners, starting when the runner receiving the baton starts running.) What other information would you need to make this accurate?

4 Even at Olympic finals teams can be disqualified (stopped from taking part) if they drop the baton or pass it outside of the changeover zone. Why does this happen so often?

5 Imagine you are the school's athletics coach. Table 2.5 lists the times for runners who often compete in the senior 4 × 100 m relay.

Use this information to select your team and decide which leg each runner should run and enter their names on the team sheet. Do you have a strategy for deciding which athlete runs which leg? What other information might you want to gather before making a decision? For example, Sajjan suggests that he is the best starter. Some athletes are better at running bends. Some are better at passing or receiving the baton.

| Athlete name | 100 m personal best / s | 200 m personal best / s | Right-handed, left-handed, or ambidextrous (happy using either hand) | Good bend runner |
|---|---|---|---|---|
| Sajjan Sidhu | 12.1 | 25.8 | right | prefers bends |
| Gar Psi Ho | 11.8 | 24.3 | right, ambidextrous | prefers bends |
| Andrew Kerr-Chin | 11.1 | 24.4 | ambidextrous | prefers straights but good at both |
| Tom Schofield | 11.7 | 25.1 | right, ambidextrous | better at straights |
| Oliver Hudson | 12.6 | 26.3 | ambidextrous | happy to run bends |

**Table 2.5**

CONTINUED

6 Collect data from your own group. Use this to select a 4 × 100 m team and decide who should run each leg. Copy and complete this team sheet.

| Team sheet | | | |
|---|---|---|---|
| Leg | Typical distance actually run / m | Athlete name | 100 m personal best |
| 1 | 105 | | |
| 2 | 125 | | |
| 3 | 125 | | |
| 4 | 120 | | |

**Table 2.6**

SELF-ASSESSMENT

In science it is often helpful to visualise tasks. For question 3, did you have a clear idea of how to work out where to place the check marks? Did the idea of sketching the speed–time graphs for the runners help? (The difference in the area under the two graphs up to the moment of baton exchange should tell you how far in front of the acceleration zone to place the check mark).

What other information did you need before deciding which runner should run each leg?

# 2.4 Calculating speed and acceleration

From a distance–time graph, we can find how fast something is moving. Figure 2.18 shows information about a car journey between two cities. The car travelled more slowly at some times than at others. It is easier to see this if we present the information as a graph.

From the graph, you can see that the car travelled slowly at the start of its journey, and also at the end, when it was travelling through the city. The graph is steeper in the middle section, when it was travelling on the open road between the cities.

The graph also shows how to use the gradient to calculate the car's speed on the open road:

speed = gradient of distance–time graph

More detail is given in Worked Example 2.6.

WORKED EXAMPLE 2.6

Use the gradient of the graph in Figure 2.18 to calculate the car's speed on the open road.

| Distance travelled / km | Time taken / h |
|---|---|
| 0 | 0.0 |
| 10 | 0.4 |
| 20 | 0.8 |
| 100 | 1.8 |
| 110 | 2.3 |

**Table 2.7:** Data for a car journey.

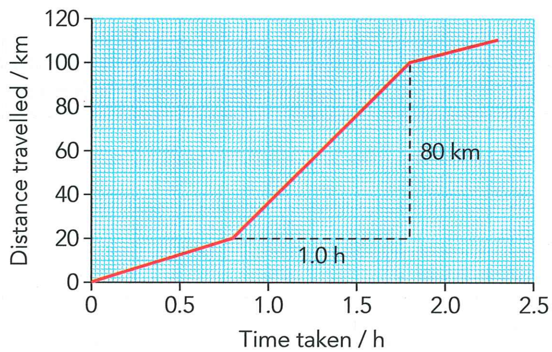



**Figure 2.18:** Distance–time graph for a car journey.

CONTINUED

speed = gradient of distance–time graph

**Step 1:** Identify the relevant straight section of the graph. Here, we are looking at the straight section in the middle of the graph, where the car's speed was constant.

**Step 2:** Draw horizontal and vertical lines to complete a right-angled triangle.

**Step 3:** Calculate the lengths of the sides of the triangle.

**Step 4:** Divide the vertical height by the horizontal width of the triangle ('up divided by along').

vertical height = 80 km

horizontal width = 1.0 h

$$\text{gradient} = \frac{80\,\text{km}}{1.0\,\text{h}} = 80\,\text{km/h}$$

**Answer**

The car's speed was 80 km/h for this section of its journey.

Note: It helps to include units in the calculation because then the answer will automatically have the correct units, in this case, km/h.

## Question

**16** Table 2.8 shows information about a train journey.

| Station | Distance travelled/ km | Time taken / minutes |
|---|---|---|
| Hornby | 0 | 0 |
| Kirby Lonsdale | 10 | 30 |
| Ingleton | 20 | 45 |
| Dolphinholme | 46 | 60 |
| Galgate | 56 | 80 |

**Table 2.8**

Use the data in Table 2.8 to plot a distance–time graph for the train. Find the train's average speed between Kirby Lonsdale and Dolphinholme. Give your answer in km/h.

## Calculating acceleration

Picture an express train setting off from a station on a long, straight track. It may take 300 s to reach a velocity of 300 km/h along the track. Its velocity has increased by 1 km/h each second, and so we say that its acceleration is 1 km/h per second.

These are not very convenient units, although they may help to make it clear what is happening when we talk about acceleration. To calculate an object's acceleration, we need to know two things:

- its change in velocity (how much it speeds up)
- the time taken (how long it takes to speed up).

The acceleration of the object is defined as the change of an object's velocity per unit time.

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

We can write the equation for acceleration in symbols with $\Delta v$ for change in velocity and $\Delta t$ for time taken. So we can write the equation for acceleration like this:

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

KEY EQUATION

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

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

Alternatively, because there are two velocities, we could use two symbols: $u$ = initial velocity and $v$ = final velocity. Now we can write the equation for acceleration like this:

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

The advantage of this equation is that if the final velocity is less than the initial velocity, the answer is negative. This tells you that the acceleration is negative (i.e. that the object is decelerating).

In the example of the express train, we have initial velocity $u = 0$ km/h, final velocity $v = 300$ km/h and time taken $t = 300$ s.

So, acceleration $a = \dfrac{300\,\text{km/h} - 0\,\text{km/h}}{300\,\text{s}} = 1$ km/h per second. Worked Example 2.7 uses the more standard velocity units of m/s.

## Units of acceleration

In Worked Example 2.7, the units of acceleration are given as $m/s^2$ (metres per second squared). These are the standard units of acceleration. The calculation shows that the aircraft's velocity increased by 2 m/s every second, or by 2 metres per second per second. It is simplest to write this as $2\,m/s^2$, but you may prefer to think of it as 2 m/s per second, as this emphasises the meaning of acceleration.

### WORKED EXAMPLE 2.7

An aircraft accelerates from 100 m/s to 300 m/s in 100 s. What is its acceleration?

**Step 1:** Start by writing down what you know, and what you want to know.

initial velocity $u = 100\,m/s$

final velocity $v = 300\,m/s$

time $t = 100\,s$

acceleration $a = ?$

**Step 2:** Now calculate the change in velocity.

change in velocity $= 300\,m/s - 100\,m/s$

$= 200\,m/s$

**Step 3:** Substitute into the equation.

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

$$= \frac{200\,m/s}{100\,s}$$

$$= 2.0\,m/s^2$$

Alternatively, you could substitute the values of $u$, $v$ and $t$ directly into the equation.

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

$$= \frac{300-100}{100}$$

$$= 2\,m/s^2$$

**Answer**

The aircraft's acceleration is $2.0\,m/s^2$

If you are working out the acceleration of an object that is slowing down, then this alternative method shown in Worked Example 2.7 will give a negative answer. If the aircraft was slowing down from 300 m/s to 100 m/s then its acceleration would be:

$$a = \frac{v-u}{t} = \frac{100\,m/s - 300\,m/s}{100\,s} = -2\,m/s^2$$

This is because acceleration is a vector quantity: it has a direction. It can be forwards (positive) or backwards (negative). So it is important always to think about velocity rather than speed when working out accelerations, because velocity is also a vector quantity.

## Questions

**17** Which of the following could not be a unit of acceleration?

$km/s^2$ mph/s km/s $m/s^2$

**18** A car sets off from traffic lights. It reaches a speed of 21 m/s in 10 s. What is its acceleration?

**19** A train, initially moving at 15 m/s, speeds up to 39 m/s in 120 s. What is its acceleration?

**20** The speed of a car increases from 12 m/s to 20 m/s in 4 seconds.

- **a** Sketch the speed–time graph.
- **b** Calculate the acceleration.
- **c** Use the graph to work out the distance covered in those 4 seconds.
- **d** Calculate the distance travelled.
- **e** If your answers to parts **c** and **d** are not the same, then work out where you have made a mistake.

## Acceleration from speed–time graphs

A speed–time graph with a steep slope shows that the speed is changing rapidly – the acceleration is greater. It follows that we can find the acceleration of an object by calculating the gradient of its speed–time graph:

acceleration = gradient of speed–time graph

Three points should be noted:

- The object must be travelling in a straight line; its velocity is changing but its direction is not.
- If the speed–time graph is curved (rather than a straight line), the acceleration is changing.
- If the graph is sloping downwards, the object is decelerating. The gradient of the graph is negative. So a deceleration is a negative acceleration.

## WORKED EXAMPLE 2.8

A train travels slowly as it climbs up a long hill. Then it speeds up as it travels down the other side. Table 2.9 shows how its speed changes. Draw a speed–time graph to show this data. Use the graph to calculate the train's acceleration during the second half of its journey.

| Time / s | Speed / m/s |
|---|---|
| 0 | 6.0 |
| 10 | 6.0 |
| 20 | 6.0 |
| 30 | 8.0 |
| 40 | 10.0 |
| 50 | 12.0 |
| 60 | 14.0 |

**Table 2.9:** Speed of a train.

Before starting to draw the graph, it is worth looking at the data in the table. The values of speed are given at equal intervals of time (every 10 s). The speed is constant at first (6.0 m/s). Then it increases in equal steps (8.0, 10.0, and so on). In fact, we can see that the speed increases by 2.0 m/s every 10 s. This is enough to tell us that the train's acceleration is 0.2 m/s$^2$. However, we will follow through the detailed calculation to illustrate how to work out acceleration from a graph.

**Step 1:** Draw the speed–time graph using the data in Table 2.9; this is shown in Figure 2.19.

The initial horizontal section shows that the train's speed was constant (zero acceleration).

The sloping section shows that the train was then accelerating.

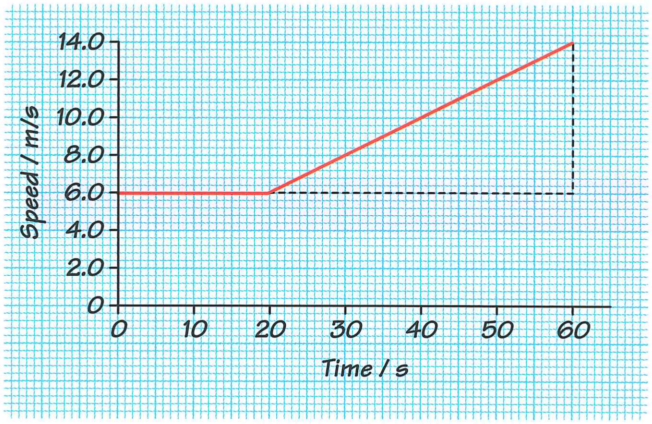



**Figure 2.19:** Speed–time graph for Worked Example 2.8.

**Step 2:** Draw in a triangle to calculate the slope of the graph, as shown on Figure 2.19. This gives us the acceleration.

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

$$= \frac{14.0\,\text{m/s} - 6.0\,\text{m/s}}{60\,\text{s} - 20\,\text{s}}$$

$$= \frac{8.0\,\text{m/s}}{40\,\text{s}}$$

$$= 0.20\,\text{m/s}^2$$

**Answer**

The train's acceleration down the hill is 0.20 m/s$^2$.

Although Worked Example 2.8 uses the equation for acceleration, you are finding the gradient of the slope in Figure 2.19.

Figure 2.20 shows the speed–time graph for a skydiver from the moment she leaves an aircraft. She jumps from 5000 m and opens her parachute when she reaches 1500 m, 60 s after she jumps. You have already learned that you can find the acceleration from the gradient of a speed–time graph. However, there are places where the gradient of the graph is changing (when the graph is not a straight line). To find the acceleration at any moment in time, a tangent to the graph is drawn. This works for any graph: straight or curved.

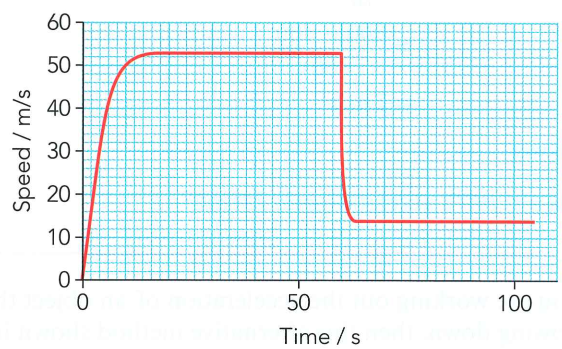



**Figure 2.20:** The speed–time graph for a skydiver, showing the first 105 s of the jump.

## WORKED EXAMPLE 2.9

Look at Figure 2.20. What is the skydiver's acceleration at:

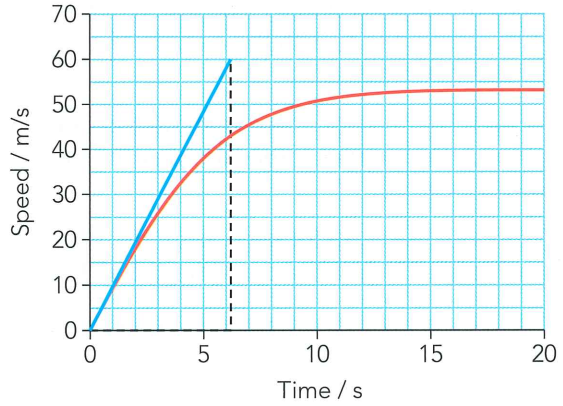
**a** 0 s

**b** 5.5 s?

**Part a**

**Step 1:** Draw a tangent to the graph at $t = 0$ s (shown below by the blue line).

**Step 2:** Draw in a triangle (shown below by the dashed lines).

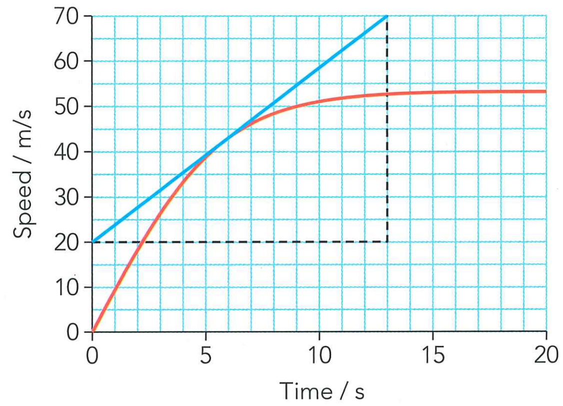



**Step 3:** Calculate the slope of the graph. This gives us the acceleration.

**Part b**

**Step 1:** Draw a tangent to the graph at $t = 5.5$ s (shown below by the blue line).

**Step 2:** Draw in a triangle to calculate the slope of the graph (shown below by the dashed lines).




**Step 3:** Calculate the slope of the graph. This gives us the acceleration.

**Answer**

The parachutist has the acceleration of free-fall ($9.8\ \mathrm{m/s^2}$) the moment she jumps out of the aircraft (at $t = 0$ s) and her acceleration decreases with time until she reaches a constant speed. After 5.5 s her acceleration is $3.8\ \mathrm{m/s^2}$.

Perhaps you can already explain why her acceleration changes as she falls but it will be explained in Chapter 3. Can you see when she opens her parachute in Figure 2.20? Recalling how to work out distance on a speed–time graph, can you work out how far she has fallen when she opens her parachute? Can you work out that she lands 160 s after she starts her jump?

## Question

**21** A car driver has to do an emergency stop. This is when the driver needs to stop the car in the shortest possible stopping distance. There is a delay between seeing a hazard and applying the brakes. This is due to the reaction time of the driver, sometimes called the thinking time. The distance the car moves in this time (when the car has not changed speed) is the thinking distance. The distance the car moves once the brakes are applied and until the car comes to a stop is the braking distance. The stopping distance = thinking distance + braking distance.

A car is travelling at 20 m/s when the driver sees a hazard. She has a reaction time of 0.7 s and brings her car to a stop 4.0 s after seeing the danger.

**a** Draw a speed–time graph to represent the car's motion during the 4.0 s described. Assume that the deceleration (negative acceleration) is constant.

**b** Use the graph to deduce (work out) the car's deceleration as it slows down.

**c** Use the graph to deduce how far the car travels during the 4.0 s described.

## ACTIVITY 2.3

### Using ticker tape to find the acceleration of a trolley down a ramp

You are going to investigate the motion of a trolley down a ramp. Some ticker tape is attached to the trolley – and a ticker timer marks the paper 50 times a second (Figure 2.21). As the trolley accelerates, the distance between the dots increases.

1. The ticker timer marks the paper 50 times a second. What interval of time does each gap represent?

   To find the speed at a particular dot, you need to measure the distance covered over a short interval of time centred on the dot. Measure the distance between the *preceding* (previous) dot and *succeeding* dot (the one that follows). For example, to find the speed at dot 15, we need to find the distance covered between dot 14 and dot 16 (13 mm) and then divide by the time taken to cover this distance (2 × 0.02 s = 0.04 s), using the equation:

   $$\text{speed} = \frac{\text{distance}}{\text{time}} = \frac{13\,\text{mm}}{0.04\,\text{s}} = 0.325\,\text{m/s}$$

2. Copy and complete Table 2.10, using the ticker tape to help you.
3. Plot a speed–time graph.
4. Use the gradient from the graph to calculate the acceleration.

### Alternative approach

Every fifth dot has been numbered. This corresponds to the distance travelled every 0.1 s.

1. Cut a copy of the the ticker tape into lengths corresponding to every fifth dot (0.1 s time interval).
2. Stick the lengths side by side (like a histogram) onto graph paper, with the bottom of each strip on the horizontal axis.
3. Draw a line through the dot at the top of each strip (or the middle of the top of each strip, if the dot is missing).
4. Work out the scale for each axis. The width of each strip is equal to a time interval of 0.1 s.
5. Work out the gradient of the speed–time graph you have constructed.

| Dot number | Time since tape started / s | Distance covered / mm | Speed / m/s |
|---|---|---|---|
| 0 | 0.0 | | |
| 5 | 0.1 | | |
| 10 | 0.2 | | |
| 15 | | 13 | 0.325 |
| 20 | | | |
| 25 | | | |
| 30 | | | |

**Table 2.10**

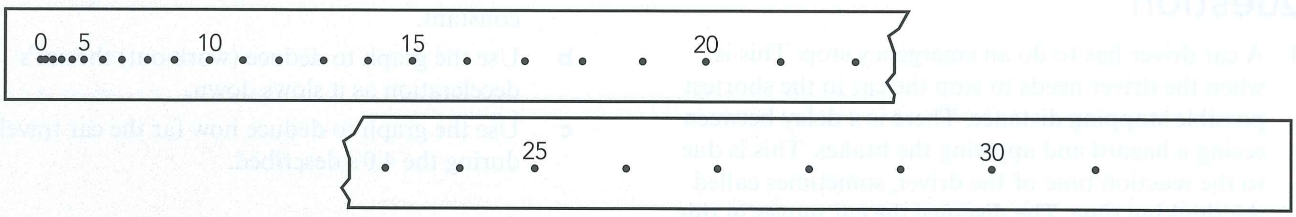



**Figure 2.21:** Ticker tape.

## PROJECT

Your teacher will decide whether you will work on your own, in pairs or as part of a small group. Your task is to plan a three-part revision lesson on the material in this chapter for the rest of your class, particularly the link between motion graphs and the equations of motion. Write down a plan to show what you would do and what resources you would use. If you have time, you can produce and teach the lesson to small groups of your classmates or the whole of your class. The following points will help you as you plan the revision lesson.

- You need to be able to answer questions on motion graphs and equations of motion so that you can then use them as a basis to write your own own questions.
- You need to produce model answers for your questions or come up with a better way of getting the ideas across.
- Insist that your classmates show their working.
- You need to label what parts of your questions are supplementary.

Here are some suggested questions which you can use in your plan for the lesson:

### Part 1: How to interpret motion graphs

Question for your classmates to answer: 'Copy and complete the table by stating what feature of the motion graph can be used to obtain the variable listed in the left-hand column. The first cell has been done for you.'

| | Distance–time graph | Speed–time graph |
|---|---|---|
| distance | read off the vertical axis | |
| speed | | |
| acceleration | | |

You might want to suggest that your classmates colour code the table in some way.

Can you think of a better way of getting information from motion graphs?

### Part 2: Linking motion graphs to equations of motion

Question for your classmates to answer: 'A body moving at 2 m/s accelerates for 2 seconds until it reaches a speed of 4 m/s. Show that the body travels a distance of 6 m and accelerates at 1 m/s$^2$.'

You need your classmates to get the same answer for the question you produce using two different methods.

**Method 1: Use the relevant equations (for acceleration and distance)**

Some of your classmates will get the distance wrong because they do not use the average speed in the equation for distance.

**Method 2: Sketch the motion graph**

Your classmates should use the gradient of the graph to find the acceleration and the area under the curve to find the distance. However, some of your classmates will sketch the motion from the origin (instead of from 2 m/s) and will work out the area of a triangle (instead of a triangle plus a square) so will get a distance travelled of 2 metres. Others will measure the horizontal and vertical distances with a ruler to work out the gradient instead of using the scale on the axes to work out the changes in the speed and time to work out the gradient.

You need to come up with similar questions (different numbers) and their model answers. Perhaps try your question on a few of your friends to check that it is clear and to pick up common mistakes. You could provide your question and a wrong solution and ask other members of your class to spot and correct the mistakes.

### Part 3: Putting learning into practice

Questions for your classmates to answer: Bloodhound LSR is being developed to achieve a new land speed record of 1000 mph. The vehicle will be timed over a 'measured mile' half-way down a 12 mile long salt pan in South Africa.

- If Bloodhound achieves 1000 mph, how long would it take to complete the 'measured mile'?

## CONTINUED


**Figure 2.22:** Bloodhound LSR during a practice run on the Hekskeenpan in South Africa.

- Sketch a speed–time graph for its journey. Label it with significant speeds and times. Assume that Bloodhound accelerates uniformly until it reaches the 'measured mile' and then decelerates uniformly so that it comes to rest 12 miles from the start (and before the end of the salt pan).
- What is the total time for the 12 mile journey?
- What is the acceleration or deceleration of the vehicle and how does this compare to the acceleration of freefall (9.81 m/s$^2$)?'

First, you need to answer the question yourself.

When you set your question, decide whether to convert the data in the question to SI units or get your classmates to do it themselves (1 mph = 0.447 m/s; 1 mile = 1610 m).

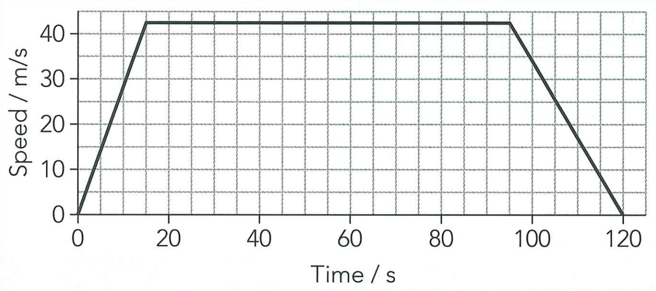
You could introduce the question with a short video clip about the vehicle. Adapt the questions above and produce a model answer so that your peers can check and correct their solutions. For example, you could flip the question by telling your peers the maximum acceleration and deceleration of the vehicle and get them to work out the minimum distance the 'track' needs to be, or you could change the data while keeping it realistic.

## SUMMARY

| |
|---|
| Speed is distance divided by time. |
| Average speed is total distance divided by total time. |
| Light gates and interrupt cards can be used to measure speed in the laboratory. |
| The equation that relates speed, distance and time can be re-arranged to find any one of the variables, given the values of the other two. |
| The gradient (slope) of a distance–time graph represents speed. |
| Acceleration is a change in speed. |
| The greater the gradient (slope) of a speed–time graph, the bigger the acceleration. |
| Distance travelled can be calculated (worked out) from the area under a speed–time graph. |
| Speed can be calculated from the gradient of a distance–time graph and acceleration can be calculated from the gradient of a speed–time graph. |
| Speed is a scalar and velocity is a vector. |
| Acceleration can be calculated from the change of speed divided by time and a negative acceleration is the same as a deceleration. |

## EXAM-STYLE QUESTIONS

Use this graph for questions 1 and 2.




**1** How is a constant velocity shown on the graph? **[1]**

**A** the sloping line at the start
**B** the horizontal part of the line
**C** the area under the line
**D** the sloping line at the end

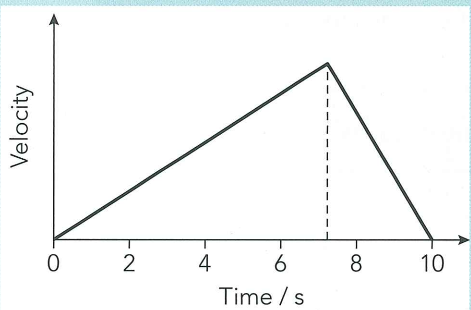
**2** How is the distance travelled shown on the graph? **[1]**

**A** the sloping line at the start
**B** the horizontal part of the line
**C** the area under the line
**D** the sloping line at the end

**3** A snail takes part in a snail race. The snail completes the 180 cm course in 7.0 minutes. What is the approximate average speed of the snail? **[1]**

**A** 0.43 m/s **B** 26 m/s **C** 0.26 m/s **D** 0.0043 m/s

**4** The velocity–time graph shows the performance of a Formula 1® racing car as it accelerates from rest for 7.33 seconds and then brakes, coming to a stop in 2.69 seconds. It covers a distance of 520 metres.




What is the approximate maximum velocity of the car? **[1]**

**A** 50 m/s **B** 75 m/s **C** 105 m/s **D** 175 m/s

CONTINUED

5 The table shows Usain Bolt's split times from his world record 100 m run in Berlin in 2009. Each split time is for a 10 m section of the 100 m distance. The time for the first 10 m includes his reaction time of 0.146 s before he left his blocks.

| Section / m | 0–10 | 10–20 | 20–30 | 30–40 | 40–50 | 50–60 | 60–70 | 70–80 | 80–90 | 90–100 |
|---|---|---|---|---|---|---|---|---|---|---|
| Time / s | 1.89 | 0.99 | 0.90 | 0.86 | 0.83 | 0.82 | 0.81 | 0.82 | 0.83 | 0.83 |

a **Calculate** the time that Usain Bolt takes to run the first 10 metres from the moment he starts moving. [1]

b Calculate Usain Bolt's average speed over the first 10 metres from the moment he starts moving. [2]

c Calculate Usain Bolt's maximum speed over the first 10 metres. Ignore his reaction time and assume his acceleration is constant. [2]

d Calculate Usain Bolt's acceleration over the first 10 metres. Ignore his reaction time and assume his acceleration is constant. [2]

e Calculate Usain Bolt's top speed in the race. Show your working. [2]

[Total: 8]

6 An aircraft happened to be flying near a volcano when it erupted. The co-pilot took some video footage. He handed the footage over to scientists for analysis. The scientists spotted a huge boulder that was moving at a constant speed horizontally (sideways) in the first frame and falling in subsequent frames of the video. They wanted to work out how far the ash and rock would spread.

a Plot a graph of the position of the boulder at intervals of 5 seconds. Plot the vertical height of the boulder (vertical axis) against the horizontal distance travelled (horizontal axis). [3]

| Time / s | Horizontal distance travelled / m | Vertical height / m |
|---|---|---|
| 0 | 0 | 4420 |
| 5 | 525 | 4292 |
| 10 | 1050 | 3924 |
| 15 | 1580 | 3311 |
| 20 | 2100 | 2453 |
| 25 | 2630 | 1349 |
| 30 | 3150 | 0 |

b **Explain** the shape of the graph. [1]

COMMAND WORDS

**calculate:** work out from given facts, figures or information

**explain:** set out purposes or reasons; make the relationships between things evident; provide why and/or how and support with relevant evidence

## CONTINUED

**c** The scientists thought the aircraft had been at an altitude (height) of 4420 metres when the video was taken but it was at 3600 metres. Use your graph to estimate the (horizontal) distance the boulder will have travelled from the point that it was recorded on video to where it hit the ground. **[2]**

**d** Use your graph to estimate how long it took the boulder to hit the ground from where it was filmed. **[1]**

**e** Calculate the horizontal speed of the boulder. **[2]**

**f** Suggest why there is ash and rocks over a wide area and not just a circle of debris that your answer to **c** might suggest. **[1]**

**[Total: 10]**

## COMMAND WORD

**suggest:** apply knowledge and understanding to situations where there are a range of valid responses in order to make proposals/ put forward considerations

## SELF-EVALUATION CHECKLIST

After studying this chapter, think about how confident you are with the different topics. This will help you to see any gaps in your knowledge and help you to learn more effectively.

| I can | See Topic... | Needs more work | Almost there | Confident to move on |
|---|---|---|---|---|
| Work out speed from distance travelled and time taken. | 2.1 | | | |
| Work out average speed from total distance travelled and total time taken. | 2.1 | | | |
| Describe experiments to measure speed in the laboratory. | 2.1 | | | |
| Work out distance travelled from a speed–time graph. | 2.3 | | | |
| Find speed on a speed-time graph. | 2.3 | | | |
| Calculate acceleration from the change in velocity and time taken. | 2.4 | | | |
| Work out acceleration from a speed–time graph. | 2.4 | | | |
| Explain the difference between speed and velocity. | 2.4 | | | |