Unit 6.1 Describing motion

context

Everything in the universe is in motion all the time. We are moving at 1300 km/h as the Earth spins on its axis and orbits the Sun. The Sun orbits the centre of our galaxy, the Milky Way. Ever since the Big Bang, our galaxy has been moving away from all the other galaxies. On a much smaller scale, molecules are whizzing around in the air, and electrons are orbiting inside them. Understanding motion is one of the keys to understanding the world around us, and scientists have developed clear ways of describing motion.

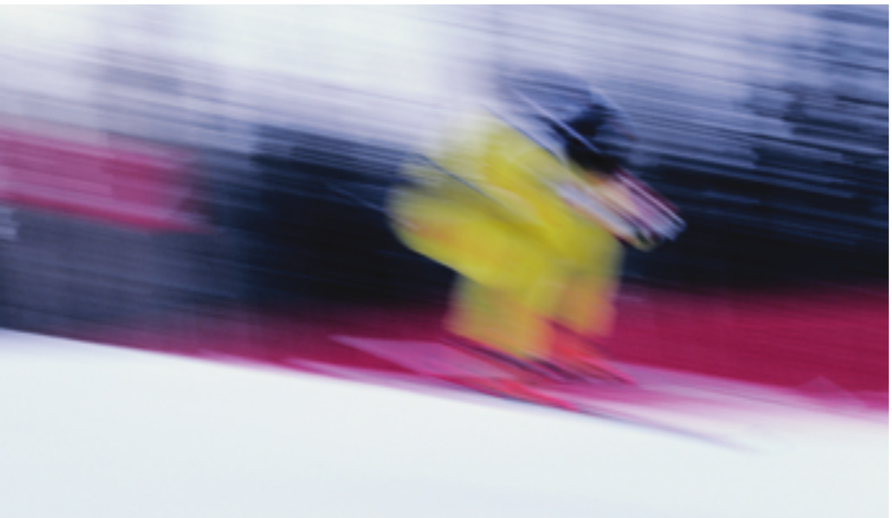

Fig 6.1.1 This skier is moving so fast that the camera cannot keep up. This makes the skier appear as a blur.

Most students move considerable distances every day: they travel to and from school, move from class to class, around their suburb or home town and within their home.

When they return home, they are back at the point they started out from that morning. Their displacement is zero.

Fig 6.1.2 Distance is how far you travel. Displacement is how far, and in which direction, you end up from where you started.

Distance and displacement

PP Quick Quiz

To describe a journey, most people would mention the distance travelled and the time it took. When physicists describe a journey, they use time much as other people would. However, they use two different terms to describe how far you have travelled:

- **distance**—this measures the actual distance travelled. Distance does not involve the direction in which you move at any time in your journey
- **displacement**—this measures how far you end up from where you started, and in which direction (up, left, north, towards the window etc.). Displacement is distance but with direction.

Distance and displacement are measured in the same units. Any length units can be used, but distance and displacement are usually converted into metres (unit symbol m) for calculations.

Science Fact File

Distance and displacement

Symbol in formulae: s – distance has no direction

- $\bar{s}$ – displacement has direction
- Unit: metres
- Unit abbreviation: m

Time

- Symbol in formulae: t
- Unit: seconds
- Unit abbreviation: s

Speed and velocity

Speed

Car speed is measured continuously by the speedometer in kilometres per hour (km/h or kmh^{-1}). This is a measure of the car's **instantaneous speed** or its speed at any moment in its travels. **Speed** is the rate at which distance is covered—the amount of distance covered for each unit of time. Commonly used units of time are hours (unit symbol h) and seconds (s).

If the speed of a car is measured in kilometres per hour (km/h), then the car would travel that number of kilometres in one hour (assuming that the car kept moving at its current speed). This means that a car travelling a country freeway at 110 km/h will travel 110 km every hour it does so.

Another common unit used to measure speed is metres per second (m/s or ms^{-1}). Scientists usually convert all speeds and velocities into metres per second for calculations. To convert kilometres per hour into metres per seconds, divide by 3.6. To convert metres per second to kilometres per hour, multiply by 3.6:

$$\text{km/h} \underset{\times 3.6}{\overset{\div 3.6}{\rightleftarrows}} \text{m/s}$$

You do not always have a speedo or radar gun with you to measure instantaneous speed. Some simple measurements, however, allow you to calculate **average speed**:

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

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

Fig 6.1.3 Police radar guns measure instantaneous speed.

Science Clip

That's slow!

The speed limit for cars in France was 13 km/h in 1893. Originally all cars in Great Britain were required to have a man walking in front of them with a red flag to alert horse riders! In 1896 the speed limit was raised to 20 km/h and, in 1904, to 33 km/h. The first Australian speeding ticket was given to Tasmanian George Innes, who was recklessly driving a car through Sydney at 13 km/h!

Science Fact File

Speed and velocity

- Symbol in formulae:
  - v – speed has no direction
  - $\vec{v}$ – velocity has direction
- Unit: metres per second
- Unit abbreviation: m/s or ms^{-1}

If a school bus took half an hour to travel 10 kilometres to school, then its average speed would be:

$$v = \frac{10}{0.5} = 20 \text{ km/h}$$

This seems slow, but is an average of all the instantaneous speeds the bus did on its journey. The bus went faster than 20 km/h, but also stopped at traffic lights and bus stops. It also had to reduce its speed through school zones and shopping areas.

Science Fact File

Symbols and units

Each of the physical quantities that are used to describe motion has both a symbol and a unit. For example, the symbol used for time is t but the unit in which time is measured is the second (s). Slightly confusingly, the symbol used for displacement is s and the unit for displacement is the metre (m). Italics are used for symbols but not for units, which makes it easier to distinguish between them. It's important to use the symbols and units correctly for clear scientific communication. We use a small arrow above the terms for quantities where direction is important, such as displacement ($\vec{s}$) and velocity ($\vec{v}$), since otherwise they use the same symbols as distance (s) and speed (v).

Fig 6.1.4 Since direction is important as well as speed, weather reports tell you the wind velocity, e.g. 30 knots south-east. A knot is a nautical mile per hour, about 1.85 km/h, so a 30-knot wind is blowing at about 56 km/h.

Fig 6.1.5 Multi-flash and composite high-speed photographs split a complex motion into a series of short time frames. The time-interval for each frame is so short that its average speed is close to the instantaneous speed for that frame.

Velocity

A weather report of 60 km/h wind gusts is useless to pilots, sailors, surfers and people fishing unless they also know the wind's direction. **Velocity** is speed in a given direction. Velocity has the same relationship to speed that displacement has to distance—they are measured in the same units, but add information about direction. Wind movement is usually stated as a velocity—for example, a 60 km/h wind coming from the south.

$$\text{average velocity} = \frac{\text{displacement}}{\text{time}}$$

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Measuring motion

Averages are useful but tell little about what is actually happening at a particular moment. If the distance or time chosen for the average is small, however, average and instantaneous speeds become closer to each other. A runner might be timed at completing the 100 metre sprint in 12 seconds, but it would be better to measure the times taken to run past markers spaced at, for example, 10 metres. The average speed of each section would show any changes that happened along the way. Spacings of one metre would be even better.

In the laboratory, the motion of an object can be measured in a number of ways depending on the equipment available.

- **Dataloggers**—there are a number of devices that will measure the distance, time, speed and direction of movement of an object, the data being transmitted by infra-red beam or cable to a computer for analysis by specialised software. The information obtained is accurate and can be easily manipulated into other forms such as graphs and values for acceleration and force.
- **Multi-flash photography**—a stroboscope is flashed onto the moving object and a camera or video on long exposure catches its image every time the strobe light flashes. Distances can be measured accurately off the image and time can be calculated from the flash rate of the strobe. The advantage of multi-flash photography is that it records different motions within the object, such as the movement of arms and legs.

- **High-speed composite photography**—many cameras will take a series of rapid images that can then be combined to form a single image. This method produces a similar image to that of multi-flash photography. If the rate is known, then speeds can easily be calculated from the image.
- **Ticker-timers**—an older device known as a ticker-timer breaks movement into a series of small intervals. It provides a way of accurately measuring distances travelled and times taken and provides the data from which average speeds can be calculated. A small electric hammer strikes a piece of carbon paper at the same frequency as its AC power supply, at a rate of 50 hertz (50 Hz) or 50 times a second. Motion is recorded as dots on a strip of paper that passes under the hammer. Unlike most dataloggers, ticker-timers can only measure straight-line motion in one direction.

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- **Rulers and stopwatches**—since average speed only needs the distance travelled and the time taken, rulers, tape measures and stopwatches can provide data that will give you a rough overview of an object's motion.

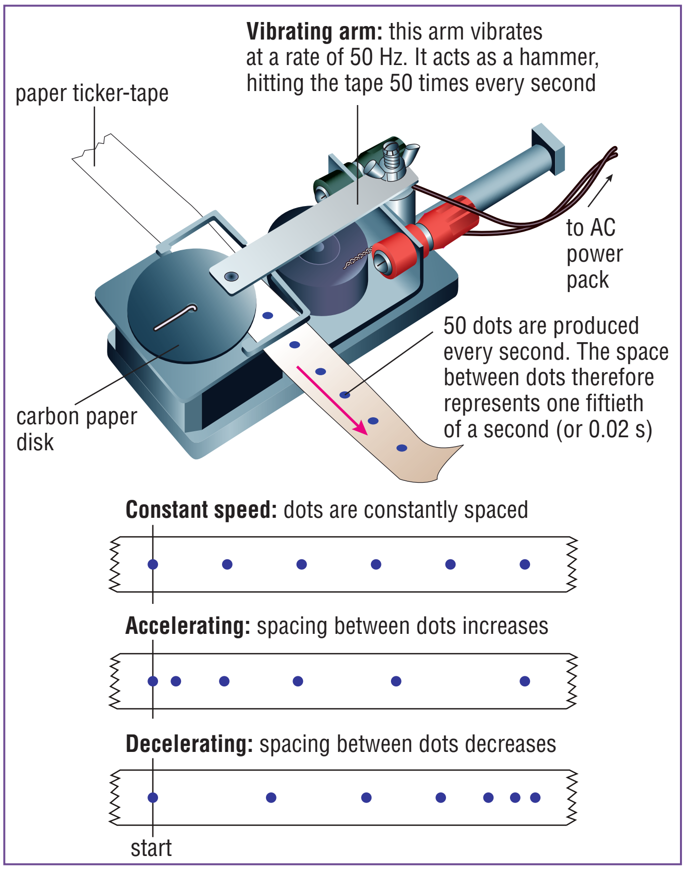

Fig 6.1.6 Although useful, the ticker-timer can only record motion in a straight line in one direction.

Graphing motion

Distance–time graphs

Graphs are very useful in representing the motion of an object travelling in a straight line.

Distance–time graphs show the total distance travelled by an object as time progresses. Time is always placed on the horizontal axis and distance on the vertical. Steep graphs indicate that the object is covering more distance and travelling faster than flatter graphs. A horizontal graph indicates no movement at all: the object is at rest or stationary. The slope or gradient of a distance–time graph gives us the object's speed.

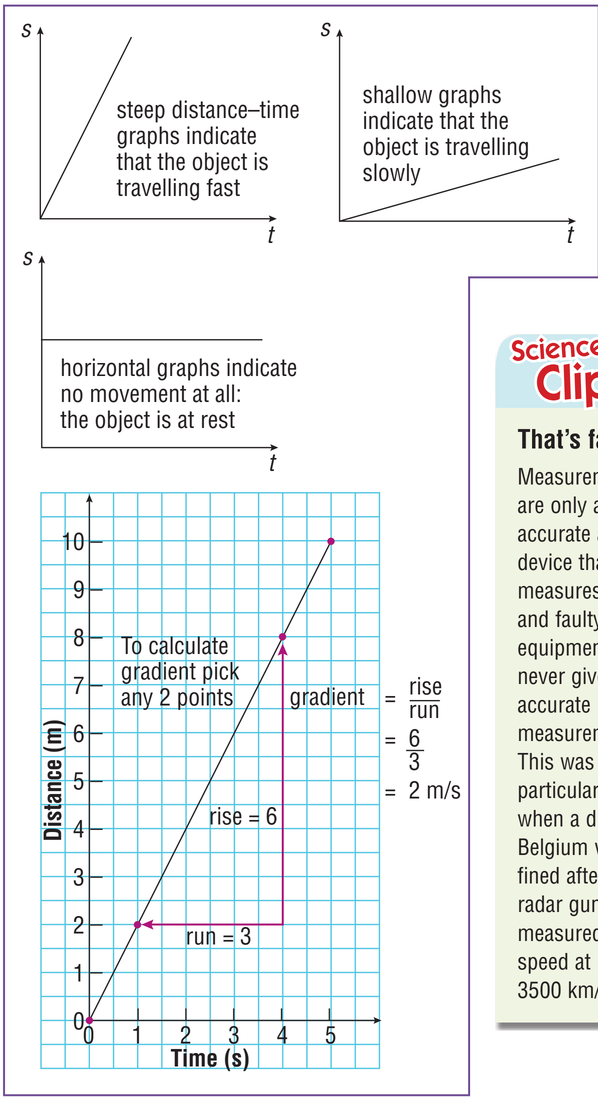

Fig 6.1.7 The slope or gradient of a distance–time graph gives the speed of an object. The steeper a distance–time graph, the faster the object is going.

Science Clip

That's fast!

Measurements are only as accurate as the device that measures them, and faulty equipment will never give accurate measurements. This was particularly true when a driver in Belgium was fined after a radar gun measured his speed at 3500 km/h!

Speed–time graphs

A graph of speed against time gives another picture of what is happening in the motion of an object. As before, time is placed on the horizontal axis. If the object is getting faster, the graph rises. If it is slowing, the graph falls. Constant speed gives a flat graph. The area under a speed–time graph gives the distance that the object has travelled up to that point. You can count the squares or use area-formulae to find the distance travelled.

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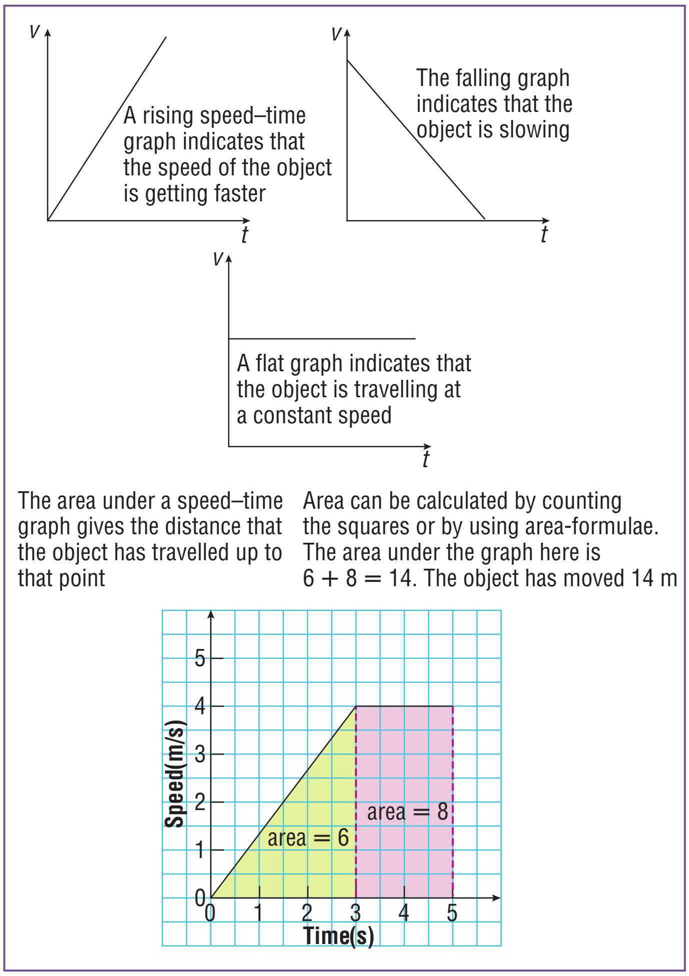

Fig 6.1.8 The total distance travelled is the area under a speed–time graph. The area here is 6 + 8 = 14. The object has moved 14 metres.

Calculating distance

The average speed formula can be rearranged to give another useful formula:

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

A car travelling at an average speed of 20 m/s for 5 seconds will have travelled a distance of:

$$s = 20 \times 5 = 100 \text{ m}$$

Humans do not respond immediately to emergencies, but take up to 1.5 seconds to react. This is their **reaction time**. This means that when in a car, a driver will not begin braking until well after they see an emergency. Meanwhile the car is travelling fast towards it.

To calculate the distance a car travels while the driver reacts, the speed must be converted into m/s to match the units used for time. Assume a car is being driven at 60 km/h (16.7 m/s) by a driver with a reaction time of 1.5 seconds. The distance the car travels before the driver brakes is then:

$$s = 16.7 \times 1.5 = 25.05 \text{ m}$$

This is equivalent to five to six car lengths.

A driver who is distracted (using a mobile phone, changing a radio station or who has consumed alcohol) may take as long as three seconds to react.

Worksheet 6.1 Distance–time graphs

PP Drag-and-drop

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Science Clip

Don't even think about stopping!

In about 700 BCE, King Sanherib of Assyria built a road from his capital, Nineveh, to nearby temples. It was so wide that it would have been equivalent to a modern freeway of 18 lanes! The king was justifiably proud of his road and didn't want it spoiled by chariots parked along it. Death was the penalty for doing so, with offenders being impaled on spikes!