# 1.2 Motion

**FOCUS POINTS**

- ★ Define speed and velocity and use the appropriate equations to calculate these and average speed.
- ★ Draw, plot and interpret distance–time or speed–time graphs for objects at different speeds and use the graphs to calculate speed or distance travelled.
- ★ Define acceleration and use the shape of a speed–time graph to determine constant or changing acceleration and calculate the acceleration from the gradient of the graph.
- ★ Know the approximate value of the acceleration of freefall, $g$, for an object close to the Earth's surface.
- ★ Describe the motion of objects falling with and without air/liquid resistance.

The concepts of speed and acceleration are encountered every day, whether it be television monitoring of the speed of a cricket or tennis ball as it soars towards the opposition or the acceleration achieved by an athlete or racing car. In this topic you will learn how to define speed in terms of distance and time. Graphs of distance against time will enable you to calculate speed and determine how it changes with time; graphs of speed against time allow acceleration to be studied. Acceleration is also experienced by falling objects as a result of gravitational attraction. All objects near the Earth's surface experience the force of gravity, which produces a constant acceleration directed towards the centre of the Earth.

## Speed

The **speed** of a body is the distance that it has travelled in unit time. When the distance travelled is $s$ over a short time period $t$, the speed $v$ is given by

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

**Key definition**
**Speed** distance travelled per unit time

If a car travels 300 km in five hours, its **average speed** is 300 km/5 h = 60 km/h. The speedometer would certainly not read 60 km/h for the whole journey and might vary considerably from this value. That is why we state the average speed. If a car could travel at a constant speed of 60 km/h for 5 hours, the distance covered would still be 300 km. It is *always* true that

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

To find the actual speed at any instant we would need to know the distance moved in a very short interval of time. This can be done by multiflash photography. In Figure 1.2.1 the golfer is photographed while a flashing lamp illuminates him 100 times a second. The speed of the club-head as it hits the ball is about 200 km/h.

▲ **Figure 1.2.1** Multiflash photograph of a golf swing

## Velocity

Speed is the distance travelled in unit time; **velocity** is the distance travelled in unit time in a given direction. If two trains travel due north at 20 m/s, they have the same speed of 20 m/s and the same velocity of 20 m/s *due north*. If one travels north and the other south, their speeds are the same but not their velocities since their directions of motion are different.

$$\text{velocity} = \frac{\text{distance moved in a given direction}}{\text{time taken}}$$
$$= \text{speed in a given direction}$$

**Key definition**
**Velocity** change in displacement per unit time

The velocity of a body is **uniform** or constant if it moves with a steady speed in a straight line. It is not uniform if it moves in a curved path. Why?

The units of speed and velocity are the same, km/h, m/s.

$$60\,\text{km/h} = \frac{60\,000\,\text{m}}{3600\,\text{s}} = 17\,\text{m/s}$$

Distance moved in a stated direction is called the **displacement**. Velocity may also be defined as

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

Speed is a *scalar* quantity and velocity a *vector* quantity. Displacement is a vector, unlike distance which is a scalar.

## Acceleration

When the velocity of an object changes, we say the object *accelerates*. If a car starts from rest and moving due north has velocity 2 m/s after 1 second, its velocity has increased by 2 m/s in 1 s and its acceleration is 2 m/s per second due north. We write this as 2 m/s$^2$.

**Acceleration** is defined as the change of velocity in unit time, or

$$\text{acceleration} = \frac{\text{change of velocity}}{\text{time taken for change}} = \frac{\Delta v}{\Delta t}$$

**Key definition**
**Acceleration** change in velocity per unit time

For a steady increase of velocity from 20 m/s to 50 m/s in 5 s

$$\text{acceleration} = \frac{(50 - 20)\,\text{m/s}}{5\,\text{s}} = 6\,\text{m/s}^2$$

Acceleration is also a vector and both its magnitude and direction should be stated. However, at present we will consider only motion in a straight line and so the magnitude of the velocity will equal the speed, and the magnitude of the acceleration will equal the change of speed in unit time.

The speeds of a car accelerating on a straight road are shown below.

| Time/s | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Speed/m/s | 0 | 5 | 10 | 15 | 20 | 25 | 30 |

The speed increases by 5 m/s every second and the acceleration of 5 m/s$^2$ is constant.

An acceleration is positive if the velocity increases, and negative if it decreases. A negative acceleration is also called a **deceleration** or **retardation**.

### Test yourself

1 What is the average speed of
  a a car that travels 400 m in 20 s
  b an athlete who runs 1500 m in 4 minutes?
2 A train increases its speed steadily from 10 m/s to 20 m/s in 1 minute.
  a What is its average speed during this time, in m/s?
  b How far does it travel while increasing its speed?
3 a A motorcyclist starts from rest and reaches a speed of 6 m/s after travelling with constant acceleration for 3 s. What is his acceleration?
  b The motorcyclist then decelerates at a constant rate for 2 s. What is his acceleration?
4 An aircraft travelling at 600 km/h accelerates steadily at 10 km/h per second. Taking the speed of sound as 1100 km/h at the aircraft's altitude, how long will it take to reach the 'sound barrier'?

# Speed–time graphs

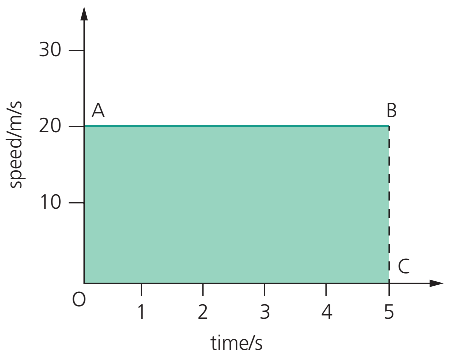
If the speed of an object is plotted against the time, the graph obtained is a **speed–time graph**. It provides a way of solving motion problems.

In Figure 1.2.2, AB is the speed–time graph for an object moving with a **constant speed** of 20 m/s.

Values for the speed of the object at 1 s intervals can be read from the graph and are given in Table 1.2.1. The data shows that the speed is constant over the 5 s time interval.

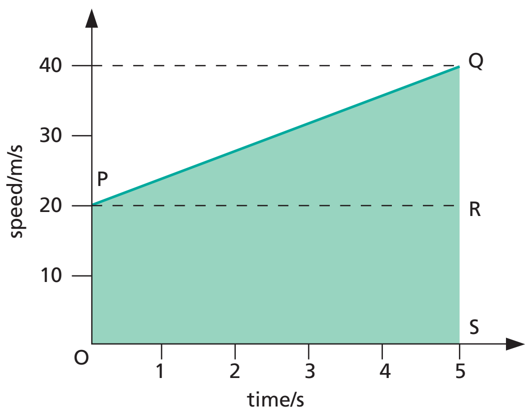
▼ **Table 1.2.1**

| **Speed/m/s** | 20 | 20 | 20 | 20 | 20 | 20 |
|---|---|---|---|---|---|---|
| **Time/s** | 0 | 1 | 2 | 3 | 4 | 5 |




▲ **Figure 1.2.2** Constant speed

The linear shape (PQ) of the speed–time graph shown in Figure 1.2.3a means that the gradient, and hence the acceleration of the body, are constant over the time period OS.




▲ **Figure 1.2.3a** Constant acceleration

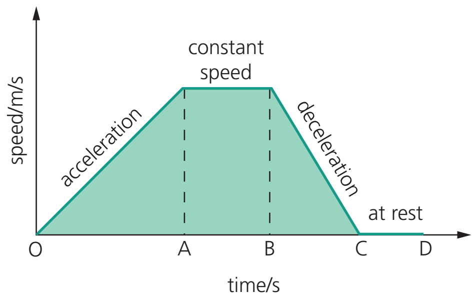
Values for the speed of the object at 1 s intervals can be read from the graph and are given in Table 1.2.2. The data shows that the speed increases by the same amount (4 m/s) every second.

▼ **Table 1.2.2**

| **Speed/m/s** | 20 | 24 | 28 | 32 | 36 | 40 |
|---|---|---|---|---|---|---|
| **Time/s** | 0 | 1 | 2 | 3 | 4 | 5 |

You can use the data to plot the speed–time graph. Join up the data points on the graph paper with the best straight line to give the line PQ shown in Figure 1.2.3a. (Details for how to plot a graph are given on pp. 297–8 in the *Mathematics for physics* section.)

Figure 1.2.3b shows the shape of a speed–time graph for an object accelerating from rest over time interval OA, travelling at a constant speed over time interval AB and then decelerating (when the speed is decreasing) over the time interval BC. The steeper gradient in time interval BC than in time interval OA shows that the deceleration is greater than the acceleration. The object remains at rest over the time interval CD when its speed and acceleration are zero.




▲ **Figure 1.2.3b** Acceleration, constant speed and deceleration

Figure 1.2.3c shows a speed–time graph for a changing acceleration. The curved shape OX means that the gradient of the graph, and hence the acceleration of the object, change over time period OY – the acceleration is changing.

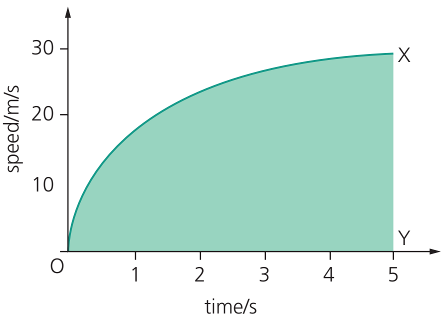
Values for the speed of the object at 1 s intervals are given in Table 1.2.3. The data shows that the speed is increasing over time interval OY, but by a smaller amount each second so the acceleration is decreasing.

▼ **Table 1.2.3**

| **Speed/m/s** | 0 | 17.5 | 23.0 | 26.0 | 28.5 | 30.0 |
|---|---|---|---|---|---|---|
| **Time/s** | 0 | 1 | 2 | 3 | 4 | 5 |

You can use the data to plot the speed–time graph. Join up the data points on the graph paper with a smooth curve as shown in Figure 1.2.3c.

Note that an object *at rest* will have zero speed and zero acceleration; its speed–time graph is a straight line along the horizontal axis.




▲ **Figure 1.2.3c** Changing acceleration

## Using the gradient of a speed–time graph to calculate acceleration

The gradient of a speed–time graph represents the acceleration of the object.

In Figure 1.2.2, the gradient of AB is zero, as is the acceleration. In Figure 1.2.3a, the gradient of PQ is QR/PR = 20/5 = 4: the acceleration is constant at $4\,m/s^2$. In Figure 1.2.3c, when the gradient along OX changes, so does the acceleration.

An object is accelerating if the speed increases with time and decelerating if the speed decreases with time, as shown in Figure 1.2.3b. In Figure 1.2.3c, the speed is increasing with time and the acceleration of the object is decreasing.

# Distance–time graphs

An object travelling with constant speed covers equal distances in equal times. Its **distance–time graph** is a straight line, like OL in Figure 1.2.4a for a constant speed of 10 m/s. The gradient of the graph is LM/OM = 40 m/4 s = 10 m/s, which is the value of the speed. The following statement is true in general:

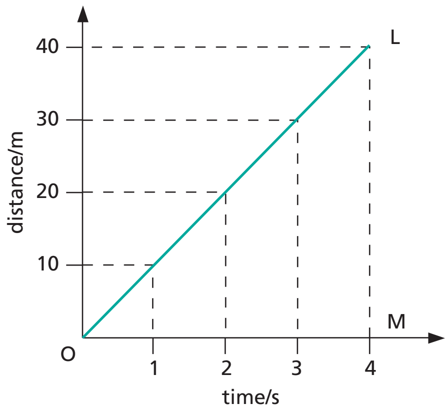
The gradient of a distance–time graph represents the speed of the object.

Values for the distance moved by the object recorded at 1 s intervals are given in Table 1.2.4. The data shows it moves 10 m in every second so the speed of the object is constant at 10 m/s.

▼ **Table 1.2.4**

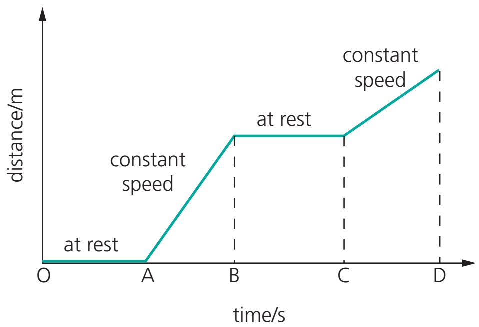
| **Distance/m** | 10 | 20 | 30 | 40 |
|---|---|---|---|---|
| **Time/s** | 1 | 2 | 3 | 4 |

You can use the data to plot the distance–time graph shown in Figure 1.2.4a.




▲ **Figure 1.2.4a** Constant speed

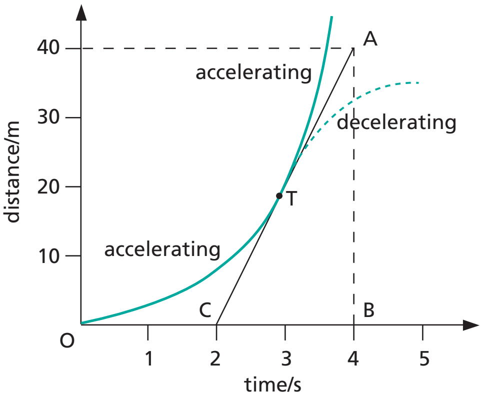
Figure 1.2.4b shows the shape of a distance–time graph for an object that is at rest over time interval OA and then moves at a constant speed in time interval AB. It then stops moving and is at rest over time interval BC before moving at a constant speed in time interval CD.




▲ **Figure 1.2.4b** Constant speed

The speed of the object is higher when the gradient of the graph is steeper. The object is travelling faster in time interval AB than it is in time interval CD; it is at rest in time intervals OA and BC when the distance does not change.

When the speed of the object is changing, the gradient of the distance–time graph varies, as in Figure 1.2.5, where the upward curve of increasing gradient of the solid green line shows the object accelerating. The opposite, upward curve of decreasing gradient (indicated by the dashed green line) shows an object decelerating above T.




▲ **Figure 1.2.5** Non-constant speed

Speed at any point equals the gradient of the **tangent**. For example, the gradient of the tangent at T is AB/BC = 40 m/2 s = 20 m/s. The speed at the instant corresponding to T is therefore 20 m/s.

# Area under a speed–time graph

The area under a speed–time graph measures the distance travelled.

In Figure 1.2.2, AB is the speed–time graph for an object moving with a constant speed of 20 m/s. Since distance = average speed × time, after 5 s it will have moved 20 m/s × 5 s = 100 m. This is the shaded area under the graph, i.e. rectangle OABC.

In Figure 1.2.3a, PQ is the speed–time graph for an object moving with *constant acceleration*. At the start of the timing the speed is 20 m/s, but it increases steadily to 40 m/s after 5 s. If the distance covered equals the area under PQ, i.e. the shaded area OPQS, then

$$\begin{aligned}
\text{distance} &= \text{area of rectangle OPRS} + \text{area of triangle PQR}\\
&= \text{OP} \times \text{OS} + \tfrac{1}{2} \times \text{PR} \times \text{QR}\\
&\quad (\textbf{area of a triangle} = \tfrac{1}{2}\ \text{base} \times \text{height})\\
&= 20\,\text{m/s} \times 5\,\text{s} + \tfrac{1}{2} \times 5\,\text{s} \times 20\,\text{m/s}\\
&= 100\,\text{m} + 50\,\text{m} = 150\,\text{m}
\end{aligned}$$

Note that when calculating the area from the graph, the unit of time must be the same on both axes.

The rule for finding distances travelled is true even if the acceleration is not constant. In Figure 1.2.3c, the distance travelled equals the shaded area OXY.

## Test yourself

**5** The speeds of a bus travelling on a straight road are given below at successive intervals of 1 second.

| **Time/s** | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| **Speed/m/s** | 0 | 4 | 8 | 12 | 16 |

**a** Sketch a speed–time graph using the values.
**b** Choose two of the following terms which describe the acceleration of the bus:
constant changing positive negative
**c** Calculate the acceleration of the bus.
**d** Calculate the area under your graph.
**e** How far does the bus travel in 4 s?

**6** The distance of a walker from the start of her walk is given below at successive intervals of 1 second.
**a** Sketch a distance–time graph of the following values.

| **Time/s** | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| **Distance/m** | 0 | 3 | 6 | 9 | 12 | 15 | 18 |

**b** How would you describe the speed at which she walks?
constant changing increasing accelerating
**c** Calculate her average speed.

# Equations for constant acceleration

Problems involving bodies moving with constant acceleration in a straight line can often be solved quickly using some *equations of motion*.

## First equation

If an object is moving with constant acceleration $a$ in a straight line and its speed increases from $u$ to $v$ in time $t$, then

$$a = \frac{\text{change of speed}}{\text{time taken}} = \frac{v-u}{t}$$

$$\therefore \quad at = v - u$$

or

$$v = u + at \quad (1)$$

Note that the initial speed $u$ and the final speed $v$ refer to the start and the finish of the *timing* and do not necessarily mean the start and finish of the motion.

## Second equation

The speed of an object moving with constant acceleration in a straight line increases steadily. Its average speed therefore equals half the sum of its initial and final speeds, that is,

$$\text{average speed} = \frac{u+v}{2}$$

If $s$ is the distance moved in time $t$, then since average speed = total distance/total time = $s/t$,

$$\frac{s}{t} = \frac{u+v}{2}$$

or

$$s = \frac{(u+v)}{2}t \quad (2)$$

## Going further

### Third equation

From equation (1), $v = u + at$

From equation (2),

$$\frac{s}{t} = \frac{u+v}{2}$$

$$\frac{s}{t} = \frac{u+u+at}{2} = \frac{2u+at}{2}$$

$$= u + \frac{1}{2}at$$

and so

$$s = ut + \frac{1}{2}at^2 \quad (3)$$

### Fourth equation

This is obtained by eliminating $t$ from equations (1) and (3). Squaring equation (1) we have

$$v^2 = (u+at)^2$$

$$\therefore \quad v^2 = u^2 + 2uat + a^2t^2$$

$$= u^2 + 2a(ut + \frac{1}{2}at^2)$$

But $\quad s = ut + \frac{1}{2}at^2$

$$\therefore \quad v^2 = u^2 + 2as$$

If we know any *three* of $u$, $v$, $a$, $s$ and $t$, the others can be found from the equations.

## Worked example

A sprint cyclist starts from rest and accelerates at 1 m/s$^2$ for 20 seconds. Find her final speed and the distance she travelled.

Since $u = 0 \quad a = 1\,\text{m/s}^2 \quad t = 20\,\text{s}$

Using $v = u + at$, we have her maximum speed

$$v = 0 + 1\,\text{m/s}^2 \times 20\,\text{s} = 20\,\text{m/s}$$

and distance travelled

$$s = \frac{(u+v)}{2}t$$

$$= \frac{(0+20)\,\text{m/s} \times 20\text{s}}{2} = \frac{400}{2} = 200\,\text{m}$$

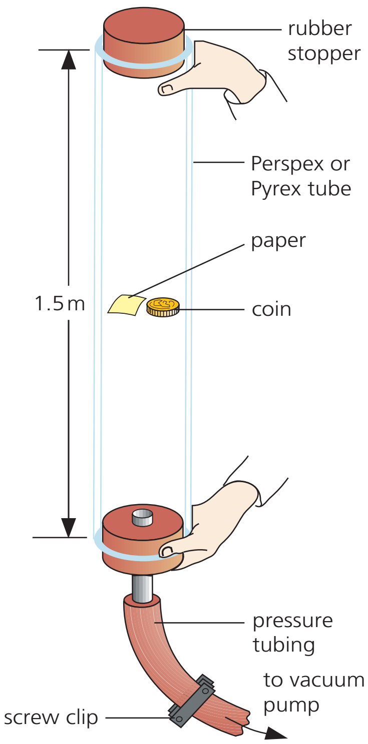
### Now put this into practice

1. An athlete accelerates from rest at a constant rate of 0.8 m/s$^2$ for 4 s. Calculate the final speed of the athlete.
2. A cyclist increases his speed from 10 m/s to 20 m/s in 5 s. Calculate his average speed over this time interval.
3. Calculate the distance moved by a car accelerating from rest at a constant rate of 2 m/s$^2$ for 5 s.

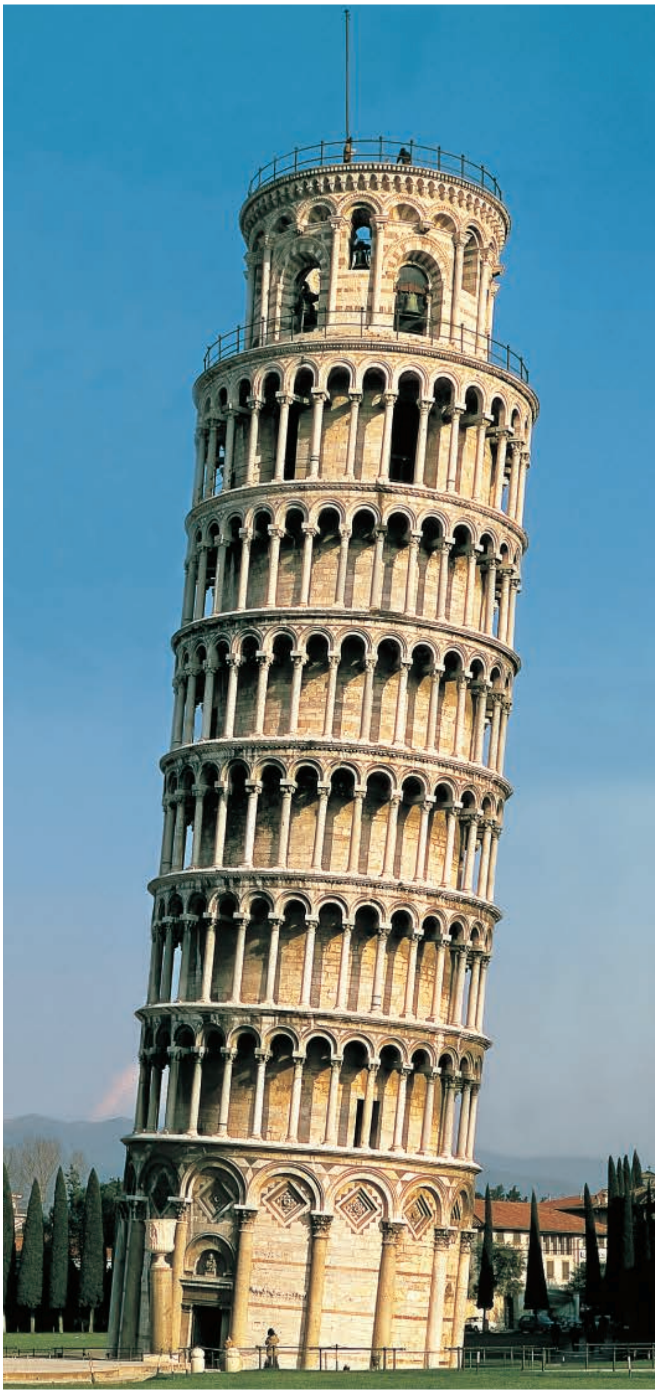
# Falling bodies

In air, a coin falls faster than a small piece of paper. In a vacuum they fall at the same rate, as may be shown with the apparatus of Figure 1.2.6. The difference in air is due to **air resistance** having a greater effect on light bodies than on heavy bodies. The air resistance to a light body is large when compared with the body's weight. With a dense piece of metal, the resistance is negligible at low speeds.

There is a story, untrue we now think, that in the sixteenth century the Italian scientist Galileo Galilei dropped a small iron ball and a large cannonball ten times heavier from the top of the Leaning Tower of Pisa (Figure 1.2.7). And we are told that, to the surprise of onlookers who expected the cannonball to arrive first, they reached the ground almost simultaneously.




▲ **Figure 1.2.6** A coin and a piece of paper fall at the same rate in a vacuum.



▲ **Figure 1.2.7** The Leaning Tower of Pisa, where Galileo is said to have experimented with falling objects

## Practical work

### Motion of a falling object

#### Safety

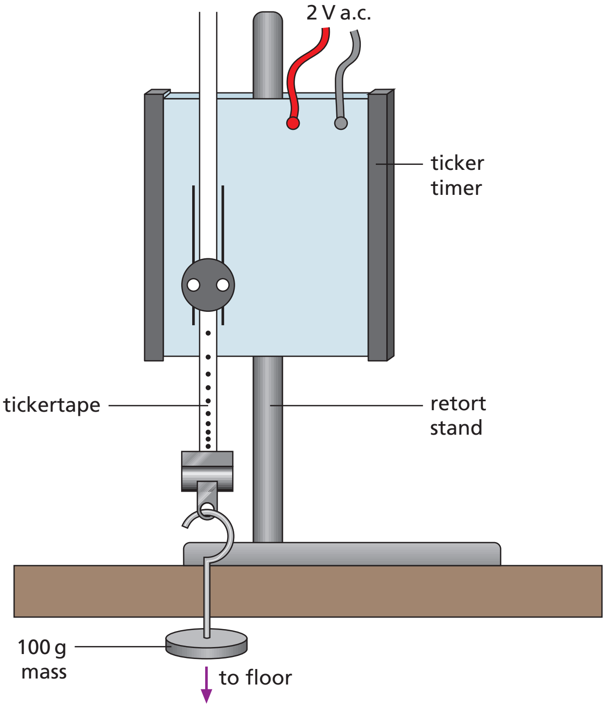
- Place something soft on the floor to absorb the impact of the masses.
- Take care to keep feet well away from the falling masses.

Arrange your experimental apparatus as shown in Figure 1.2.8 and investigate the motion of a 100 g mass falling from a height of about 2 m.

A tickertape timer has a marker that vibrates at 50 times a second and makes dots at 1/50 s intervals on a paper tape being pulled through it. Ignore the start of the tape where the dots are too close.

Repeat the experiment with a 200 g mass and compare your results with those for the 100 g mass.

1 The spacing between the dots on the tickertape increases as the mass falls. What does this tell you about the speed of the falling mass?
2 The tape has 34 dots on it by the time the mass falls through 2 m. Estimate how long it has taken the mass to fall through 2 m.
3 Why would a stopwatch not be chosen to measure the time of fall in this experiment?
4 How would you expect the times taken for the 100 g and 200 g masses to reach the ground to differ?




▲ **Figure 1.2.8**

# Acceleration of free fall

All bodies falling freely under the force of gravity do so with **uniform acceleration** if air resistance is negligible (i.e. the ‘steps’ on the tape chart from the practical work should all be equally spaced).

This acceleration, called the **acceleration of free fall**, is denoted by the italic letter $g$. Its value varies slightly over the Earth but is constant in each place; on average it is about 9.8 m/s$^2$, or near enough 10 m/s$^2$. The velocity of a free-falling body therefore increases by about 10 m/s every second. A ball shot straight upwards with a velocity of 30 m/s decelerates by about 10 m/s every second and reaches its highest point after 3 s.

**Key definition**

**Acceleration of free fall** $g$ for an object near to the surface of the Earth, this is approximately constant and is approximately 9.8 m/s$^2$

In calculations using the equations of motion, $g$ replaces $a$. It is given a positive sign for falling bodies (i.e. $a = g = +9.8$ m/s$^2$) and a negative sign for rising bodies since they are decelerating (i.e. $a = -g = -9.8$ m/s$^2$).

## Going further

### Measuring $g$

Using the arrangement in Figure 1.2.9, the time for a steel ball-bearing to fall a known distance is measured by an electronic timer.

When the two-way switch is changed to the 'down' position, the electromagnet releases the ball and simultaneously the clock starts. At the end of its fall the ball opens the 'trap-door' on the impact switch and the clock stops.

The result is found from the third equation of motion $s = ut + \frac{1}{2}at^2$, where $s$ is the distance fallen (in m), $t$ is the time taken (in s), $u = 0$ (the ball starts from rest) and $a = g$ (in m/s$^2$).

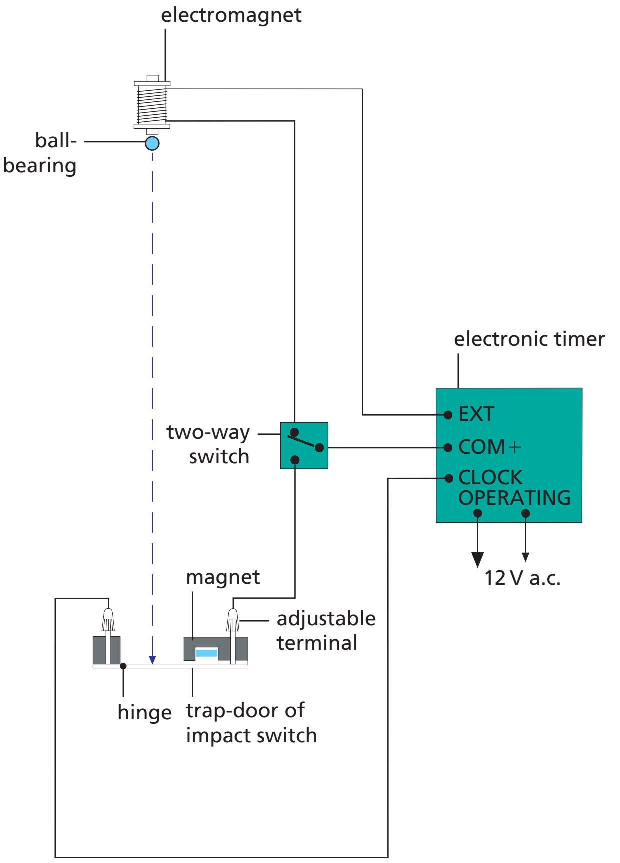
Hence

$$s = \frac{1}{2}gt^2$$

or

$$g = 2s/t^2$$

Air resistance is negligible for a dense object such as a steel ball-bearing falling a short distance.




▲ **Figure 1.2.9**

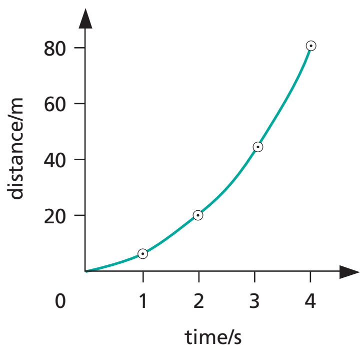
A rough estimate for $g$ can be made by timing the fall of a rubber ball from the top of a building. It will only take a second to reach the ground from a height of 5 m, so you will need fast reactions if you use a stopwatch for the measurement. Watch out that you do not hit anybody below!

### Distance–time graphs for a falling object

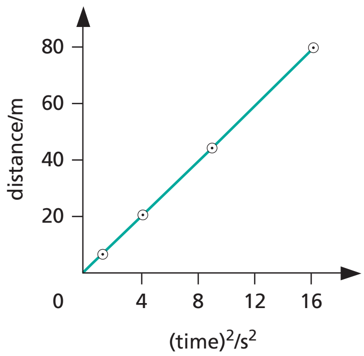
For an object falling freely from rest in a uniform gravitational field without air resistance, there will be constant acceleration $g$, so we have

$$s = \frac{1}{2}gt^2$$

A graph of distance $s$ against time $t$ is shown in Figure 1.2.10a. The gradually increasing slope indicates the speed of the object increases steadily. A graph of $s$ against $t^2$ is shown in Figure 1.2.10b; it is a straight line through the origin since $s \propto t^2$ ($g$ being constant at one place).




▲ **Figure 1.2.10a** A graph of distance against time for a body falling freely from rest




▲ **Figure 1.2.10b** A graph of distance against (time)$^2$ for a body falling freely from rest

## Test yourself

7 An object falls from a hovering helicopter and hits the ground at a speed of 30 m/s. How long does it take the object to reach the ground and how far does it fall? Sketch a speed–time graph for the object (ignore air resistance).

8 A stone falls from rest from the top of a high tower. Ignore air resistance and take $g = 9.8\,\text{m/s}^2$. Calculate
   - **a** the speed of the stone after 2 seconds
   - **b** how far the stone has fallen after 2 seconds.

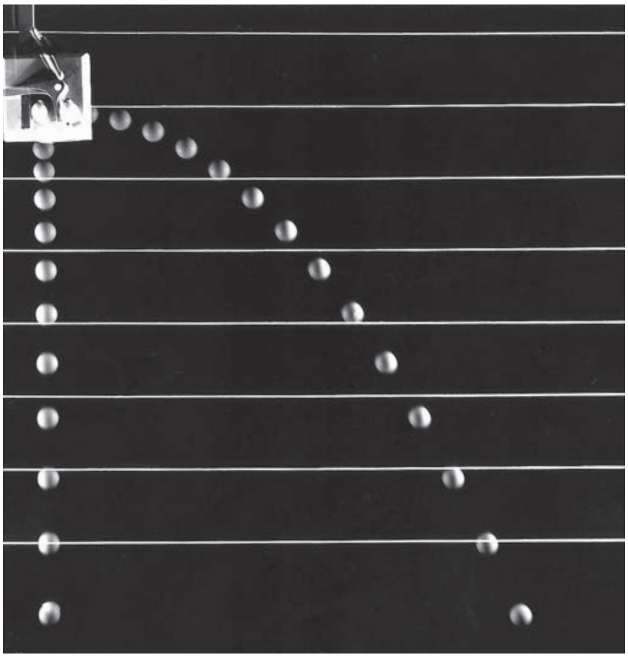
9 At a certain instant a ball has a horizontal velocity of 12 m/s and a vertical velocity of 5 m/s. Calculate the resultant velocity of the ball at that instant.

## Going further

### Projectiles

The photograph in Figure 1.2.11 was taken while a lamp emitted regular flashes of light. One ball was *dropped from rest* and the other, a projectile, was *thrown sideways* at the same time. Their vertical accelerations (due to gravity) are equal, showing that a projectile falls like a body which is dropped from rest. Its horizontal velocity does not affect its vertical motion.

The horizontal and vertical motions of a body are independent and can be treated separately.



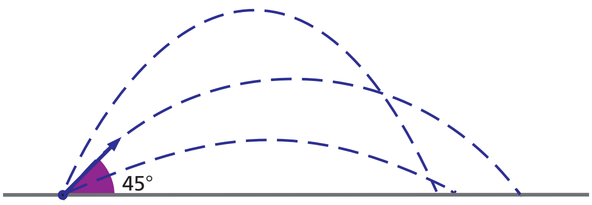
▲ **Figure 1.2.11** Comparing free fall and projectile motion using multiflash photography

For example, if a ball is thrown horizontally from the top of a cliff and takes 3 s to reach the beach below, we can calculate the height of the cliff by considering the vertical motion only. We have $u = 0$ (since the ball has no vertical velocity initially), $a = g = +9.8\,\text{m/s}^2$ and $t = 3\,\text{s}$. The height $s$ of the cliff is given by

$$s = ut + \frac{1}{2}at^2$$
$$= 0 \times 3\,\text{s} + \frac{1}{2}(+9.8\,\text{m/s}^2)3^2\,\text{s}^2$$
$$= 44\,\text{m}$$

Projectiles such as cricket balls and explosive shells are projected from near ground level and at an angle. The horizontal distance they travel, i.e. their range, depends on

- the speed of projection – the greater this is, the greater the range, and
- the angle of projection – it can be shown that, neglecting air resistance, the range is a maximum when the angle is 45° (Figure 1.2.12).




▲ **Figure 1.2.12** The range is greatest for an angle of projection of 45°.

## Air resistance: terminal velocity

When an object falls in a uniform gravitational field, the air resistance (**fluid** friction) opposing its motion *increases as its speed rises*, so reducing its acceleration. Eventually, air resistance acting upwards equals the weight of the object acting downwards. The resultant force on the object is then zero since the gravitational force balances the frictional force. The object falls at a constant velocity, called its **terminal velocity**, whose value depends on the size, shape and weight of the object.

A small dense object, such as a steel ball-bearing, has a high terminal velocity and falls a considerable distance with a constant acceleration of 9.8 m/s$^2$ before air resistance equals its weight. A light object, like a raindrop, or an object with a large surface area, such as a parachute, has a low terminal velocity and only accelerates over a comparatively short distance before air resistance equals its weight. A skydiver (Figure 1.2.13) has a terminal velocity of more than 50 m/s (180 km/h) before the parachute is opened.

Objects falling in liquids behave similarly to those falling in air.

▲ **Figure 1.2.13** Synchronised skydivers

In the absence of air resistance, an object falls in a uniform gravitational field with a constant acceleration as shown in the distance–time graph of Figure 1.2.10a.

## Revision checklist

After studying Topic 1.2 you should know and understand the following:

✓ that a negative acceleration is a deceleration or retardation.

After studying Topic 1.2 you should be able to:

✓ define speed and velocity, and calculate average speed from total distance/total time; sketch, plot, interpret and use speed–time and distance–time graphs to solve problems

✓ define and calculate acceleration and use the fact that deceleration is a negative acceleration in calculations

✓ state that the acceleration of free fall, $g$, for an object near to the Earth is constant and use the given value of 9.8 m/s$^2$

✓ describe the motion of objects falling in a uniform gravitational field.

# Exam-style questions

**1** The speeds of a car travelling on a straight road are given below at successive intervals of 1 second.

| **Time/s** | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| **Speed/m/s** | 0 | 2 | 4 | 6 | 8 |

Calculate

**a** the average speed of the car in m/s [2]

**b** the distance the car travels in 4 s [3]

**c** the constant acceleration of the car. [2]

[Total: 7]

**2** If a train travelling at 10 m/s starts to accelerate at 1 m/s$^2$ for 15 s on a straight track, calculate its final speed in m/s.

[Total: 4]

**3** The distance–time graph for a girl on a cycle ride is shown in Figure 1.2.14.

**a** Calculate

**i** how far the girl travelled [1]

**ii** how long the ride took [1]

**iii** the girl's average speed in km/h [1]

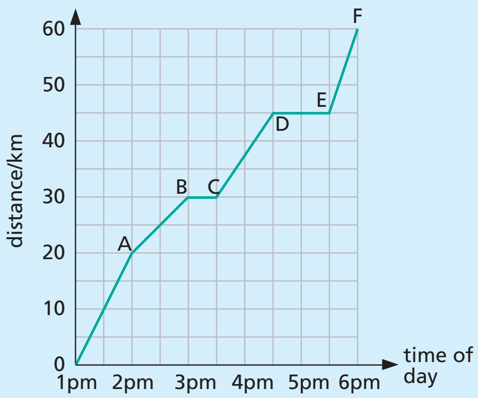
**iv** the number of stops the girl made [1]

**v** the total time the girl stopped [1]

**vi** the average speed of the girl *excluding* stops. [2]

**b** Explain how you can tell from the shape of the graph when the girl travelled fastest. Over which stage did this happen? [2]

[Total: 9]




▲ **Figure 1.2.14**

**4** The graph in Figure 1.2.15 represents the distance travelled by a car plotted against time.

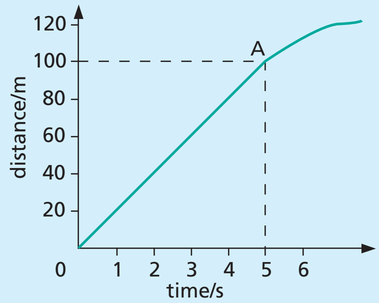
**a** State how far the car has travelled at the end of 5 seconds. [1]

**b** Calculate the speed of the car during the first 5 seconds. [1]

**c** State what has happened to the car after A. [2]

**d** Draw a graph showing the speed of the car plotted against time during the first 5 seconds. [3]

[Total: 7]




▲ **Figure 1.2.15**

**5** Figure 1.2.16 shows an incomplete speed–time graph for a boy running a distance of 100 m.

**a** Calculate his acceleration during the first 4 seconds. [2]

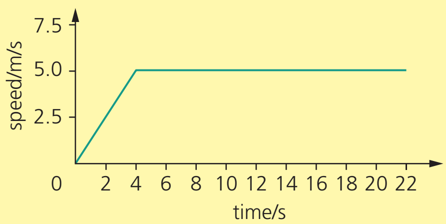
**b** Calculate how far the boy travels during

**i** the first 4 seconds [2]

**ii** the next 9 seconds? [2]

**c** Copy and complete the graph, showing clearly at what time he has covered the distance of 100 m. Assume his speed remains constant at the value shown by the horizontal portion of the graph. [4]

[Total: 10]




▲ **Figure 1.2.16**

**6** The approximate speed–time graph for a car on a 5-hour journey is shown in Figure 1.2.17. (There is a very quick driver change midway to prevent driving fatigue!)

**a** State in which of the regions OA, AB, BC, CD, DE the car is
  **i** accelerating
  **ii** decelerating
  **iii** travelling with constant speed. [3]

**b** Calculate the value of the acceleration, deceleration or constant speed in each region. [3]

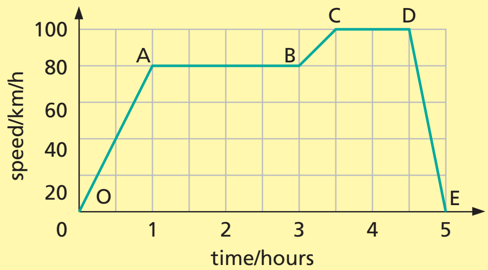
**c** Calculate the distance travelled over each region. [3]

**d** Calculate the total distance travelled. [1]

**e** Calculate the average speed for the whole journey. [1]

**f** State what times the car is at rest. [1]

[Total: 12]




▲ **Figure 1.2.17**

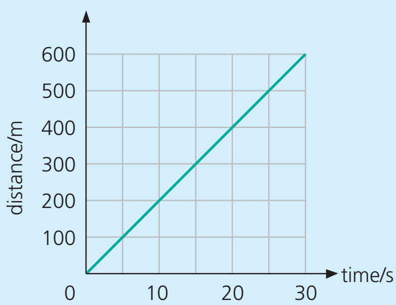
**7** The distance–time graph for a motorcyclist riding off from rest is shown in Figure 1.2.18.

**a** Describe the motion. [2]

**b** Calculate how far the motorbike moves in 30 seconds. [1]

**c** Calculate the speed. [2]

[Total: 5]




▲ **Figure 1.2.18**

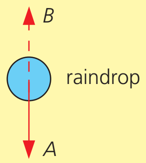
**8** A ball is dropped from rest from the top of a high building. Ignore air resistance and take $g = 9.8\,\text{m/s}^2$.

**a** Calculate the speed of the ball after
  **i** 1 s [2]
  **ii** 3 s. [2]

**b** Calculate how far it has fallen after
  **i** 1 s [2]
  **ii** 3 s. [2]

[Total: 8]

**9** Figure 1.2.19 shows the forces acting on a raindrop which is falling to the ground.




▲ **Figure 1.2.19**

**a** **i** $A$ is the force which causes the raindrop to fall. Give the name of this force. [1]
  **ii** $B$ is the total force opposing the motion of the drop. State *one* possible cause of this force. [1]

**b** What happens to the drop when force $A$ = force $B$? [2]

[Total: 4]