Science 9–10

Chapter 15 — Physical sciences B: electricity generation, forces and motion

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Contents

Generating electricity: AC from magnets and turbines, DC from photovoltaic cells and batteries

Chapter 15 — Physical sciences B: electricity generation, forces and motion (Science, Levels 9 and 10)

Subtopic 15A · VC2 Science Understanding — Physical sciences

CD code: `VC2S10U16` (delivered whole by this subtopic) **Content description (verbatim):** "electricity can be generated as alternating current (AC) using magnets (via turbines turned by wind, water, tides or steam that is generated by the combustion of oil, gas or coal or by nuclear energy) or as direct current (DC) using photovoltaic cells or batteries" **Elaboration ids drawn on:** `VC2S10U16.E01` · `VC2S10U16.E02` · `VC2S10U16.E03` · `VC2S10U16.E04` · `VC2S10U16.E05` (No elaboration id is withheld under the TOC's D10 ICIP decision for this CD.) **Achievement standard (extract served):** "They analyse and represent energy conservation, including efficiency, in systems, and model how different forms of energy are transformed into electrical energy." (This extract is shared with subtopic 14C, per TOC D14; each subtopic quotes it against its own CD.) **Maths interlock (D11):** none new — the arithmetic here is multiplication, division and unit conversion, all within the band's maths.

Theory

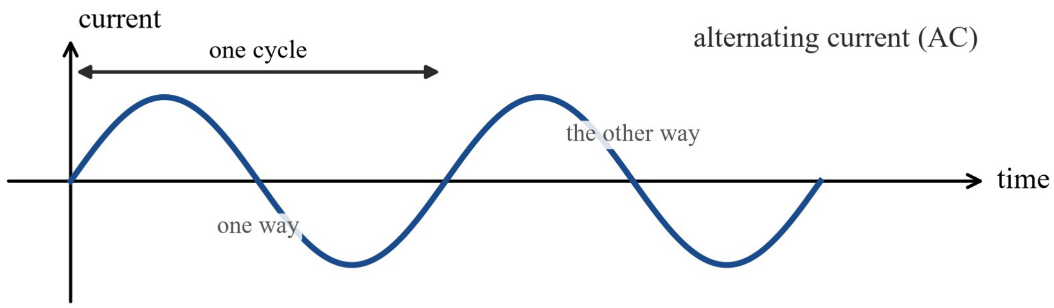
Electricity is energy on the move. Electrical energy is one of the most useful forms of energy because it travels easily through wires and can be transformed into light, thermal energy, sound or motion almost anywhere it is needed. But electrical energy does not come from the ground or the air ready-made: it must be **generated** by transforming energy from a source into electrical energy. This subtopic covers the two ways this is done at large scale and small:

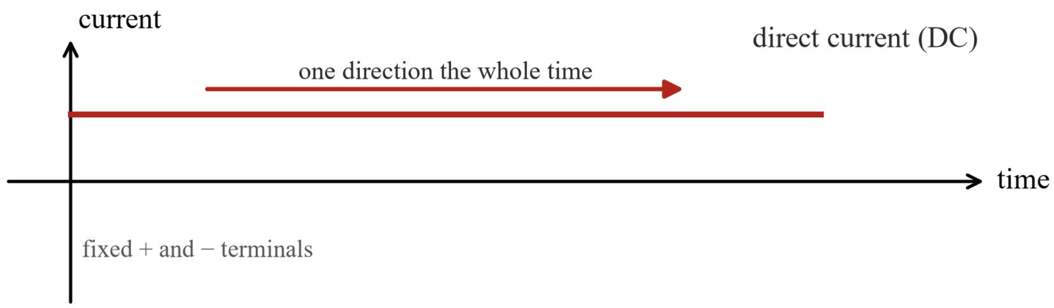
- **alternating current (AC)**, produced using magnets in a generator that is spun by a **turbine** — turned by wind, water, tides, or steam made by burning oil, gas or coal, or by nuclear energy; and
- **direct current (DC)**, produced by **photovoltaic cells** (solar cells) and by **batteries**.

In every case the story is the same shape: energy starts in one store, is transformed step by step, and ends up partly as electrical energy — with some of it always dissipated to the surroundings, mostly as thermal energy. Efficiency and how to calculate it belong to subtopic 14C; here the focus is on **modelling the transformation chains** themselves.

Two kinds of current. An electric current is a flow of charge, and there are two kinds.

- In a **direct current (DC)** the charge flows in one direction the whole time. The source has a fixed **polarity**: one terminal is always positive (+) and the other always negative (−). Batteries and photovoltaic cells produce DC.
- In an **alternating current (AC)** the direction of the flow reverses again and again, regularly. The charge surges one way, then back the other way, over and over. The household **mains** supply — the AC delivered to homes and schools through the power grid — is alternating current.





Current against time for the two kinds of current: alternating current rises and falls, reversing direction each half cycle, while direct current stays steady in one direction

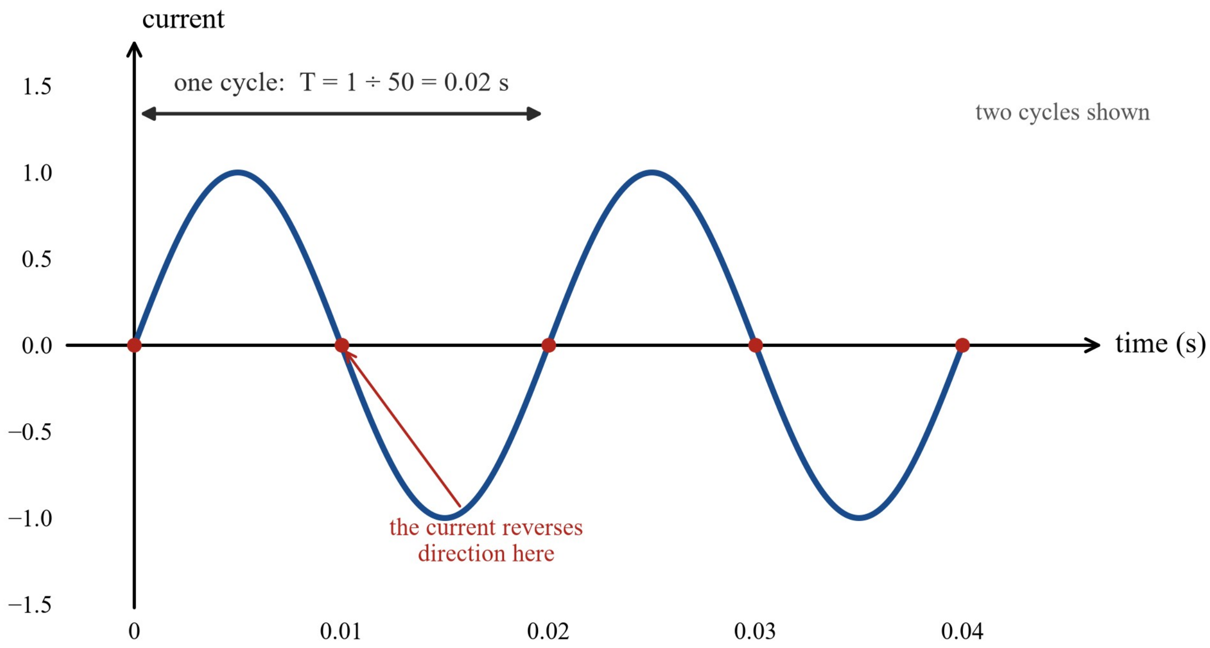
The **grid** is the network of wires and cables that carries electricity from generators to users. In Australia the mains supply is **230 V AC at a frequency of 50 Hz**.

Frequency and period. The **frequency** of an AC supply is the number of complete cycles the current makes each second. One **cycle** is one full pattern of the current — surging one way, then back the other way — after which the pattern repeats. Frequency is measured in **hertz** (Hz); 1 Hz means one cycle each second.

The **period** is the time taken for one complete cycle. Frequency and period are linked:

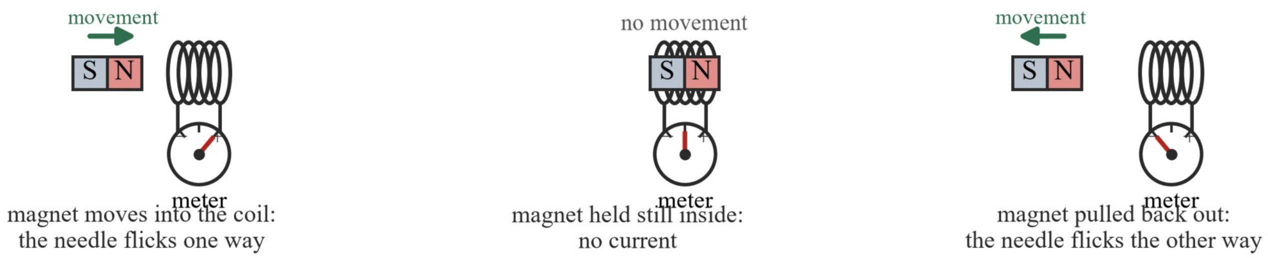
$$T = \frac{1}{f}$$

where T is the period in seconds and f is the frequency in hertz. For the Australian mains supply, $f = 50$ Hz, so one cycle takes $T = 1 \div 50 = 0.02$ s. During each cycle the current reverses direction twice, so in a 50 Hz supply the charge changes direction 100 times every second.



Current against time for the 50 hertz mains supply: one cycle takes 0.02 seconds, and the current reverses direction twice in each cycle

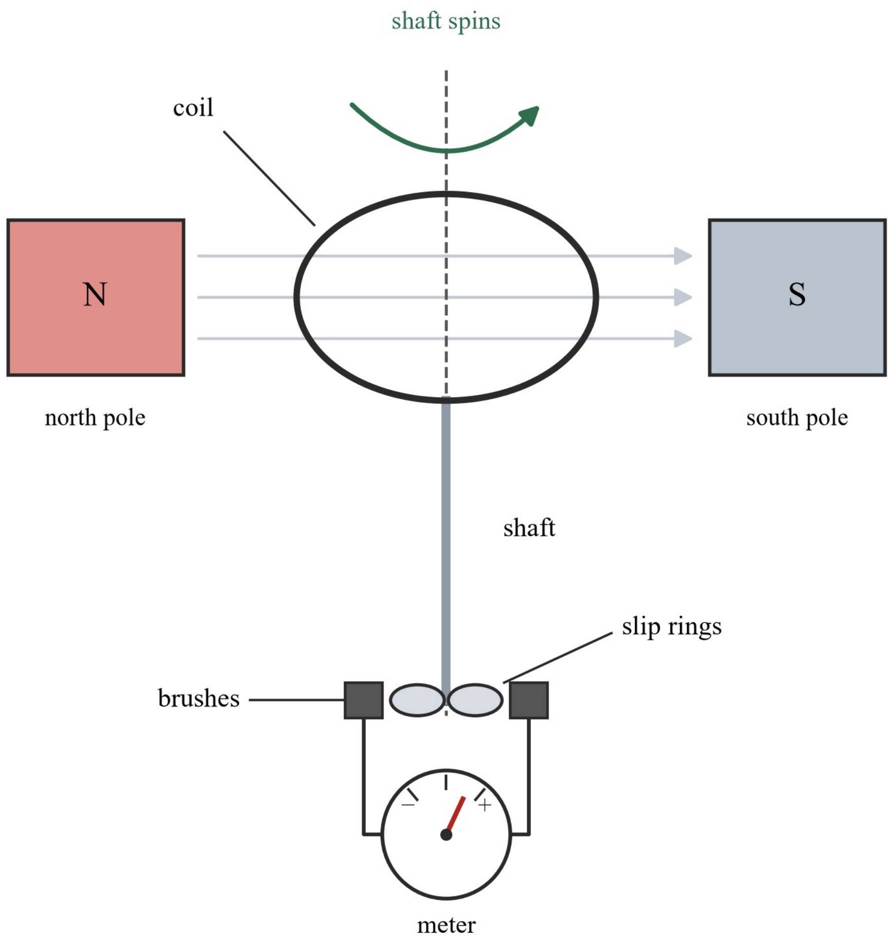
How magnets and a coil generate AC. There is a remarkable link between magnetism and electricity: a magnet and a coil of wire can produce an electric current. Move a magnet into a coil of wire connected to a sensitive current meter and the meter's needle flicks — a current has been **induced** in the wire. Hold the magnet still and nothing happens. Pull the magnet back out and the needle flicks the other way — the current is in the opposite direction. Move the magnet faster and the current is larger.



A bar magnet and a coil of wire connected to a meter: moving the magnet in makes the needle flick one way, holding it still gives no current, and pulling it out makes the needle flick the other way

This effect is called **electromagnetic induction**: a current is produced in a wire when there is a changing magnetic effect around it, caused by movement between the magnet and the coil. The key requirement is **movement** — no movement, no current.

An **AC generator** turns this effect into a continuous supply. A magnet (or a coil of wire) is mounted on a spinning shaft and arranged so that each side of the coil moves past the magnet's north pole, then past its south pole, then past the north pole again. As the coil spins, the induced current reverses direction every half turn — so the output is alternating current. In one complete turn of the shaft, the generator produces one complete cycle of AC. Spin the shaft faster and the frequency rises. The spinning part of a generator is driven, in most large power stations, by a **turbine**.

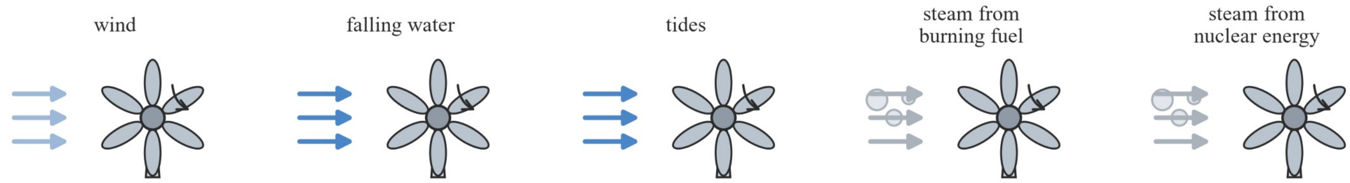


A labelled alternating current generator: a coil spins on a shaft between the north and south poles of a magnet, and connects through slip rings and brushes to a meter

A bicycle **dynamo** is a small version of the same idea: a magnet spins near a coil when the wheel turns, and the lamp lights. (A car's **alternator** works the same way and produces AC, which the car's electronics then turn into DC to charge the battery.)

Turbines, and what turns them. A **turbine** is a wheel with blades, designed to spin when something pushes against the blades — like a pinwheel spins in the wind. In a power station the turbine's shaft is connected to the generator, so when the turbine spins, the generator spins and produces AC. The turbine–generator pair is much the same whatever spins the turbine; what changes is **where the turning motion comes from**.

Five sources that spin a turbine



The same turbine wheel spun in five ways: by wind, by falling water, by the tides, by steam from burning fuel, and by steam from nuclear energy

The content description names five sources:

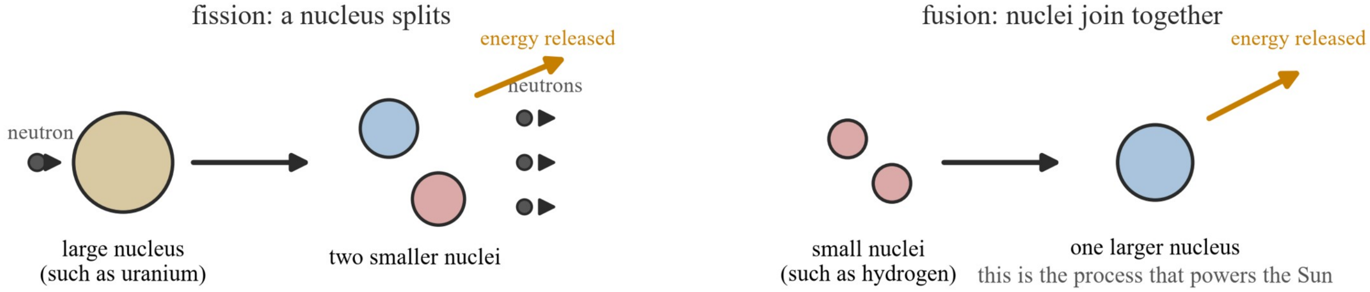
- **Wind.** Moving air has kinetic energy. The air pushes the turbine's blades and the blades spin: kinetic energy of the wind → kinetic energy of the turbine → electrical energy. Wind turbines stand on tall towers where the wind is stronger and steadier.

- **Water.** In a hydroelectric scheme, water held behind a dam falls through pipes and spins a turbine: gravitational potential energy of the stored water → kinetic energy of the falling water → kinetic energy of the turbine → electrical energy.
- **Tides.** The sea level rises and falls twice a day as the tides change. Tidal schemes let the moving water of the tide spin a turbine, in the same chain as water above.
- **Steam from burning oil, gas or coal.** Burning (combustion) releases the chemical energy stored in the fuel as thermal energy. That thermal energy boils water into high-pressure steam, and the steam is blown onto the turbine blades: chemical energy → thermal energy → kinetic energy of the steam and turbine → electrical energy.
- **Steam from nuclear energy.** In a nuclear power station the heat comes from **fission** in a reactor instead of from burning: nuclear energy → thermal energy → kinetic energy of the steam and turbine → electrical energy. The turbine and generator are the same as in any steam-driven station.

Notice what this list says — and what it does not. In all five cases something spins the turbine: wind, water and tides directly, and combustion and nuclear energy through steam. The generator itself always needs a magnet, a coil and movement. Sources that do not involve a spinning turbine — photovoltaic cells and batteries — are the DC sources, coming next.

Fission and fusion — two nuclear processes (elaboration `VC2S10U16.E04`). The nucleus is the tiny, dense centre of an atom. Two different nuclear processes can release energy from nuclei:

- **Fission** is the splitting of a large nucleus, such as the nucleus of a uranium atom. When the nucleus splits, energy is released, and the split can set off further splits in a **chain reaction**. In a nuclear reactor the chain reaction is controlled so that the energy is released steadily as thermal energy, which makes steam for the turbine. Fission is what every nuclear power station in the world uses today. Fission does not involve burning, so it does not produce carbon dioxide — but it does produce radioactive waste, which must be managed and stored carefully for very long times.
- **Fusion** is the joining together of small nuclei, such as the nuclei of hydrogen atoms, to make a larger nucleus. Fusion releases even more energy than fission, and it is the process that powers the Sun and the other stars. On Earth, fusion needs temperatures far higher than any furnace can reach, and no one has yet built a fusion reactor that can generate electricity for the grid. Research continues in several countries.

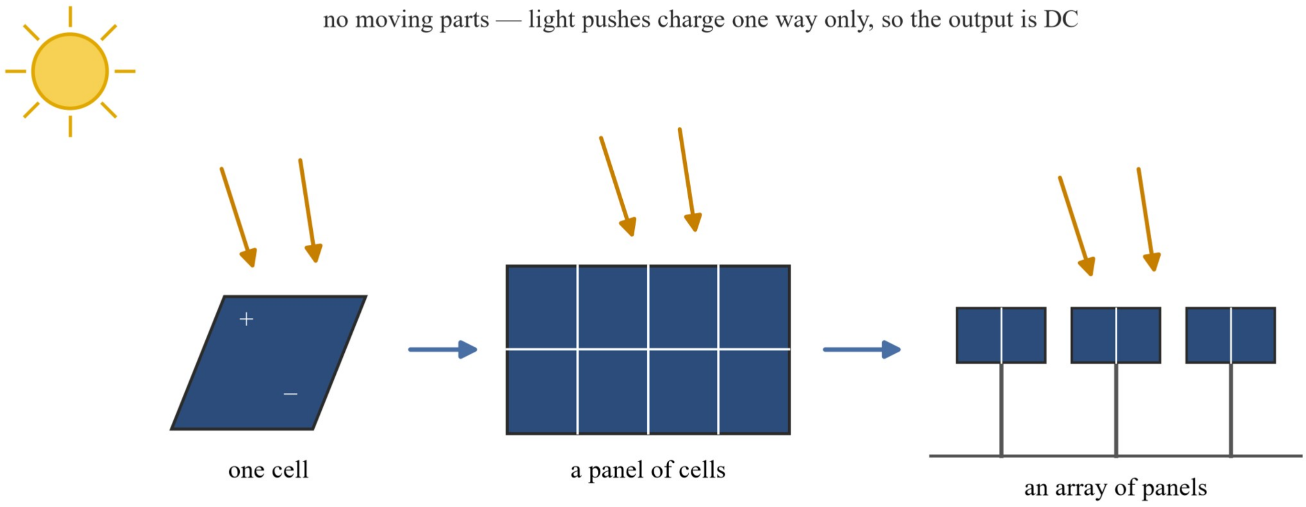


Fission and fusion side by side: in fission a neutron splits a large uranium nucleus into two smaller nuclei, releasing energy; in fusion small hydrogen nuclei join into one larger nucleus, releasing energy

So today: fission is used in power stations; fusion powers the stars and is still a subject of research. (Nuclear processes are described here in words only — nuclear equations and calculations of nuclear energy are VCE Physics content and are not part of this book, per TOC D9.)

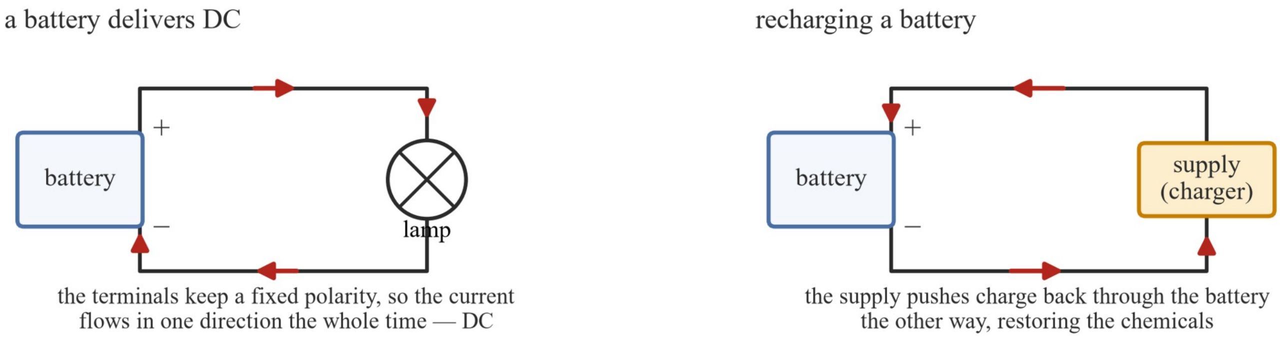
DC from photovoltaic cells. A **photovoltaic cell** — from *photo*, meaning light: it is a cell that makes electricity from light — is a device that transforms light energy **directly** into electrical energy, with no moving parts and no turbine. When light from the Sun falls on the cell, its energy pushes charge in one direction only inside the material of the cell, so the output is **direct current**.

Single cells are small, so they are connected together into **panels**, and panels into **arrays**, to deliver useful amounts of power. Rooftop panels on homes, and large solar farms with thousands of panels, work on this principle. The output of a photovoltaic array depends on the light falling on it: it produces nothing at night and less on cloudy days, which is why solar electricity is often paired with batteries to store energy for later.



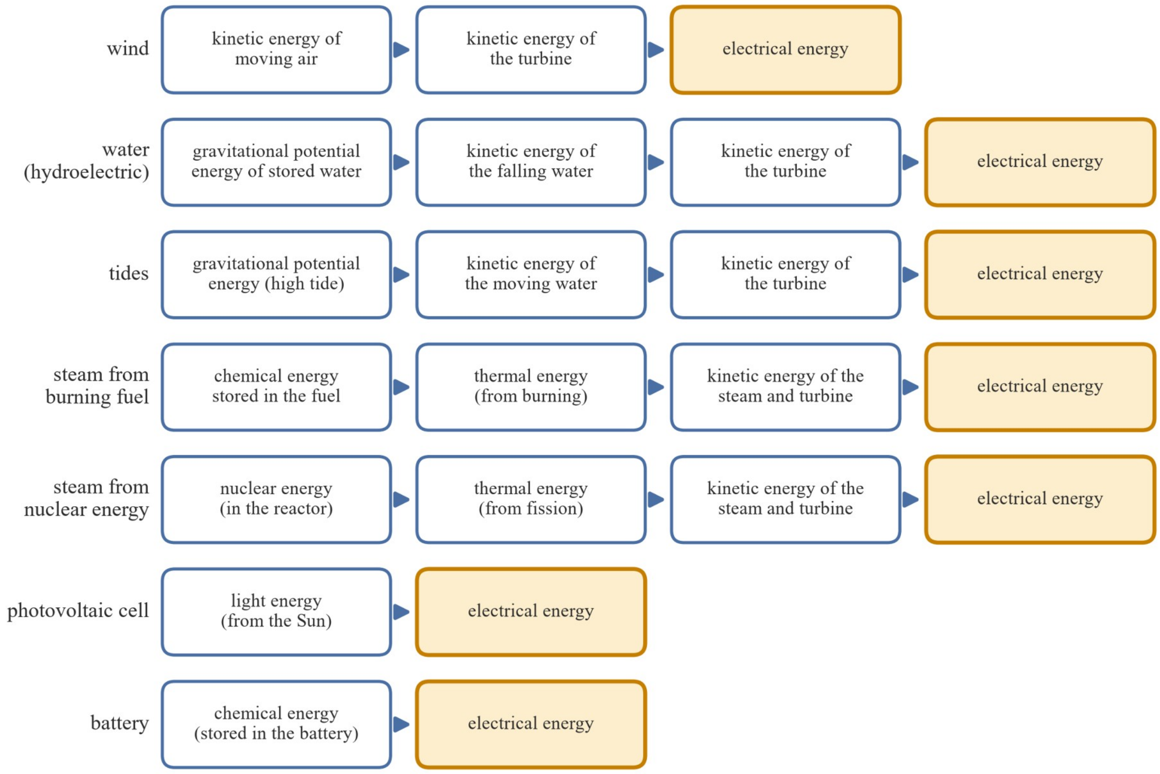
Photovoltaic cells joined into a panel and panels joined into an array: light from the Sun falls on the cells and pushes charge one way only, so the output is direct current

DC from batteries. A **battery** transforms stored chemical energy into electrical energy. Chemical reactions inside the battery push charge around a circuit. Because the battery's terminals keep a fixed polarity — one always +, one always − — the charge always flows the same way through the external circuit: a battery can only deliver DC.



A battery with fixed positive and negative terminals sends current one way around a circuit with a lamp, and a charger pushes charge back the other way to recharge the battery

Batteries come in two broad kinds. Some are single-use: when the chemicals are used up, the battery is flat. Others are **rechargeable**: connecting them to a supply pushes charge back through them the other way, restoring the chemicals so the battery can deliver energy again. The lithium-ion cells in phones, laptops and electric cars are rechargeable. Batteries are also used at grid scale: large battery banks store electrical energy when there is more than enough (a sunny or windy afternoon, for example) and release it when demand is high, keeping the grid steady.



In every chain, some energy is dissipated to the surroundings at each step, mostly as thermal energy.

Energy transformation chains for wind, water, tides, steam from burning fuel, steam from nuclear energy, a photovoltaic cell and a battery: every chain ends in electrical energy, with some energy dissipated as thermal energy at each step

Comparing AC and DC (elaboration `VC2S10U16.E02`). The two kinds of current are alike in what they are — a flow of charge that carries energy from a source to a user — and different mainly in the direction of the flow and in the sources that produce them:

	AC	DC
Direction of charge flow	reverses every half cycle	one direction the whole time
Terminals of the source	swap + and − each half cycle	fixed + and −
Sources in this subtopic	magnet-and-coil generator spun by a turbine	photovoltaic cells; batteries
Everyday examples	mains supply to homes (230 V, 50 Hz in Australia)	phone battery, torch, car battery

In Victoria. Victoria's electricity comes from a mix of sources: brown-coal-fired power stations in the Latrobe Valley (such as Loy Yang), gas-fired stations, wind farms (such as the Macarthur Wind Farm near Warrnambool), rooftop photovoltaic panels, hydroelectric generators, and a growing number of large battery banks. All of the mains supply is delivered as **230 V, 50 Hz AC**. The split between these sources changes from year to year; for current figures, the primary sources are the Australian Energy Market Operator (AEMO) and the Victorian Department of Energy, Environment and Climate Action (DEECA) — see Question 10, which asks you to research one of these sources and cite your data properly.

Activities

Activity 1 — Build a simple AC generator (elaboration `VC2S10U16.E01`). Wind about 100 turns of insulated copper wire around a cardboard tube to make a coil, and connect the two ends to a sensitive current meter. Fix a strong magnet to a shaft or a string so that it can spin close to the coil. Spin the magnet by hand and watch the meter. You should see: no current while the magnet is still; the needle flicking one way and then the other as the magnet spins — an alternating current. Spin faster and the flicks come more often and grow larger. *Safety: strong magnets can pinch fingers; keep fingers and hair clear of spinning parts; connect the generator only to the meter — never to any mains socket.*

Activity 2 — Power from a wind vane (elaboration `VC2S10U16.E05`). Build a wind vane — a set of paper or card blades fixed to a shaft — and connect the shaft to a small electric motor. A motor works backwards as a generator: spinning its shaft produces a voltage. Blow on the blades, or use a fan, and connect the motor's terminals to a meter or a small lamp. Investigate one question at a time: does the output grow when the wind is stronger? When the blades are set at a different angle? When there are more blades? Change only one thing per trial, and record what you observe each time. *Safety: keep fingers clear of the blades; use a fan only with teacher approval.*

Activity 3 — Venn diagram of AC and DC (elaboration `VC2S10U16.E02`). Draw two large overlapping circles, one labelled AC and one labelled DC. Sort the statements below into the diagram: AC only, DC only, or both (in the overlap). Then add two statements of your own. Statements: *the charge flows in one direction the whole time · the direction reverses regularly · the current carries energy · produced by a battery · produced by a turbine-driven generator · the Australian mains supply · produced by a photovoltaic cell · measured in hertz · has a frequency · the source has a fixed polarity*.

Worked examples

*The power unit used here is the **watt** (W): 1 W = 1 J/s — a power of 1 W means 1 J of energy is transferred each second. Power is the rate of energy transfer:*

$$P = \frac{E}{t} \text{ so } E = Pt$$

Larger powers: 1 kW = 1 000 W, 1 MW = 1 000 000 W. A handy energy unit for generation is the kilowatt-hour: 1 kWh is the energy transferred by a 1 kW device in 1 hour, so 1 kWh = 1 000 W × 3 600 s = 3 600 000 J = 3.6 MJ.

Example 1 — scaffolded

The Australian mains supply is 230 V AC at a frequency of 50 Hz. (a) State what the frequency of 50 Hz tells you about the current. (b) Calculate the period of the supply — the time for one complete cycle. (c) Calculate how many complete cycles the current makes in 1.0 minute.

Working	Comment
(a) 50 cycles each second	Frequency is the number of complete cycles per second.
(b) $T = 1 \div f = 1 \div 50 = 0.02$ s	Period and frequency are linked by $T = 1/f$.
(c) 50 × 60 = 3 000 cycles	50 cycles each second for 60 seconds.

The direction reverses twice in each cycle, so in one minute the current reverses direction 6 000 times.

Example 2 — scaffolded

A wind turbine delivers a steady 2.0 MW of power for 6.0 hours. (a) Write this power in kilowatts. (b) Calculate the energy transferred, in kilowatt-hours. (c) Convert this energy to megajoules. (d) Write the energy transformation chain for the turbine.

Working	Comment
(a) 2.0 MW = 2 000 kW	1 MW = 1 000 kW.
(b) $E = Pt = 2\,000 \times 6.0 = 12\,000$ kWh	Power in kW × time in hours gives energy in kWh.

Working	Comment
(c) 12 000 × 3.6 = 43 200 MJ	1 kWh = 3.6 MJ.
(d) kinetic energy of the wind → kinetic energy of the blades and shaft → electrical energy	Some energy is also dissipated as thermal energy and sound.

Example 3 — unscaffolded

A rooftop photovoltaic array delivers an average power of 1.5 kW during 5.0 hours of daylight. Calculate the energy it transfers in that time, in megajoules, state the energy transformation involved, and explain why the array's output is DC.

The energy transferred is

$$E = P\,t = 1.5 \times 5.0 = 7.5\,\mathrm{kWh}$$

and since 1 kWh = 3.6 MJ,

$$E = 7.5 \times 3.6 = 27\,\mathrm{MJ}\,.$$

The transformation is **light energy → electrical energy**. The output is DC because the material of each cell pushes the charge in one direction only when light falls on it — the cell has no rotating part and nothing to reverse the flow, so the current keeps the same direction.

Example 4 — unscaffolded

In a simple AC generator, the coil rotates 15 times each second. State the frequency of the AC produced and calculate its period. The turbine then speeds up until the coil rotates 50 times each second. State the new frequency and period, and describe what has changed about the current's direction.

Each complete turn of the coil produces one complete cycle of AC, so a coil rotating 15 times each second produces AC of frequency

$$f = 15\,\mathrm{Hz}$$

with period

$$T = \frac{1}{f} = \frac{1}{15} \approx 0.067\,\mathrm{s}\,.$$

At 50 rotations each second the new frequency is **50 Hz** — the frequency of the Australian mains — and the new period is T = 1 ÷ 50 = **0.02 s**. The current reverses direction twice in every cycle, so at the higher speed it reverses 2 × 50 = 100 times each second — twice as often as before. The current still alternates; it simply completes each cycle sooner.

Practice questions

Scaffolded questions

Question 1 (a) Define alternating current. (b) Define direct current. (c) Give one source of AC and one source of DC from this subtopic.

Question 2 A magnet is held near a coil of wire connected to a sensitive current meter. (a) Describe what is observed when the magnet is moved into the coil. (b) Describe what is observed when the magnet is held still inside the coil. (c) Describe what is observed when the magnet is pulled back out of the coil. (d) State how the observation changes if the magnet is moved faster.

Question 3 Copy and complete each energy transformation chain. (a) Coal-fired power station: chemical energy → …… energy → kinetic energy → …… energy. (b) Wind turbine: kinetic energy of the …… → kinetic energy of the blades → …… energy. (c) Photovoltaic cell: …… energy → …… energy.

Question 4 The Australian mains supply has a frequency of 50 Hz. (a) State what this frequency means. (b) Calculate the period of the supply. (c) Calculate the number of complete cycles in 2.0 minutes.

Question 5 A photovoltaic cell produces electricity when light falls on it. (a) State the energy transformation in a photovoltaic cell. (b) State whether the output is AC or DC. (c) Give one advantage and one limitation of photovoltaic cells as a source of electricity.

Question 6 A battery powers a torch. (a) State the energy transformation taking place in the battery. (b) Explain why a battery can only deliver direct current. (c) State the difference between a rechargeable battery and a single-use battery.

Unscaffolded questions

Question 7 Explain why a magnet-and-coil generator produces alternating current rather than direct current. In your answer, refer to the movement of the coil relative to the magnet.

Question 8 Sort the ten statements from Activity 3 into a Venn diagram with three regions: AC only, DC only, and both. List the statements in each region, and justify one of your placements.

Question 9 Fission and fusion are both nuclear processes that release energy. (a) Describe what happens to the nuclei in fission, and what happens in fusion. (b) State which process is used in nuclear power stations today. (c) State which process powers the Sun and the other stars. (d) Give one reason why fusion is not yet used to generate electricity on Earth.

Question 10 Investigate one power source used to turn turbines in Victoria — for example, brown coal in the Latrobe Valley, wind at the Macarthur Wind Farm, or hydroelectricity. Report: (a) the energy transformation chain from source to electrical energy; (b) how the turbine is turned; and (c) where you obtained any figures, cited in the form used in this book: organisation, title, year, web address, and the date you retrieved the data. The primary sources for Victorian generation are AEMO and DEECA.

Question 11 A hydroelectric generator delivers a steady 4.0 MW for 30 minutes. Calculate the energy transferred, in megajoules.

Question 12 A grid battery stores 18 000 MJ of energy and supplies an average power of 5.0 MW to the grid. (a) Calculate how long, in hours, the battery can supply this power. (b) State whether the battery's output is AC or DC.

Question 13 The coil of a simple AC generator rotates 20 times each second. (a) State the frequency of the AC produced. (b) Calculate the period. (c) State how the operator could increase the frequency without rebuilding the generator.

Question 14 A student claims: "All electricity is generated by a turbine spinning a magnet inside a coil." Evaluate this claim. In your answer, name two sources of electricity that support or refute it, and state the correct version of the claim.

Question 15 For each of a wind turbine, a rooftop photovoltaic array and a car battery: (a) state whether it produces AC or DC; and (b) write its energy transformation chain. (c) Many homes with rooftop photovoltaic panels also install a battery. Explain why the battery is useful, referring to when the panels do and do not produce.

Question 16 In a gas-fired power station, gas is burned to make steam, which spins a turbine connected to a generator delivering 25 MW. (a) Write the full energy transformation chain from the gas to the grid. (b) Explain why the useful electrical energy delivered to the grid is less than the energy that was stored in the gas. (c) State the kind of current delivered to the grid, and its frequency in Australia.

Answers

Question 1 (a) a current whose direction reverses regularly; (b) a current that flows in one direction the whole time; (c) AC: turbine-driven generator (mains supply); DC: battery or photovoltaic cell. **Question 2** (a) the needle flicks — a current is induced; (b) nothing — no current; (c) the needle flicks the other way; (d) the current is larger. **Question 3** (a) thermal; electrical; (b) moving air (wind); electrical; (c) light; electrical. **Question 4** (a) 50 complete cycles each second; (b) 0.02 s; (c) 6 000. **Question 5** (a) light energy → electrical energy; (b) DC; (c) see solution. **Question 6** (a) chemical energy → electrical energy; (b) see solution; (c) see solution. **Question 7** See solution. **Question 8** See solution. **Question 9** (a) see solution; (b) fission; (c) fusion; (d) see solution. **Question 10** See solution (research task — answers will vary; marking is on the chain, the mechanism and a properly cited source). **Question 11** 7 200 MJ. **Question 12** (a) 1.0 h; (b) DC. **Question 13** (a) 20 Hz; (b) 0.05 s; (c) spin the coil faster. **Question 14** The claim is refuted by photovoltaic cells and batteries — see solution. **Question 15** See solution. **Question 16** (a) see solution; (b) some energy is dissipated to the surroundings, mostly as thermal energy; (c) AC, 50 Hz.

Fully-worked solutions

Question 1 (a) An alternating current is a current in which the direction of the flow of charge reverses regularly, again and again. (b) A direct current is a current in which the charge flows in one direction the whole time. (c) AC: a generator spun by a turbine — the mains supply is the everyday example. DC: a battery (or a photovoltaic cell).

Question 2 (a) The meter's needle flicks: moving the magnet into the coil induces a current in the wire. (b) Nothing happens. Induction needs movement between the magnet and the coil — with the magnet still, there is no current. (c) The needle flicks the opposite way: reversing the motion reverses the direction of the induced current. (d) The current is larger (the needle flicks further). Faster movement induces a larger current.

Question 3 (a) chemical energy → **thermal** energy → kinetic energy → **electrical** energy. Burning releases thermal energy, which makes steam; the steam spins the turbine. (b) kinetic energy of the **moving air (wind)** → kinetic energy of the blades → **electrical** energy. (c) **light** energy → **electrical** energy.

Question 4 (a) A frequency of 50 Hz means the current completes 50 cycles each second. (b) $T = 1 \div f = 1 \div 50 =$ **0.02 s**. (c) 2.0 minutes = 120 s, so cycles = 50 × 120 = **6 000**.

Question 5 (a) Light energy → electrical energy. (b) DC — the cell pushes charge in one direction only. (c) One advantage: no moving parts and no fuel to burn, so it can sit quietly on a roof and produce from sunlight. One limitation: the output depends on the light — nothing at night, less in cloudy weather — so it must be paired with storage or other sources to supply power all the time. (Any reasonable advantage/limitation pair is accepted.)

Question 6 (a) Chemical energy → electrical energy. (b) The battery's terminals keep a fixed polarity — one is always + and the other always − — because the chemical reactions inside always push charge the same way. The charge therefore flows in one direction through the external circuit the whole time: DC. (c) A single-use battery is flat once its chemicals are used up. A rechargeable battery can be restored: connecting it to a supply drives the chemical reactions backwards, so it can deliver energy again.

Question 7 As the coil spins, each side of it moves past the magnet's north pole and then past its south pole. The induced current depends on this movement, and it reverses direction every time the motion relative to the poles reverses — that is, every half turn of the coil. Because the turning motion repeats, the current reverses regularly, again and again: alternating current. A generator of this kind cannot produce DC, because DC needs a flow in one fixed direction, and nothing about a spinning coil keeps the flow in one direction — the movement itself keeps reversing.

Question 8 - **AC only:** *the direction reverses regularly · produced by a turbine-driven generator · the Australian mains supply · measured in hertz · has a frequency.* - **DC only:** *the charge flows in one direction the whole time · produced by a battery · produced by a photovoltaic cell · the source has a fixed polarity.* - **Both:** *the current carries energy.*

Sample justification: "measured in hertz" sits in the AC region because hertz measures frequency — the number of cycles per second — and only a current that repeats a cycle, AC, has a frequency. A DC current does not cycle, so it has no frequency. (Any one well-justified placement earns the mark.)

Question 9 (a) In **fission**, a large nucleus — such as a uranium nucleus — splits into smaller pieces, releasing energy. In **fusion**, small nuclei — such as hydrogen nuclei — join together to make a larger nucleus, releasing energy. (b) **Fission** is used in nuclear power stations today. (c) **Fusion** powers the Sun and the other stars. (d) Fusion needs temperatures far higher than any furnace on Earth can reach, and no one has yet built a reactor that can hold the reacting material hot enough, and produce more energy than it uses, for a useful time. (Any one of these points earns the mark.)

Question 10 This is a research task; answers will vary by source chosen. A model answer for wind at the Macarthur Wind Farm: (a) Kinetic energy of the wind → kinetic energy of the blades and shaft → electrical energy. (b) The moving air pushes the blades, spinning the shaft, which spins the generator. (c) Current capacity and generation figures for Victorian generators are published by AEMO (Australian Energy Market Operator) and by DEECA (Victorian Department of Energy, Environment and Climate Action); retrieve the figures yourself and cite them as: organisation, title, year, web address, retrieved date — the date you actually read the page. Do not quote a figure you cannot trace to a page. Marks are awarded for the chain, the mechanism, and a citation with a real retrieval date — not for the size of the number.

Question 11 P = 4.0 MW = 4 000 kW; t = 30 min = 0.50 h. $E = Pt$ = 4 000 × 0.50 = 2 000 kWh. Since 1 kWh = 3.6 MJ, E = 2 000 × 3.6 = **7 200 MJ**. (Check in joules: E = 4 000 000 × 1 800 = 7 200 000 000 J = 7 200 MJ. ✓)

Question 12 (a) $t = E \div P$. Convert the energy: 18 000 MJ ÷ 3.6 = 5 000 kWh. The power is 5.0 MW = 5 000 kW, so t = 5 000 ÷ 5 000 = **1.0 h**. (Check in joules: 18 000 000 000 J ÷ 5 000 000 W = 3 600 s = 1.0 h. ✓) (b) A battery's output is **DC** — its terminals have a fixed polarity.

Question 13 (a) One turn gives one cycle, so the frequency is **20 Hz**. (b) T = 1 ÷ 20 = **0.05 s**. (c) Spin the coil faster — increasing the rotation rate increases the frequency. No change to the generator itself is needed.

Question 14 The claim is **refuted**. It is true of AC generation — a turbine-driven generator spins a magnet or coil and produces AC by induction. But two sources of electricity in this subtopic have no turbine and no spinning magnet: a **photovoltaic cell** transforms light energy directly into electrical energy, and a **battery** transforms stored chemical energy into electrical energy, both with no moving parts at all, and both produce DC. The correct version of the claim is: "All **AC** electricity in this subtopic is generated by a turbine spinning a magnet or coil; DC is produced by photovoltaic cells and batteries, which have no turbine."

Question 15 - Wind turbine: (a) AC; (b) kinetic energy of the wind → kinetic energy of the blades and shaft → electrical energy. **- Rooftop photovoltaic array:** (a) DC; (b) light energy → electrical energy. **- Car battery:** (a) DC; (b) chemical energy → electrical energy. (c) The panels produce only when light falls on them — they make nothing at night and less in cloudy weather, while the home still needs power in the evening. The battery stores the energy the panels make during the day and releases it later, so the home can use solar energy after the Sun has set.

Question 16 (a) Chemical energy (in the gas) → thermal energy (from burning) → kinetic energy (of the steam and turbine) → electrical energy (from the generator). (b) No generator transforms all of the input energy into electrical energy. Some energy is dissipated to the surroundings at every step — mostly as thermal energy (the hot exhaust and the warmed cooling water and air) and a little as sound. The energy is not destroyed — it is conserved — but only part of it ends up as useful electrical energy on the grid. Calculating that share is the efficiency work of subtopic 14C. (c) The grid receives **AC**, at **50 Hz** in Australia.

Where this leads: the AC generator built here is explained at a deeper level in VCE Physics Unit 3, Area of Study 3 ("How are fields used in electricity generation?"), using fields, flux and induction — reference-only for this book; those calculations are not taught here (TOC D9), nor are nuclear equations. Efficiency calculations and Sankey diagrams of generation belong to subtopic 14C (`VC2S10U15`), which shares this subtopic's achievement standard. The same generation technologies are compared on sustainability grounds in VCE Environmental Science Unit 4, Area of Study 2 ("What might be a more sustainable mix of energy sources?"), also reference-only.

Newton’s laws and the relationship between force, mass and acceleration

Chapter 15 — Physical sciences B: electricity generation, forces and motion (Science, Levels 9 and 10)

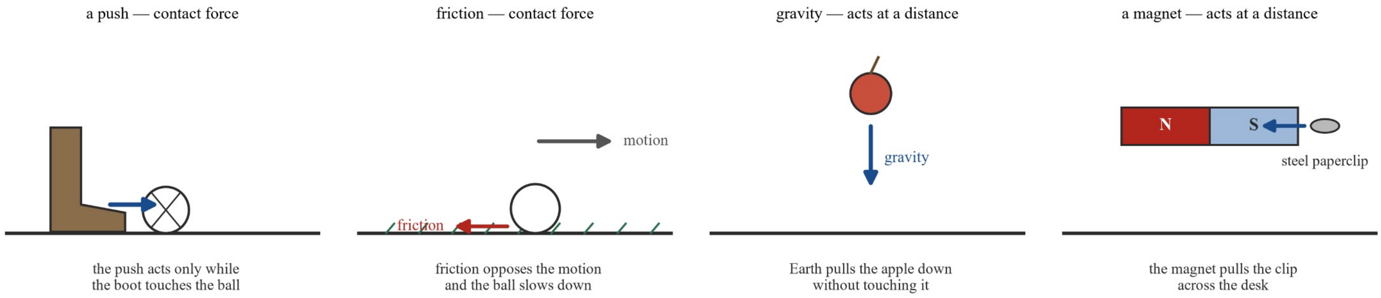
Subtopic 15B · VC2 Science Understanding — Physical sciences

CD code: `VC2S10U17` (split delivery †; this subtopic is the accountable owner) **Content description (verbatim):** “Newton’s laws of motion can be used to quantitatively analyse the relationship between force, mass and acceleration of objects” **This subtopic’s limb (TOC §4 clause split):** Newton’s laws, force–mass–acceleration. Partner `15C` (not an owner) delivers quantitative motion analysis and applications. **Elaboration ids drawn on:** `VC2S10U17.E03` · `VC2S10U17.E04` (`VC2S10U17.E02` is withheld under the TOC’s D10 ICIP decision and is not taught here.) **Achievement standard (extract served):** “They use Newton’s laws to describe and predict the motion of objects in a system.” **Maths interlock (D11):** `VC2M10A05` — substituting into and rearranging formulas, used here with $F = ma$.

Theory

Forces and net force. A **force** is a push or a pull. Forces can change an object’s motion: they can start it moving, stop it, speed it up, slow it down or change its direction. Forces are measured in **newtons** (N). Some forces act only when two objects touch — the push of a foot on a football, or the friction between a tyre and the road. Others act at a distance: gravity pulls objects toward Earth without touching them, and a magnet can pull a steel paperclip from across a desk.

Friction is a contact force that opposes motion between two surfaces. It is the reason a ball rolled across the grass slows down and stops: friction acts against the ball’s motion.

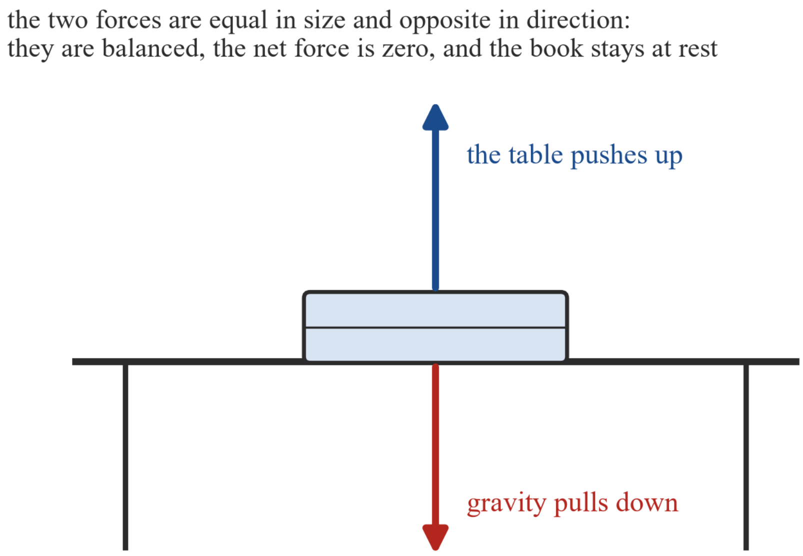


Four small pictures of forces. A boot kicks a football and the push acts only while they touch. A ball rolls across grass while friction acts backward against its motion. Earth’s gravity pulls a falling apple down without touching it. A bar magnet pulls a steel paperclip across a desk without touching it.

Often several forces act on an object at the same time. The **net force** is the overall force you get when all the individual forces are combined. Along a straight line, forces in one direction add together, and forces in the opposite direction subtract.

- If the forces are **balanced** — the net force is zero — the object’s motion does not change. An object at rest stays at rest, and an object already moving keeps moving at a steady speed in a straight line.
- If the forces are **unbalanced** — the net force is not zero — the object’s motion changes: it speeds up, slows down or changes direction.

A book sitting on a table has two forces on it: gravity pulling down and the table pushing up. The two forces are equal in size and opposite in direction, so they are balanced and the book stays at rest.



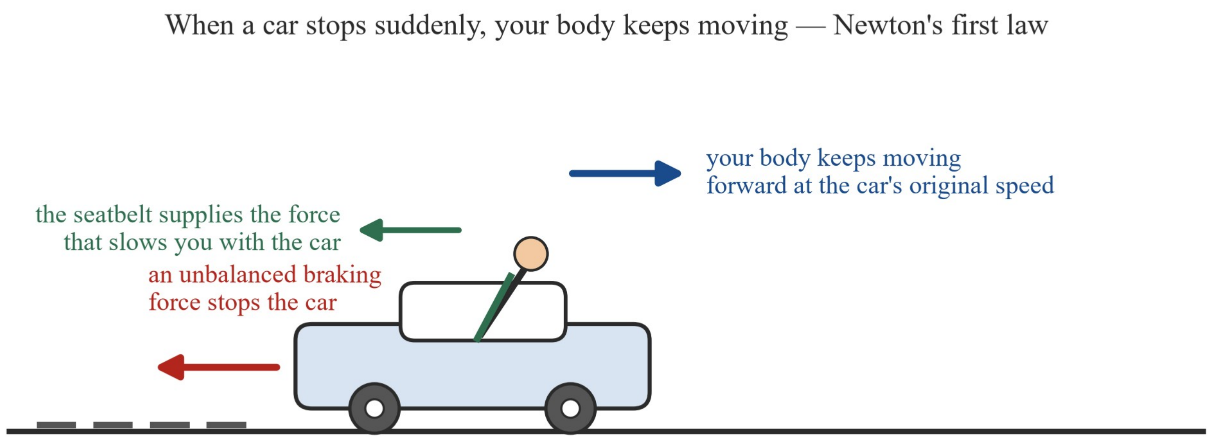
A book resting on a table with two force arrows of equal length drawn from its centre: a blue arrow up for the push of the table and a red arrow down for gravity. The two forces are equal in size and opposite in direction, so they are balanced, the net force is zero and the book stays at rest.

Newton’s first law. Newton’s first law of motion states:

> An object stays at rest, or keeps moving in a straight line at a steady speed, unless an unbalanced force acts on it.

This law is sometimes called the law of **inertia**. Inertia is the tendency of an object to resist any change to its motion: an object at rest “wants” to stay at rest, and a moving object “wants” to keep moving the way it already is. The more mass an object has, the more inertia it has — a truck is much harder to start moving, and much harder to stop, than a bicycle.

The first law also explains what happens when a car stops suddenly. Your body keeps moving forward at the car’s original speed until an unbalanced force — a seatbelt, in a well-designed car — slows you down with the car. More about this below.



Side view of a car that has stopped suddenly, with skid marks behind it and a red arrow backward for the unbalanced braking force. The person inside leans forward, a blue arrow shows their body keeps moving forward at the car's original speed, and a green arrow shows the seatbelt supplies the force that slows them with the car.

Newton's second law. Newton's second law connects the net force on an object to the object's mass and its acceleration:

$$F = ma$$

where F is the net force in newtons (N), m is the mass in kilograms (kg) and a is the acceleration in metres per second per second (m/s^2).

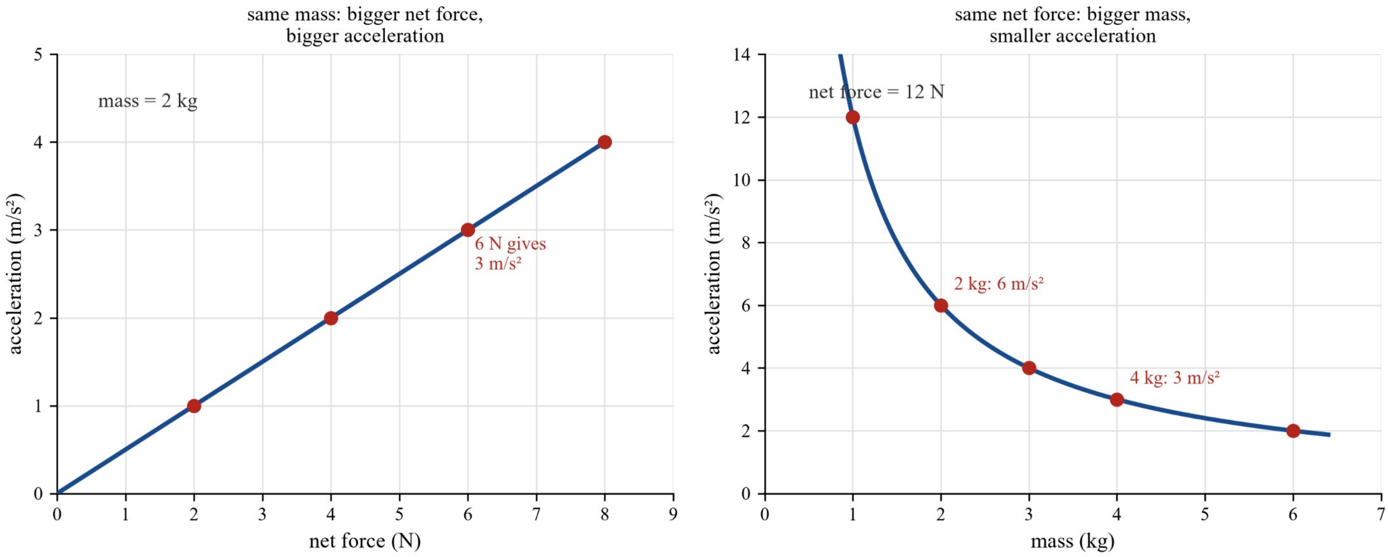
Acceleration means how quickly an object's velocity changes. Velocity is an object's speed together with the direction it is moving in. An object accelerates when it speeds up, slows down or changes direction. In this subtopic we work with motion along a straight line, so direction is simply "forward" or "backward". Acceleration is calculated as

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

where u is the starting velocity, v is the final velocity and t is the time taken for the change. An acceleration of 2 m/s^2 means the velocity grows by 2 m/s every second. Slowing down is an acceleration in the opposite direction to the motion — a **negative** acceleration, written with a minus sign (for example, −3 m/s^2).

The second law says two things about how the size of the acceleration is set:

- **Bigger net force, bigger acceleration.** Push a shopping trolley harder and it speeds up faster. Double the net force and the acceleration doubles.
- **Bigger mass, smaller acceleration.** For the same net force, an object with twice the mass accelerates only half as much. A loaded trolley is harder to get moving than an empty one.

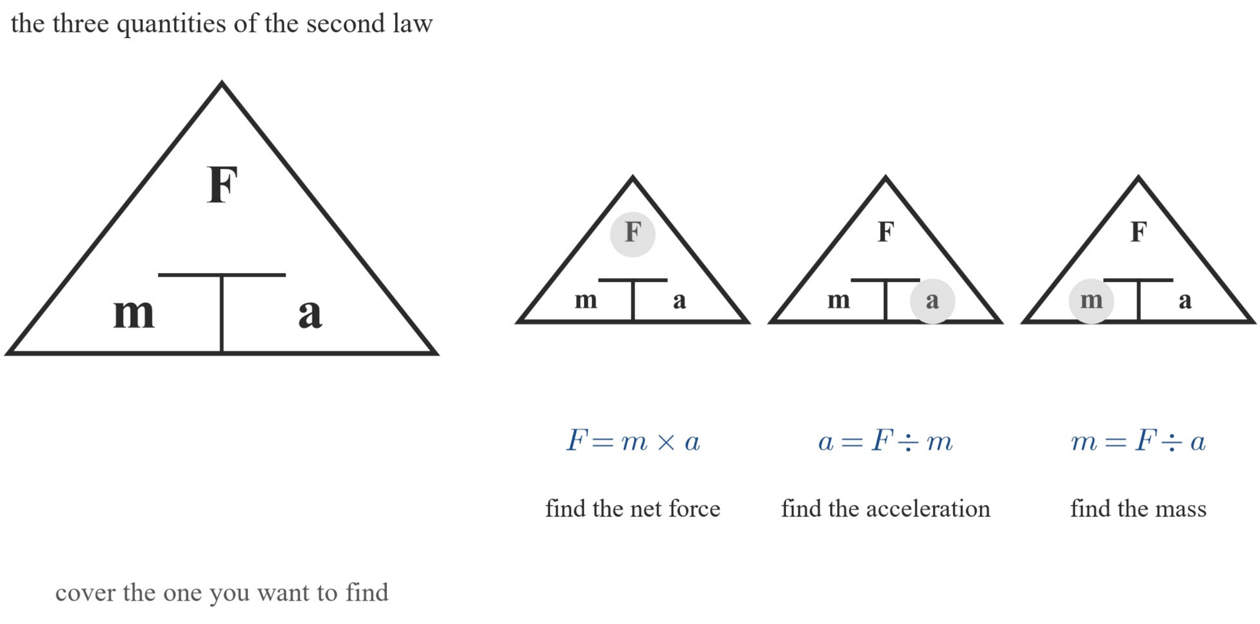


Two graphs of the second law. Left: for a fixed mass of 2 kg, acceleration against net force is a straight line through the origin, so a bigger net force gives a bigger acceleration. Right: for a fixed net force of 12 N, acceleration against mass is a falling curve, so a bigger mass gives a smaller acceleration; 2 kg gives 6 m/s² and 4 kg gives 3 m/s².

The units fit together too: a net force of 1 N is exactly the force needed to give a mass of 1 kg an acceleration of 1 m/s², so 1 N = 1 kg × 1 m/s².

This is where the Maths interlock `VC2M10A05` does its work: $F = ma$ can be rearranged to find any one of the three quantities when the other two are known:

$$a = \frac{F}{m} \quad m = \frac{F}{a}$$

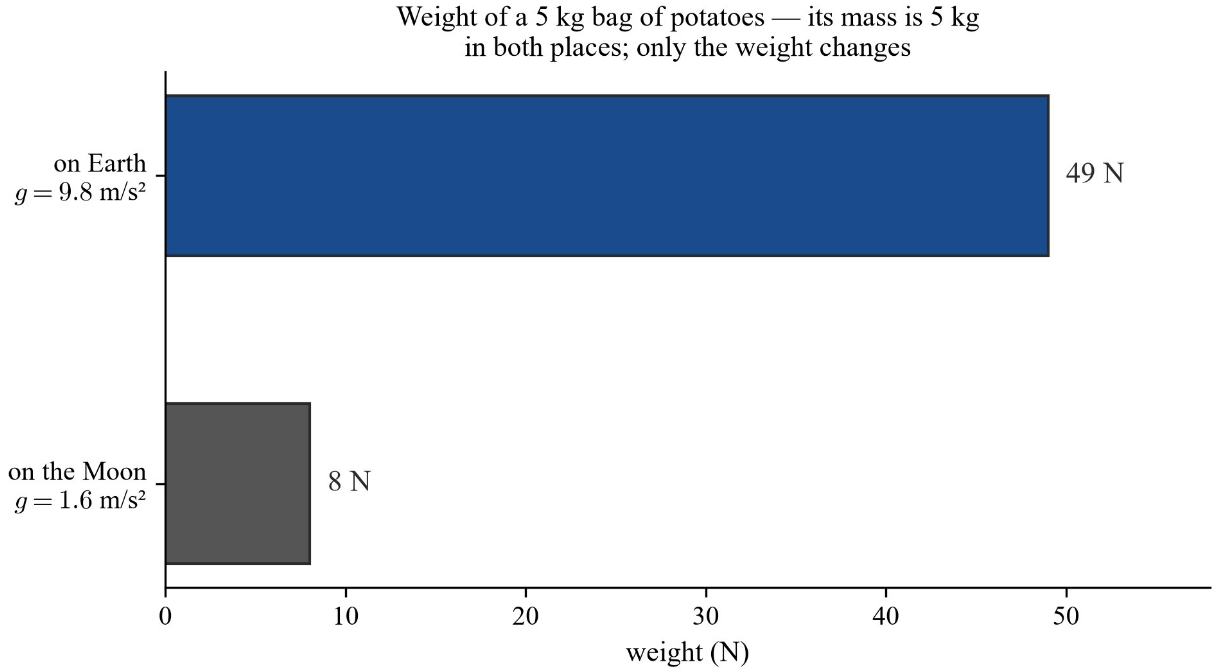


The F = ma formula triangle with F on top and m and a underneath, beside three smaller triangles showing the cover rule: cover F to get F = m times a, cover a to get a = F divided by m, and cover m to get m = F divided by a.

Mass and weight. Mass and weight are related but they are not the same thing. **Mass** is the amount of matter in an object, measured in kilograms. It is the same everywhere: a 5 kg bag of potatoes has a mass of 5 kg on Earth, on the Moon and in deep space. **Weight** is the force of gravity on an object, measured in newtons. Weight depends on where the object is, because the strength of gravity differs from place to place. Near Earth's surface gravity gives objects an acceleration of about 9.8 m/s², so the weight of an object of mass m is

$$W = mg \left(g = 9.8\,\text{m/s}^2 \text{ near Earth's surface} \right)$$

A 5 kg bag of potatoes weighs 5 × 9.8 = 49 N on Earth, but only about 5 × 1.6 = 8 N on the Moon, where gravity is much weaker. Its mass is 5 kg in both places. When an object falls and air resistance is small enough to ignore, gravity is the only force acting, and the object accelerates downward at 9.8 m/s² whatever its mass.

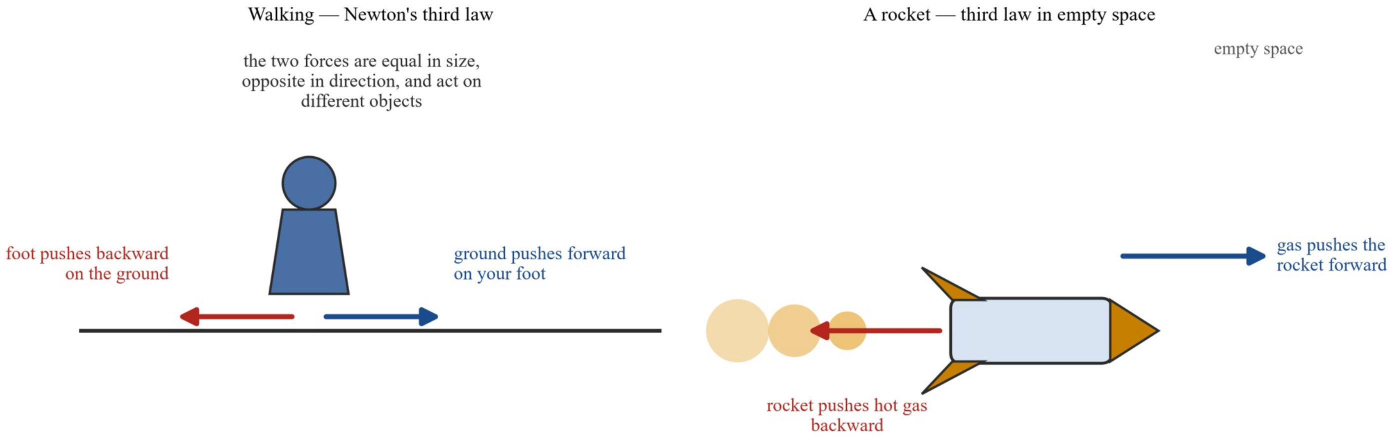


Bar chart of the weight of a 5 kg bag of potatoes: 49 N on Earth where g = 9.8 m/s² and 8 N on the Moon where g = 1.6 m/s². Its mass is 5 kg in both places; only the weight changes.

Newton's third law. Newton's third law of motion states:

> Whenever one object exerts a force on a second object, the second object exerts an equal force back on the first object, in the opposite direction.

Forces always come in pairs. When you walk, your foot pushes backward on the ground and the ground pushes forward on your foot — that forward force is what moves you ahead. A swimmer pushes water backward with their hands and feet, and the water pushes the swimmer forward. A rocket engine pushes hot gas out backward at high speed, and the gas pushes the rocket forward. The rocket does not need air to push against: the force pair is between the rocket and its own gas, so it works in empty space.

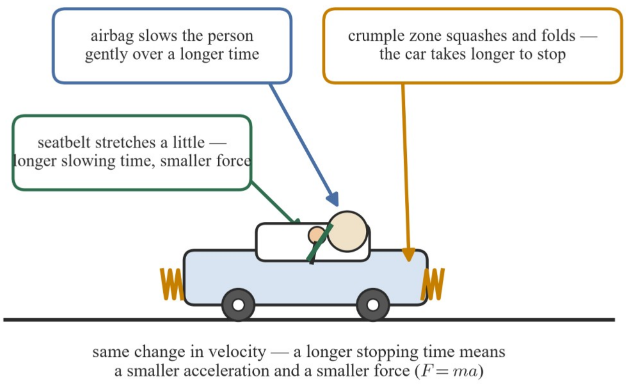


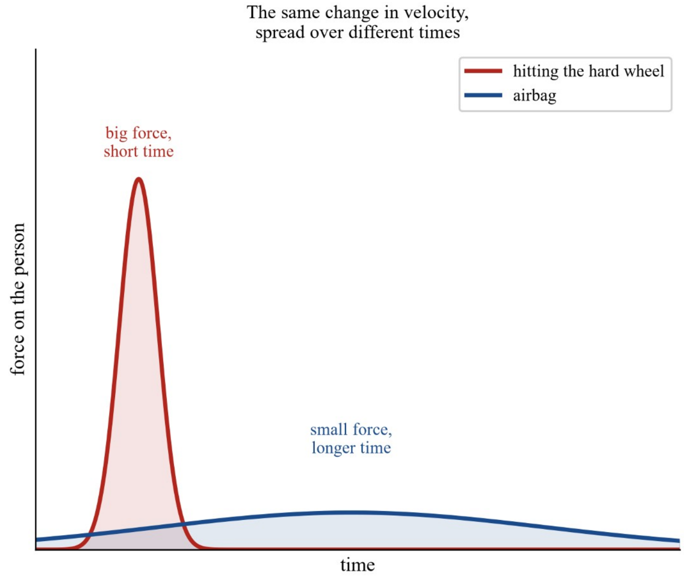
Two examples of Newton's third law. Left: a person walking; a red arrow backward shows the foot pushing backward on the ground and an equal blue arrow forward shows the ground pushing forward on the foot. Right: a rocket in empty space; a red arrow backward shows the rocket pushing hot gas backward and a blue arrow forward shows the gas pushing the rocket forward. The two forces of each pair are equal in size, opposite in direction and act on different objects.

One detail matters: the two forces of a third-law pair act on **different objects**, so they do not cancel each other out. The forward force of the ground acts on your foot, and the backward force of your foot acts on the ground. Each force affects the motion of the object it acts on.

Putting the laws to work — vehicle safety. Car safety features are built directly on Newton's laws (elaboration `VC2S10U17.E03`). When a car crashes, the car stops very suddenly, but the people inside keep moving forward at the car's original speed — first law. Something must slow them down, and the second law says the force needed depends on how quickly their velocity changes: $F = ma$. For the same change in velocity, slowing down over a **longer** time means a **smaller** acceleration and therefore a **smaller** force on the body.

- A **seatbelt** stretches a little and slows the person over a longer time than a hard impact with the steering wheel or windscreen would, so the force on the chest is smaller. It also keeps the person inside the car.
- An **airbag** inflates in front of the person and slows them down gently over a longer time, and spreads the force over a larger area of the body instead of one hard point.
- A **crumple zone** at the front and rear of the car is designed to squash and fold during a crash. The squashing takes time, so the car itself takes longer to stop. The acceleration of the car — and of the people slowed with it — is smaller, and so is the force on them.





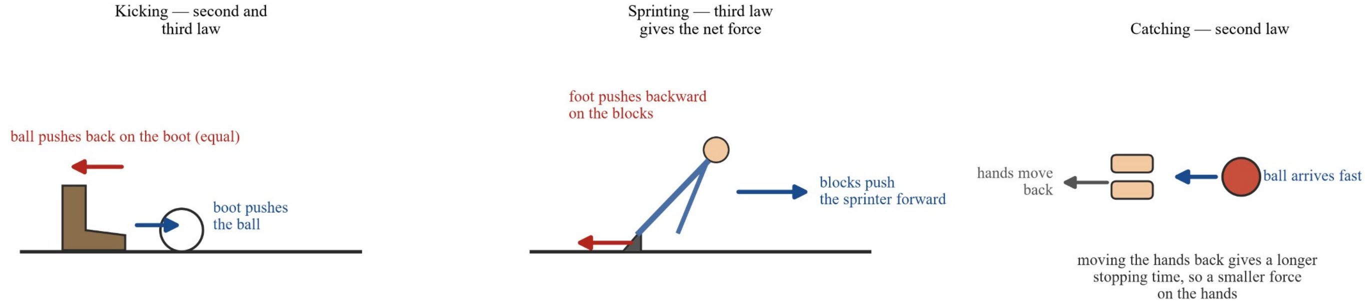
Left: side view of a car with labels for three safety features — a crumple zone that squashes and folds so the car takes longer to stop, an airbag that slows the person gently over a longer time, and a seatbelt that stretches a little for a longer slowing time and a smaller force. Right: two force–time curves for the same change in velocity; hitting the hard steering wheel gives a big force over a short time, and the airbag gives a small force over a longer time.

The same reasoning runs through everyday rules: it is safer to fall onto a soft mat than onto concrete, because the mat lengthens the time over which your body stops, which lowers the acceleration and the force.

Newton's laws in sport. The laws apply just as well on the field (elaboration `VC2S10U17.E04`).

- **Kicking a football.** The boot exerts a force on the ball; the bigger the force, the bigger the ball's acceleration while the boot is in contact with it — second law. The ball also exerts an equal force back on the boot — third law.
- **Sprinting.** A sprinter in the starting blocks pushes backward hard against the blocks, and the blocks push the sprinter forward — third law. That forward force is the net force that accelerates the runner out of the blocks — second law.
- **Catching a cricket ball.** A fielder who moves their hands backward as the ball arrives lengthens the time over which the ball slows to a stop. The change in velocity is the same, so a longer time means a smaller acceleration and a smaller force on the hands — second law. Catching with stiff hands stings because the stopping time, and therefore the force, is larger the other way around.

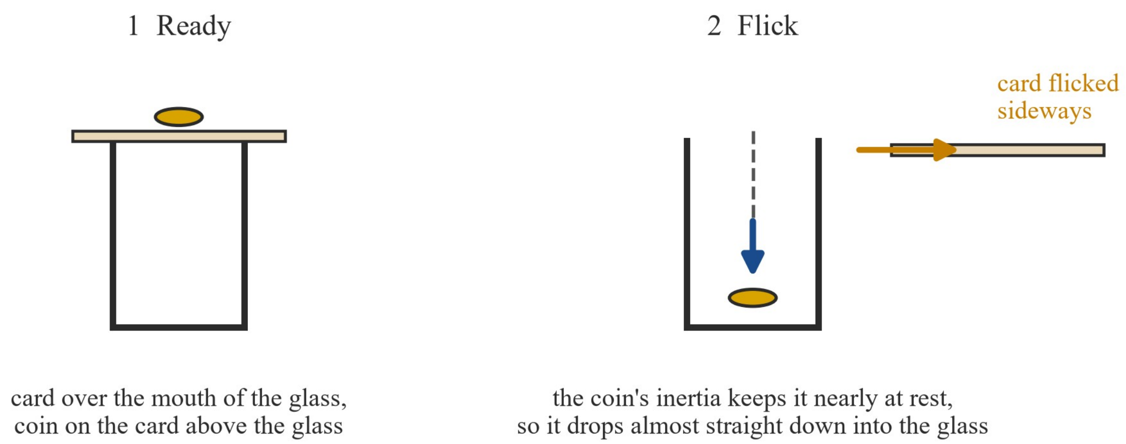
- **Helmets and padding.** A helmet's inner layer squashes in an impact, lengthening the time for the head to slow down. Smaller acceleration means a smaller force on the head — the same $F = ma$ reasoning as crumple zones and airbags.



Newton's laws in three sports. Kicking: the boot pushes the ball forward and the ball pushes back on the boot with an equal force. Sprinting: the sprinter pushes backward on the blocks and the blocks push the sprinter forward. Catching: the fielder moves their hands back with the ball, giving a longer stopping time and a smaller force on the hands.

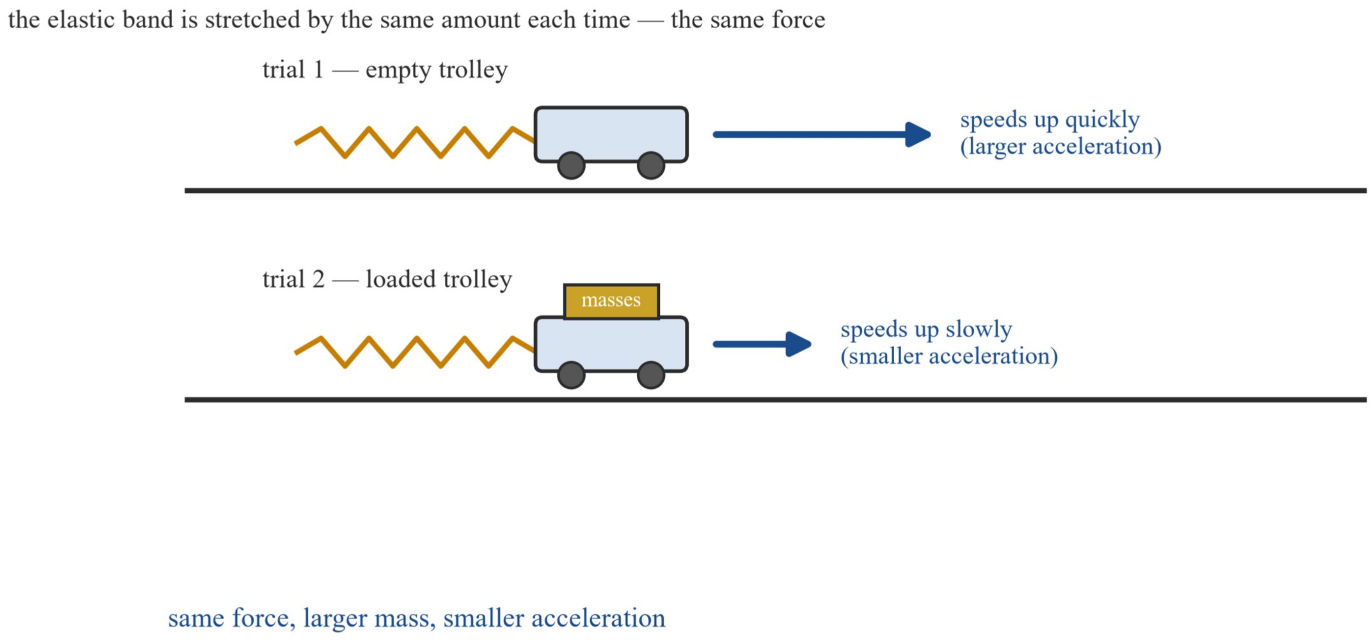
Activities

Activity 1 — Coin and card (first law). Place a playing card over the mouth of a glass and a coin on the card, directly above the glass. Flick the card sideways sharply with your finger. The card shoots away but the coin drops almost straight down into the glass: the coin's inertia keeps it nearly at rest while the card is removed from under it.



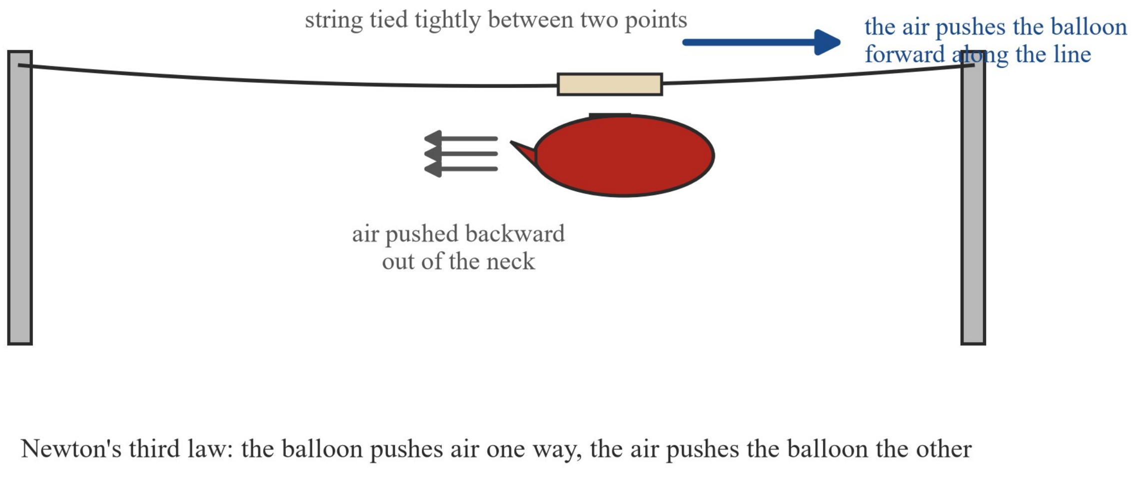
Two steps of the coin and card activity. First, a playing card lies over the mouth of a glass with a coin on the card above the glass. Second, after the card is flicked sideways, the coin drops almost straight down into the glass because its inertia keeps it nearly at rest.

Activity 2 — Same force, different mass (second law). Use an elastic band to pull an empty dynamics trolley along a smooth bench, stretching the band by the same amount each time so the force is the same. Watch how quickly the trolley speeds up. Repeat with masses added to the trolley, pulling with the same stretch of the band. The heavier trolley gains speed more slowly: same force, larger mass, smaller acceleration. (Keep feet clear of the trolley's path, and stop it before it reaches the bench edge.)



Two trials pulling a dynamics trolley with an elastic band stretched by the same amount each time, so the force is the same. The empty trolley speeds up quickly, shown by a long acceleration arrow; the trolley with added masses speeds up slowly, shown by a shorter arrow — same force, larger mass, smaller acceleration.

Activity 3 — Balloon rocket (third law). Thread a length of fishing line or smooth string through a drinking straw and tie the line tightly between two points across the room. Inflate a balloon, pinch the neck closed (do not tie it), tape the balloon to the straw, and let the neck go. The balloon pushes air out one way and the air pushes the balloon — with the straw riding the line — the other way.



A balloon rocket: a drinking straw threaded on a string tied tightly between two posts, with a balloon taped to the straw. Air pushed backward out of the neck pushes the balloon forward along the line — Newton's third law.

Worked examples

All data in this section are given to two significant figures, so final answers are also given to two significant figures unless the arithmetic is exact.

Example 1 — scaffolded

A small car of mass 1 200 kg accelerates at 2.5 m/s² along a straight, level road. Calculate the net force acting on the car.

Working	Comment
m = 1 200 kg, a = 2.5 m/s²	List the known quantities.
$F = ma$	Newton's second law connects net force, mass and acceleration.
F = 1 200 × 2.5 = 3 000 N	Substitute and multiply.

The net force on the car is 3 000 N, in the direction of the acceleration. Notice this is the **net** force — the push of the engine forward minus friction and air resistance backward — not the engine's push alone.

Example 2 — scaffolded

A cyclist and bicycle with a combined mass of 80 kg are moving along a level path. The cyclist's pedalling produces a forward driving force of 120 N, while friction and air resistance together exert 40 N backward. (a) Calculate the net force on the cyclist and bicycle. (b) Calculate their acceleration.

Working	Comment
Forward force = 120 N, backward force = 40 N, m = 80 kg	List the known quantities.
(a) Net force = 120 − 40 = 80 N forward	The two forces act in opposite directions, so subtract.
(b) $F = ma$, so $a = F/m$	Rearrange the second law for acceleration.
a = 80 ÷ 80 = 1.0 m/s²	The velocity grows by 1.0 m/s each second.

Example 3 — unscaffolded

A lunar rover has a mass of 900 kg. Calculate its weight on Earth, where g = 9.8 m/s², and on the Moon, where g = 1.6 m/s², and state its mass in each place.

Weight is the force of gravity on an object, $W = mg$. On Earth:

$$W = 900 \times 9.8 = 8\,820\,\text{N} \approx 8\,800\,\text{N (to two significant figures).}$$

On the Moon:

$$W = 900 \times 1.6 = 1\,440\,\text{N} \approx 1\,400\,\text{N (to two significant figures).}$$

Mass is the amount of matter in an object and does not depend on location, so the rover's mass is 900 kg on Earth **and** 900 kg on the Moon. Only its weight changes, because the Moon's gravity is weaker.

Example 4 — unscaffolded

A car of mass 900 kg is travelling at 15 m/s in a straight line. The driver brakes and the car comes to rest in 5.0 s. Calculate the car's acceleration and the net braking force.

First find the acceleration from the change in velocity:

$$a = \frac{v - u}{t} = \frac{0 - 15}{5.0} = -3.0\,\text{m/s}^2.$$

The acceleration is negative because it acts opposite to the car's motion — the car is slowing down. Now use the second law:

$$F = m\,a = 900 \times 3.0 = 2\,700\,\text{N}.$$

The net braking force is 2 700 N, acting opposite to the car's motion.

Practice questions

Scaffolded questions

Question 1 A box on a level floor is pushed with a force of 35 N to the right. Friction between the box and the floor exerts 12 N to the left. (a) Calculate the net force on the box. (b) State whether the forces on the box are balanced or unbalanced. (c) Describe the effect of the net force on the box's motion.

Question 2 A passenger's bag is sitting on the seat of a car travelling in a straight line at a steady speed. (a) State Newton's first law of motion. (b) The driver brakes hard. Explain, using the first law, why the bag slides forward on the seat. (c) Explain how wearing a seatbelt protects a person in this situation, in terms of forces and motion.

Question 3 A go-kart of mass 600 kg accelerates at 1.5 m/s^2 on a straight track. (a) Calculate the net force acting on the go-kart. (b) The engine is adjusted so that the net force doubles while the mass stays the same. State the new acceleration and explain your reasoning. (c) A different go-kart has a net force of 750 N and an acceleration of 2.5 m/s^2. Calculate its mass.

Question 4 A school bag has a mass of 5.0 kg. (a) Calculate the weight of the bag on Earth, where $g = 9.8$ m/s^2. (b) Explain the difference between the mass of the bag and its weight. (c) The bag is taken to Mars, where $g = 3.7$ m/s^2. Calculate its weight on Mars.

Question 5 A swimmer pushes the water backward with their hands and feet. (a) State Newton's third law of motion. (b) Identify the third-law force pair for the swimmer, and say which object each force acts on. (c) The force the swimmer exerts on the water and the force the water exerts on the swimmer are equal in size. Explain why these two forces do not cancel each other out.

Question 6 A car hits a wall and stops very suddenly. (a) Name the Newton law that explains why the driver keeps moving forward when the car stops. (b) Using $F = ma$, explain how an airbag reduces the force on the driver compared with hitting the steering wheel. (c) Explain how a crumple zone protects the people in the car, in terms of time, acceleration and force.

Unscaffolded questions

Question 7 A soccer player kicks a ball of mass 0.45 kg, giving it an acceleration of 30 m/s^2 while the boot is in contact with it. Calculate the net force on the ball during the kick.

Question 8 A trolley is pushed with a net force of 180 N and accelerates at 1.2 m/s^2. Calculate the mass of the trolley.

Question 9 A sprinter of mass 62 kg pushes backward against the starting blocks. The blocks push the sprinter forward, giving an acceleration of 4.0 m/s^2 at the start of the race. Calculate the forward net force on the sprinter.

Question 10 A car of mass 800 kg is travelling at 20 m/s in a straight line when the driver brakes to rest over 4.0 s. Calculate the car's acceleration and the net braking force, giving the direction of the force.

Question 11 A small car has a mass of 1 200 kg. Calculate its weight on Earth ($g = 9.8$ m/s^2) and on the Moon ($g = 1.6$ m/s^2), and state the car's mass in each place.

Question 12 A cyclist rides in a straight line at a steady speed. The forward driving force from pedalling is 60 N. State the total backward force of friction and air resistance, the net force on the cyclist, and the cyclist's acceleration. Explain your reasoning.

Question 13 A ball of mass 0.50 kg is dropped from rest. Air resistance is small enough to ignore. Calculate the force acting on the ball as it falls and its acceleration. State whether a 2.0 kg ball dropped the same way would have a different acceleration, and explain why.

Question 14 A rocket in empty space fires its engine, pushing hot gas backward. Explain, using Newton's third law, why the rocket accelerates forward even though there is no air or ground to push against.

Question 15 An Australian-rules footballer kicks a football of mass 0.43 kg. While the boot is in contact with the ball, the net force on the ball is 260 N. Calculate the ball's acceleration during the kick. Then explain, using Newton's laws, why "following through" — keeping the boot in contact with the ball for longer — sends the ball away faster.

Question 16 A fielder catches a cricket ball of mass 0.16 kg travelling at 25 m/s. (a) If the ball is stopped in 0.05 s by stiff hands, calculate the size of the net force needed to stop it. (b) If the fielder moves their hands back with the ball so that it stops in 0.50 s instead, calculate the new net force. (c) Use $F = ma$ to explain why moving the hands back makes the catch more comfortable.

Answers

Question 1 (a) 23 N to the right; (b) unbalanced; (c) the box accelerates to the right — it speeds up in the direction of the net force. **Question 2** (a) see solution; (b) the bag keeps moving forward at the car's original speed (first law) while the seat slows under it; (c) the seatbelt supplies the unbalanced force that slows the person with the car. **Question 3** (a) 900 N; (b) 3.0 m/s²; (c) 300 kg. **Question 4** (a) 49 N; (b) see solution; (c) 18.5 N ≈ 19 N. **Question 5** (a) see solution; (b) swimmer pushes water backward; water pushes swimmer forward; (c) they act on different objects. **Question 6** (a) first law; (b) longer stopping time → smaller acceleration → smaller force; (c) see solution. **Question 7** 13.5 N ≈ 14 N. **Question 8** 150 kg. **Question 9** 248 N ≈ 250 N. **Question 10** acceleration −5.0 m/s²; net force 4 000 N, opposite to the car's motion. **Question 11** Earth: 11 760 N ≈ 12 000 N; Moon: 1 920 N ≈ 1 900 N; mass 1 200 kg in both places. **Question 12** backward force 60 N; net force 0 N; acceleration 0 m/s². **Question 13** force 4.9 N (its weight); acceleration 9.8 m/s²; the 2.0 kg ball has the same acceleration. **Question 14** The gas pushed backward pushes the rocket forward with an equal force; the pair acts on two different objects. **Question 15** about 600 m/s²; see solution for the follow-through explanation. **Question 16** (a) 80 N; (b) 8.0 N; (c) see solution.

Fully-worked solutions

Question 1 Push = 35 N right, friction = 12 N left. (a) The forces act in opposite directions, so net force = 35 − 12 = 23 N to the right. (b) The net force is not zero, so the forces are **unbalanced**. (c) By Newton's second law, an unbalanced net force causes an acceleration. The box speeds up in the direction of the net force — to the right.

Question 2 (a) Newton's first law: an object stays at rest, or keeps moving in a straight line at a steady speed, unless an unbalanced force acts on it. (b) The bag and the car are both moving forward at the same steady speed. When the driver brakes, a force slows the car — but no comparable force acts on the bag straight away. By the first law the bag keeps moving forward at its original speed, so it slides forward on the seat while the car slows beneath it. (c) The seatbelt exerts an unbalanced backward force on the person, slowing them down together with the car instead of letting them keep moving forward into the steering wheel, dashboard or windscreen. The belt also stretches slightly, which spreads the slowing over a longer time; by $F = ma$ a longer slowing time means a smaller acceleration and a smaller force on the person's body.

Question 3 m = 600 kg, a = 1.5 m/s². (a) $F = ma$ = 600 × 1.5 = 900 N. (b) Acceleration is proportional to net force ($a = F/m$). Doubling the net force with the same mass doubles the acceleration: new acceleration = 2 × 1.5 = 3.0 m/s². (c) Rearrange $F = ma$ to $m = F/a$: m = 750 ÷ 2.5 = 300 kg.

Question 4 m = 5.0 kg. (a) $W = mg$ = 5.0 × 9.8 = 49 N. (b) **Mass** is the amount of matter in the bag and is measured in kilograms; it is the same everywhere. **Weight** is the force of gravity on the bag and is measured in newtons; it depends on the strength of gravity where the bag is. (c) On Mars: $W = mg$ = 5.0 × 3.7 = 18.5 N ≈ 19 N (to two significant figures).

Question 5 (a) Newton's third law: whenever one object exerts a force on a second object, the second object exerts an equal force back on the first, in the opposite direction. (b) The swimmer exerts a backward force **on the water**; the water exerts an equal forward force **on the swimmer**. (c) The two forces act on **different objects** — one on the water, one on the swimmer. Forces only cancel when they act on the same object. The forward force on the swimmer is what accelerates them through the water.

Question 6 (a) Newton's **first law**: the driver keeps moving forward at the car's original speed until an unbalanced force acts on them. (b) The driver must go from the car's speed to rest either way — the change in velocity is fixed. An airbag lengthens the **time** over which that change happens. By $a = (v - u)/t$, a longer time means a smaller acceleration, and by $F = ma$ a smaller acceleration means a smaller net force on the driver. Hitting the hard steering wheel stops the driver in a much shorter time, giving a larger acceleration and a larger force. (c) The crumple zone is designed to squash and fold in the crash, so the car takes a longer time to come to rest. A longer stopping time means a smaller acceleration for the car and its occupants, and by $F = ma$ a smaller force acts on them.

Question 7 m = 0.45 kg, a = 30 m/s². $F = ma$ = 0.45 × 30 = 13.5 N ≈ 14 N (to two significant figures).

Question 8 F = 180 N, a = 1.2 m/s². Rearrange $F = ma$ to $m = F/a$: m = 180 ÷ 1.2 = 150 kg.

Question 9 m = 62 kg, a = 4.0 m/s². The forward force of the blocks on the sprinter is the net force: $F = ma = 62 \times 4.0 = 248$ N ≈ 250 N (to two significant figures). By the third law the sprinter pushes back on the blocks with an equal force, but that force acts on the blocks, not on the sprinter.

Question 10 m = 800 kg, u = 20 m/s, v = 0 m/s, t = 4.0 s. Acceleration: $a = (v - u)/t = (0 - 20) \div 4.0 = -5.0$ m/s². The negative sign means the acceleration is opposite to the car's motion (the car is slowing). Net force: $F = ma = 800 \times 5.0 = 4\ 000$ N. The net braking force is **4 000 N, acting opposite to the car's motion**.

Question 11 m = 1 200 kg. Earth: $W = mg = 1\ 200 \times 9.8 = 11\ 760$ N ≈ 12 000 N (to two significant figures). Moon: $W = mg = 1\ 200 \times 1.6 = 1\ 920$ N ≈ 1 900 N (to two significant figures). Mass does not depend on location: the car's mass is **1 200 kg on Earth and 1 200 kg on the Moon**. Only the weight changes, because gravity is weaker on the Moon.

Question 12 Steady speed in a straight line means the motion is not changing, so by the first law the forces must be balanced: the net force is zero. Therefore the total backward force of friction and air resistance equals the forward driving force: **60 N backward**. Net force = 60 − 60 = **0 N**, and with zero net force the acceleration is **0 m/s²**.

Question 13 m = 0.50 kg. With air resistance ignored, the only force on the falling ball is its weight: $F = mg = 0.50 \times 9.8 = 4.9$ N, acting downward. Its acceleration is $a = F/m = 4.9 \div 0.50 =$ **9.8 m/s²** downward. A 2.0 kg ball dropped the same way has **the same acceleration**, 9.8 m/s². The heavier ball has a larger weight ($F = mg$), but it also has a larger mass, and in $a = F/m$ the mass cancels: $a = mg/m = g$. Near Earth's surface all objects fall with the same acceleration when air resistance is ignored.

Question 14 By Newton's third law, the rocket exerts a backward force on the hot gas, and the gas exerts an equal forward force on the rocket. These are the two halves of one force pair, acting on two different objects: the gas and the rocket. The forward force on the rocket is unbalanced, so by the second law the rocket accelerates forward. The interaction is between the rocket and its own gas — nothing outside is needed — so the rocket works in empty space, where there is no air or ground to push against.

Question 15 m = 0.43 kg, F = 260 N. $a = F/m = 260 \div 0.43 = 604.65\ldots$ m/s² ≈ 600 m/s² (to two significant figures). While the boot touches the ball, the force gives the ball an acceleration (second law). Acceleration is the rate of change of velocity, so the longer the force acts, the more the ball's velocity changes. Following through keeps the boot in contact with the ball for a longer time, so the ball's velocity grows by more and the ball leaves the boot moving faster.

Question 16 m = 0.16 kg, u = 25 m/s, v = 0 m/s. (a) Stopped in t = 0.05 s: $a = (0 - 25) \div 0.05 = -500$ m/s². The size of the net force is $F = ma = 0.16 \times 500 =$ **80 N**. (b) Stopped in t = 0.50 s: $a = (0 - 25) \div 0.50 = -50$ m/s². The net force is $F = ma = 0.16 \times 50 =$ **8.0 N**. (c) The ball's change in velocity — from 25 m/s to rest — is the same either way. Moving the hands back spreads that change over ten times the time, so the acceleration is ten times smaller, and by $F = ma$ the force on the hands is ten times smaller too. The smaller force makes the catch comfortable instead of stinging.

Where this leads: this subtopic is revisited at higher precision in VCE Physics Unit 2, Area of Study 1 ("How is motion understood?"), reference-only for this book; two-dimensional motion and momentum are VCE-only and are not taught here (TOC D9). Motion graphs and distance–time–speed calculations belong to the partner subtopic 15C.

Analysing motion quantitatively: distance, time, speed and acceleration — graphs, formulas and vehicle-safety applications

Chapter 15 — Physical sciences B: electricity generation, forces and motion (Science, Levels 9 and 10)

Subtopic 15C · VC2 Science Understanding — Physical sciences

CD code: `VC2S10U17` (split delivery †; this subtopic is the partner — the owner is 15B) **Content description (verbatim):** "Newton's laws of motion can be used to quantitatively analyse the relationship between force, mass and acceleration of objects" **This subtopic's limb (TOC §4 clause split):** quantitative motion analysis and applications. Partner `15B` (the owner) delivers Newton's laws and force–mass–acceleration. **Elaboration ids drawn on:** `VC2S10U17.E01` · `VC2S10U17.E05` · `VC2S10U17.E06` (`VC2S10U17.E02` is withheld under the TOC's D10 ICIP decision and is not taught here.) **Achievement standard (extract served):** "They use Newton's laws to describe and predict the motion of objects in a system." **Maths interlock (D11):** `VC2M9A03/VC2M9A04` — linear graphs and gradient: the gradient operation learnt in Maths is the same operation used on motion graphs here; `VC2M10A05` (substituting into and rearranging formulas) and `VC2M10ST02` (line of good fit) are re-used from 15B.

Theory

Distance, time and speed. When something moves, three quantities describe its motion. **Distance** is how much ground the object covers, measured in metres (m). **Time** is how long the motion takes, measured in seconds (s). **Speed** is how quickly distance is covered — the distance travelled per unit of time:

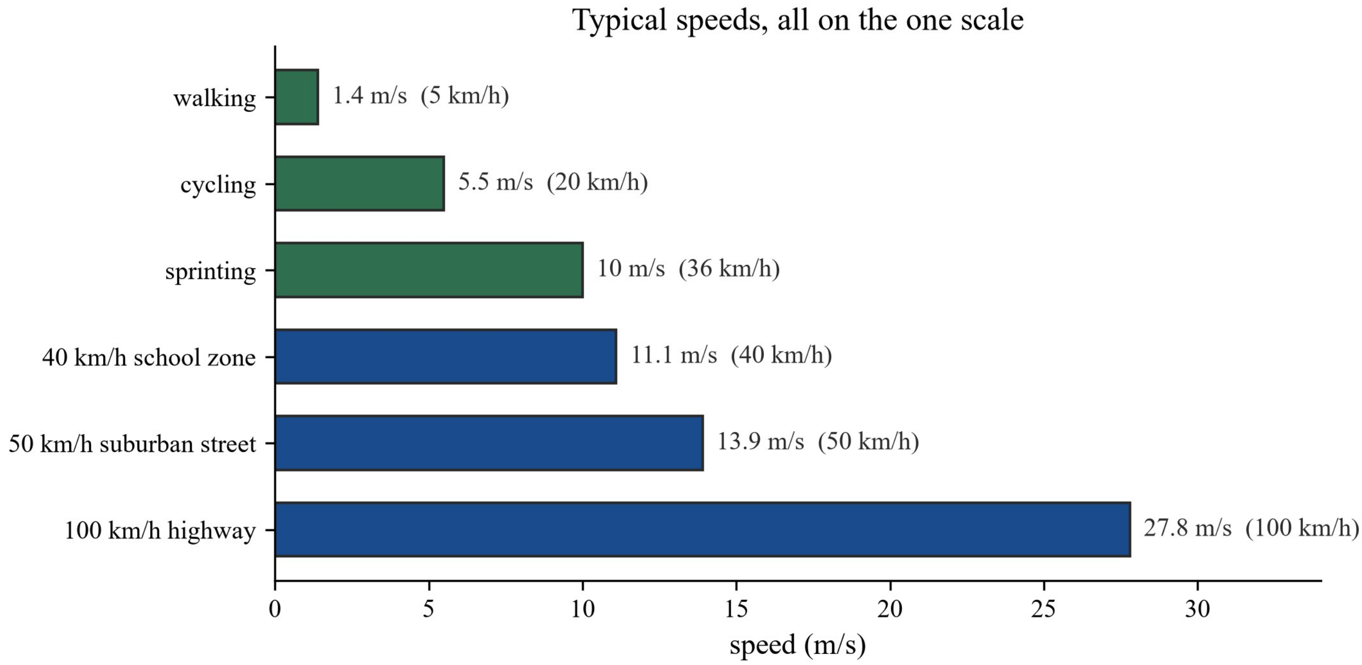
$$v = \frac{d}{t}$$

where v is the speed in metres per second (m/s), d is the distance in metres and t is the time in seconds. A sprinter who covers 100 m in 10 s has a speed of 100 ÷ 10 = 10 m/s.

Road speeds in Australia are posted in kilometres per hour (km/h), so it is useful to convert between the two units. One hour is 3 600 seconds and one kilometre is 1 000 m, so to go from km/h to m/s you divide by 3.6, and to go from m/s to km/h you multiply by 3.6:

$$50\,\text{km/h} = 50 \div 3.6 \approx 14\,\text{m/s} \quad 10\,\text{m/s} = 10 \times 3.6 = 36\,\text{km/h}$$

The figure below puts everyday speeds on one scale so they can be compared.



Horizontal bar chart on a single scale in metres per second: walking about 1.4 m/s, cycling about 5.5 m/s, sprinting about 10 m/s, a 40 km/h school zone 11.1 m/s, a 50 km/h suburban street 13.9 m/s, and a 100 km/h highway 27.8 m/s, with each bar also labelled in km/h.

Average speed. Most journeys do not happen at one steady speed — a trip to school includes stopping at lights and waiting at crossings. The **average speed** for a whole journey is the total distance divided by the total time:

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

If you travel 2 000 m in 500 s, your average speed is 4.0 m/s, even though at any particular moment you may have been moving faster, slower or not at all. The speed at one particular moment is what a speedometer shows; the average is a summary of the whole trip.

Measuring motion. Speeds in the laboratory are measured the same way they are defined: measure a distance, measure the time to cover it, and divide. The figure shows a simple setup: a trolley rolls along a straight run, markers are placed at measured distances, and a stopwatch is started as the trolley passes the 0 m marker and read as it passes each later marker.

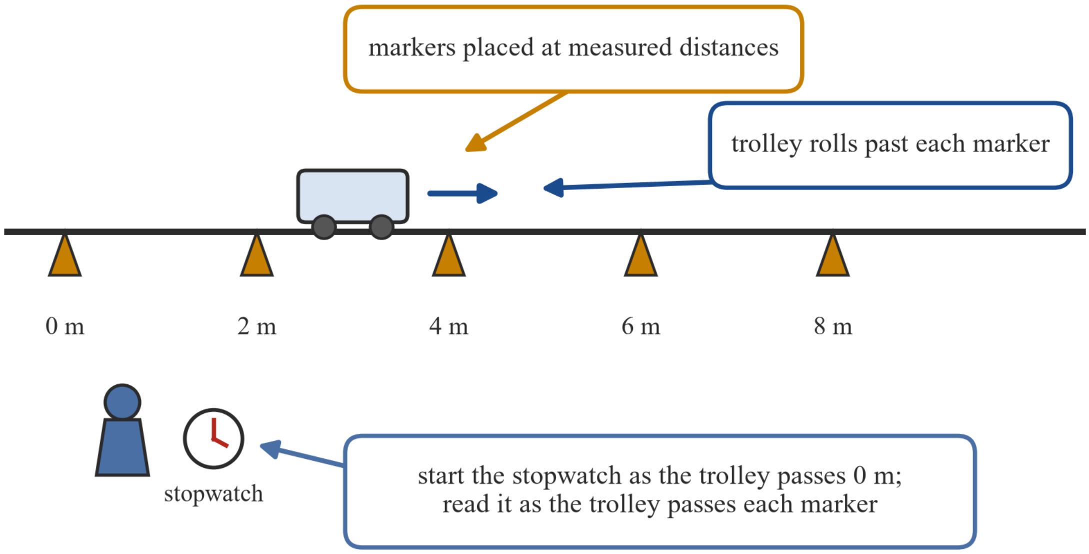
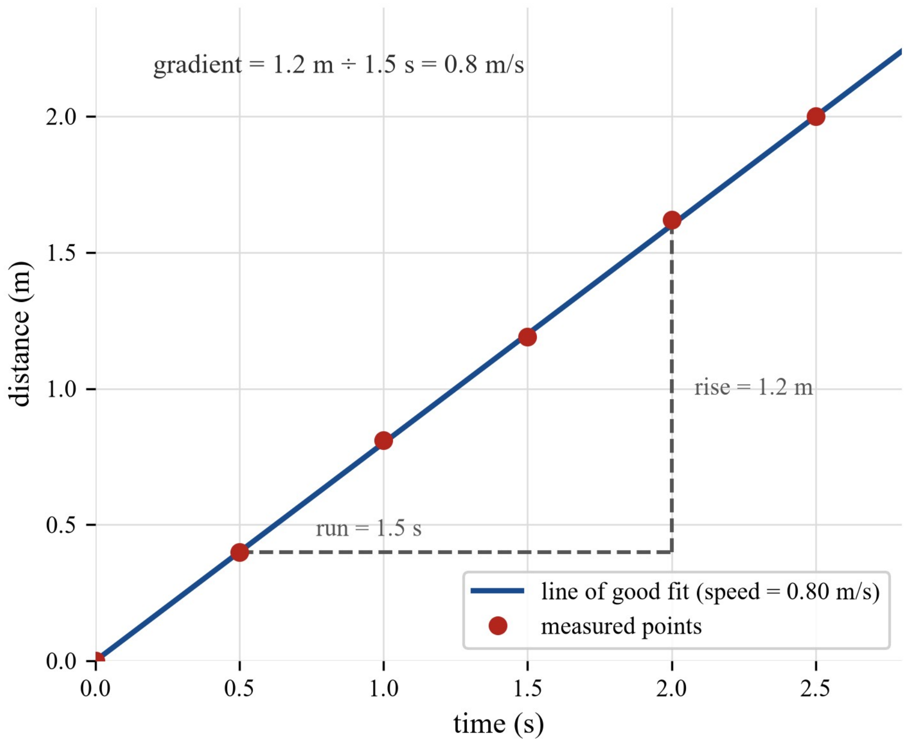


Diagram of a trolley on a straight track with markers at 0 m, 2 m, 4 m, 6 m and 8 m; a student with a stopwatch starts it as the trolley passes 0 m and reads it at each marker.

A set of readings from this setup (simulated data for practice) looks like this:

time (s)	0.0	0.5	1.0	1.5	2.0	2.5
distance (m)	0.0	0.40	0.81	1.19	1.62	2.00

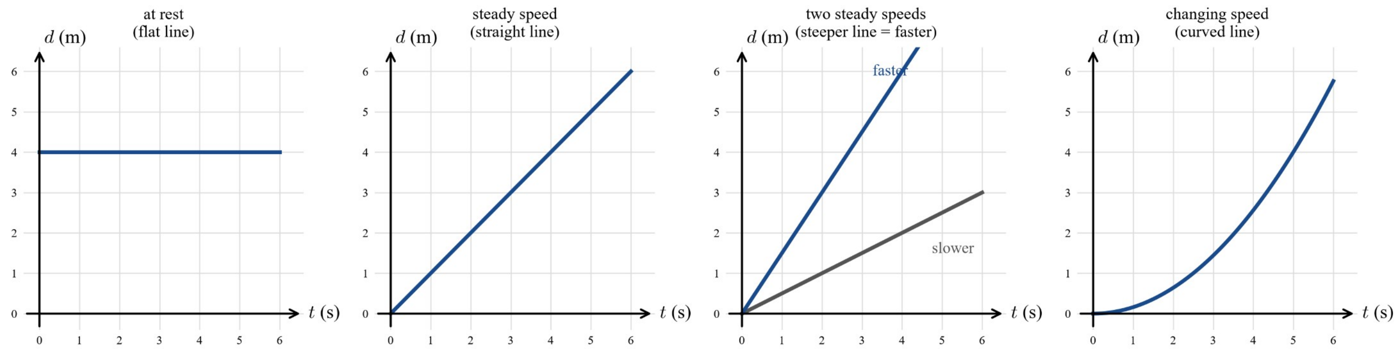
Plotting distance against time and drawing a **line of good fit** (the Maths skill `VC2M10ST02`, re-used from 15B) smooths out the small timing errors in the individual readings.



Simulated data for practice

Distance–time scatter plot of the trolley readings with a straight line of good fit through the origin; a gradient triangle between (0.5 s, 0.4 m) and (2.0 s, 1.6 m) gives gradient = 1.2 m ÷ 1.5 s = 0.8 m/s. Labelled "Simulated data for practice".

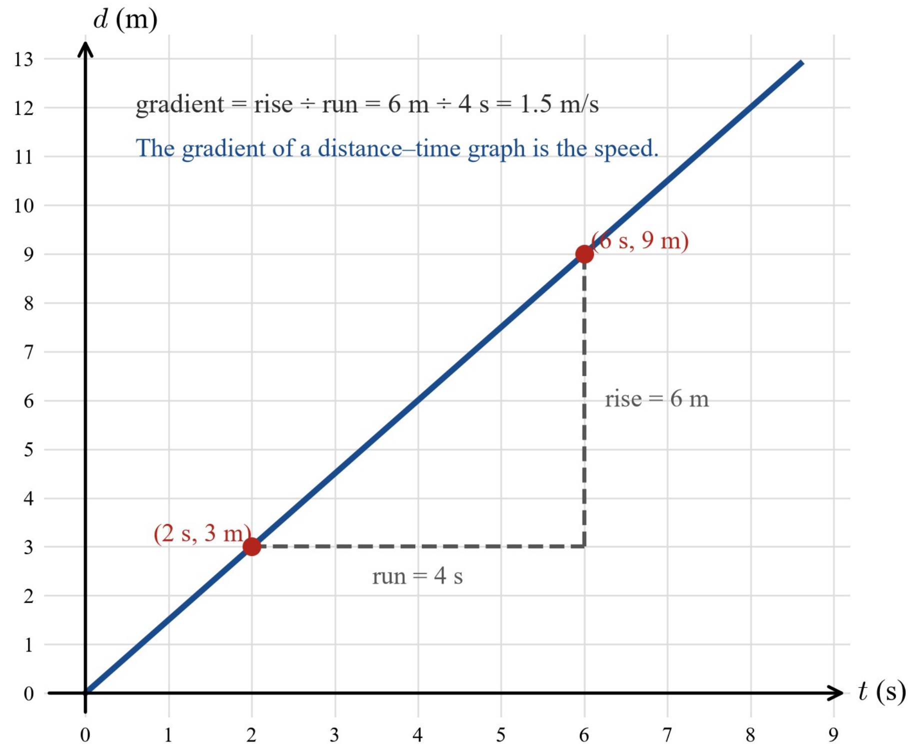
Distance–time graphs. A distance–time graph shows the whole story of a motion at a glance. The shape of the line tells you what the object is doing.



Four small distance–time graphs: a flat horizontal line labelled "at rest"; a straight climbing line labelled "steady speed"; two straight lines of different steepness labelled "two steady speeds (steeper line = faster)"; and a curved line bending upwards labelled "changing speed".

- A **flat line** means the distance is not changing: the object is at rest.
- A **straight climbing line** means a steady speed: equal distances in equal times.
- A **steeper line** means a faster speed.
- A **curved line** means a changing speed — the object is accelerating.

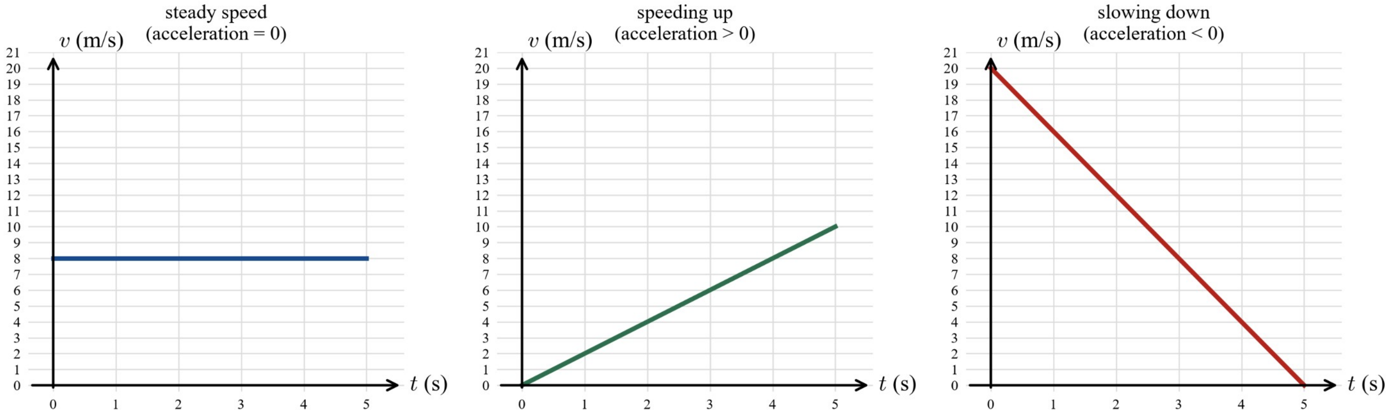
The steepness of the line is its **gradient**, and the gradient of a distance–time graph is the speed. This is exactly the gradient operation you know from Maths (`VC2M9A03`/ `VC2M9A04`) — rise ÷ run — with one new idea: on a motion graph the answer carries a unit and a meaning.



Distance–time straight line through the origin with two marked points, (2 s, 3 m) and (6 s, 9 m); a dashed gradient triangle shows rise = 6 m and run = 4 s, so gradient = 6 m ÷ 4 s = 1.5 m/s, with the caption "The gradient of a distance–time graph is the speed."

In the figure, rise = 6 m and run = 4 s, so the gradient = 6 ÷ 4 = 1.5 m/s: the object is moving at 1.5 m/s. For the trolley data above, the gradient of the line of good fit is 0.80 m/s — the trolley's speed.

Speed–time graphs. A speed–time graph tells the same kind of story one step up: the value of the line is the speed itself, so the shapes read differently.



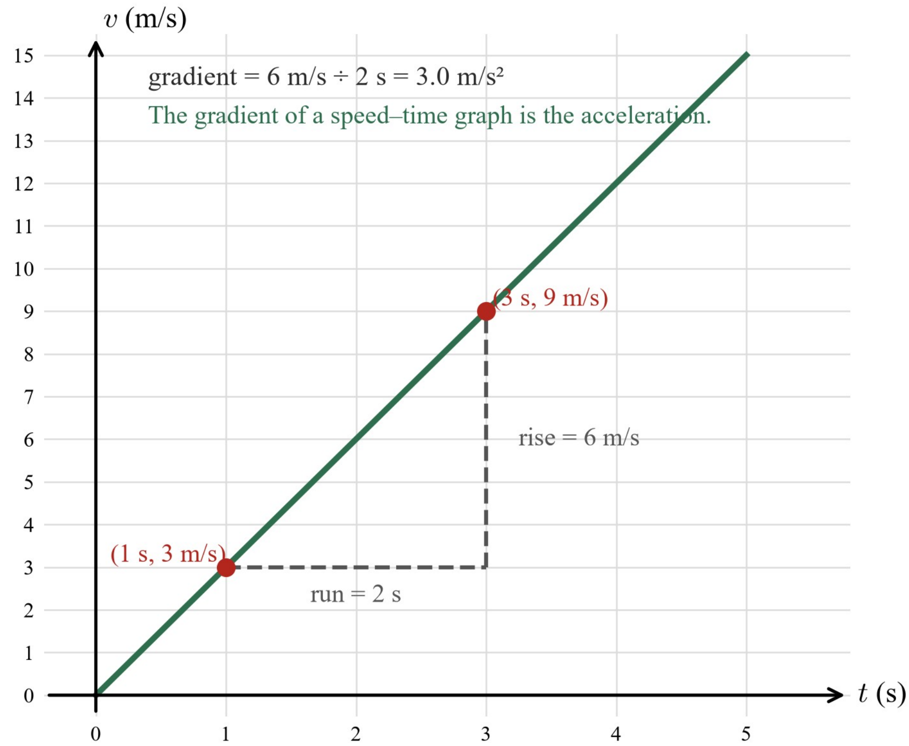
Three small speed–time graphs: a flat horizontal line at 8 m/s labelled "steady speed (acceleration = 0)"; a straight climbing line labelled "speeding up (acceleration > 0)"; and a straight falling line from 20 m/s to 0 labelled "slowing down (acceleration < 0)".

- A **flat line** means a steady speed — the acceleration is zero.
- A **climbing line** means the speed is growing — positive acceleration.
- A **falling line** means the speed is shrinking — negative acceleration. Slowing down is often called **deceleration**.

The gradient of a speed–time graph is the **acceleration**: the change in speed per second. Subtopic 15B writes this as a formula, with u the starting speed, v the final speed and t the time taken:

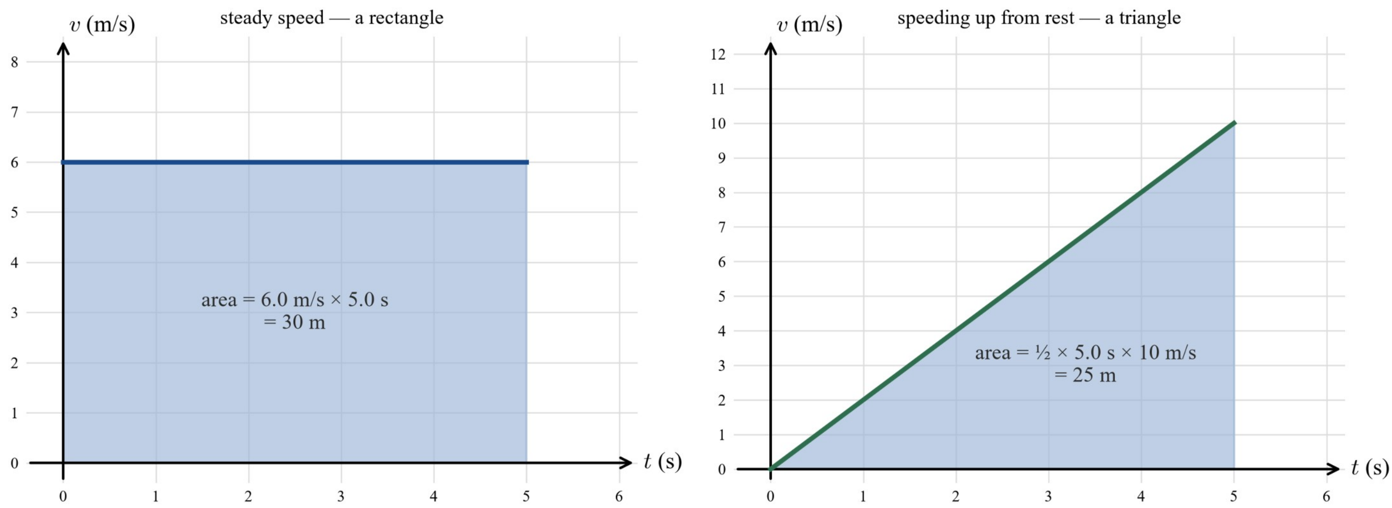
$$a = \frac{v - u}{t}$$

The graph and the formula are the same calculation. In the figure below, the gradient is (9 − 3) ÷ (3 − 1) = 6 ÷ 2 = 3.0 m/s²: the speed grows by 3.0 m/s every second.



Speed–time straight line through the origin with two marked points, (1 s, 3 m/s) and (3 s, 9 m/s); a dashed gradient triangle shows rise = 6 m/s and run = 2 s, so gradient = 3.0 m/s², with the caption "The gradient of a speed–time graph is the acceleration."

Area under a speed–time graph is distance. The second big idea on motion graphs is that the area between the line and the time axis is itself a quantity: on a speed–time graph, that area is the **distance travelled**. The units show why: m/s × s = m.



Two speed–time graphs with the area under the line shaded. Left: a flat line at 6.0 m/s for 5.0 s, a rectangle with area = 6.0 m/s × 5.0 s = 30 m. Right: a straight line climbing from rest to 10 m/s over 5.0 s, a triangle with area = ½ × 5.0 s × 10 m/s = 25 m.

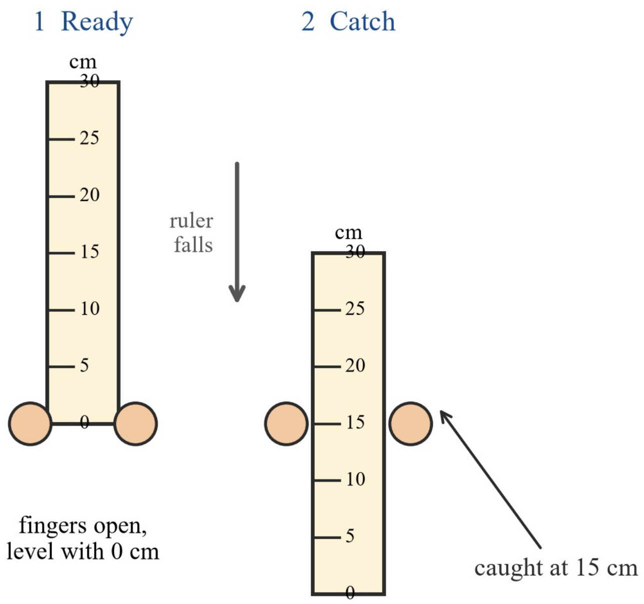
- For a **steady speed** the area is a rectangle: distance = speed × time.
- For **speeding up from rest at a steady acceleration** the area is a triangle: distance = ½ × time × final speed.
- For a line that starts above zero, the shape is a rectangle plus a triangle — or, equally, average speed × time, where the average of a steadily changing speed is ½(u + v).

So a car that slows steadily from 20 m/s to rest in 5.0 s travels ½ × (20 + 0) × 5.0 = 50 m while stopping. Graphs and formulas are two views of the same motion: the gradient gives the acceleration, and the area gives the distance.

Reaction time and thinking distance. When a driver sees a hazard, the car does not brake instantly. The driver has to see the hazard, decide to act and move a foot onto the brake pedal — and that takes time, typically about one second for an alert, sober driver. During this **reaction time** the car keeps moving at full speed, and the distance covered is the **thinking distance**. Once the brake is pressed, the car slows to rest over the **braking distance**. Together they make the **stopping distance**:

$$\text{stopping distance} = \text{thinking distance} + \text{braking distance}$$

Reaction time can be measured with a falling ruler: a partner drops the ruler and you catch it, and the distance it fell before you caught it is set by your reaction time (because a falling object accelerates at 9.8 m/s²). The table converts catch distance to reaction time.



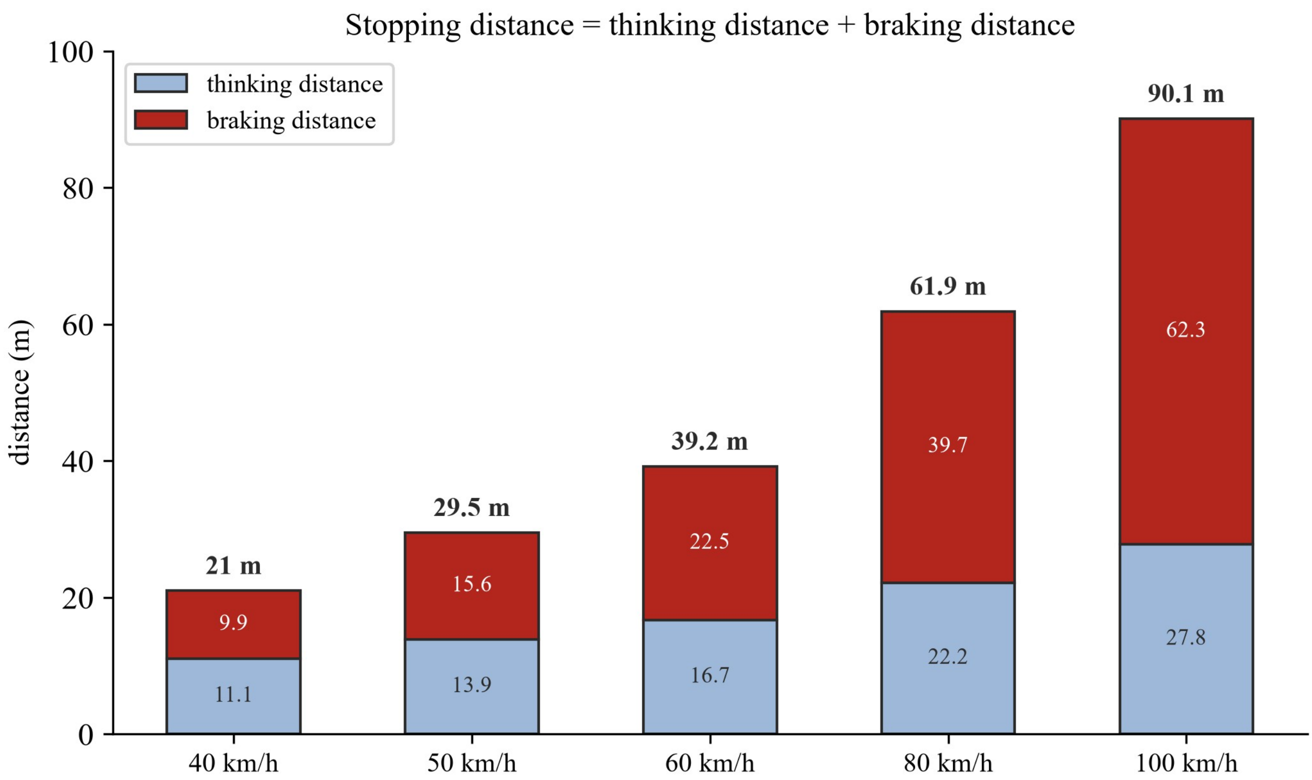
distance caught → reaction time

5 cm	0.10 s
10 cm	0.14 s
15 cm	0.17 s
20 cm	0.20 s
25 cm	0.23 s
30 cm	0.25 s

calculated from g = 9.8 m/s²

Diagram of the ruler-drop reaction-time test: a ruler held with the 0 cm mark level with the catcher's open fingers ("1 Ready"), the ruler falling, and the catcher gripping it at 15 cm ("2 Catch"); beside it a table converting distance caught to reaction time, from 5 cm = 0.10 s to 30 cm = 0.25 s, calculated from g = 9.8 m/s².

Stopping distances from a simple model. Using a reaction time of 1.0 s and a braking deceleration of 6.2 m/s² on a dry road (a typical good car on good tyres), the model gives the stopping distances in the figure below. Thinking distance is speed × reaction time, so it is **proportional** to speed: double the speed, double the thinking distance. Braking distance grows even faster — with the **square** of the speed: double the speed and the braking distance is about four times as long (9.9 m at 40 km/h, 39.7 m at 80 km/h).

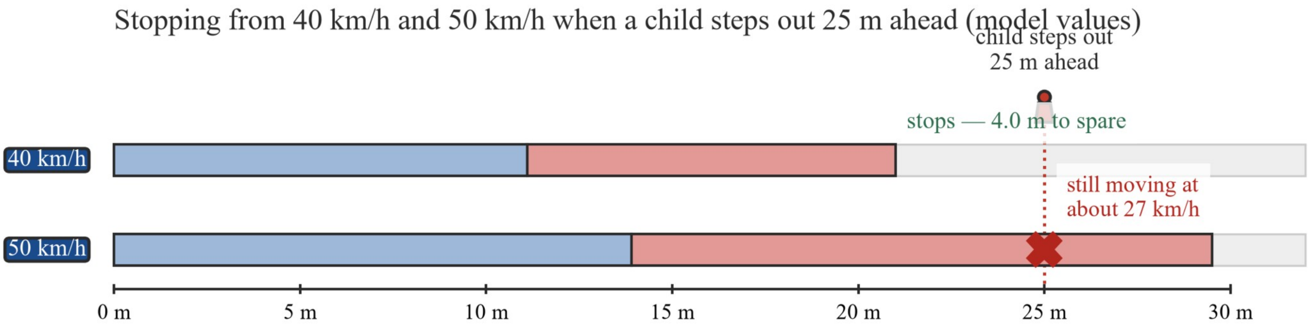


Computed from a simple model: reaction time 1.0 s, braking deceleration 6.2 m/s² (dry road).

Stacked bar chart of thinking distance (pale blue) and braking distance (red) at 40, 50, 60, 80 and 100 km/h, with totals labelled 21 m, 29.5 m, 39.2 m, 61.9 m and 90.1 m; note "Computed from a simple model: reaction time 1.0 s, braking deceleration 6.2 m/s² (dry road)".

This is why speed matters so much in crashes. The difference between 40 km/h and 100 km/h is not just "2.5 times as fast" — the stopping distance grows from about 21 m to about 90 m.

School zones — a data-backed argument (elaboration `VC2S10U17.E05`). Suppose a child steps onto the crossing 25 m ahead of a car at the moment the driver sees them. The figure shows what the model says happens at 40 km/h and at 50 km/h.

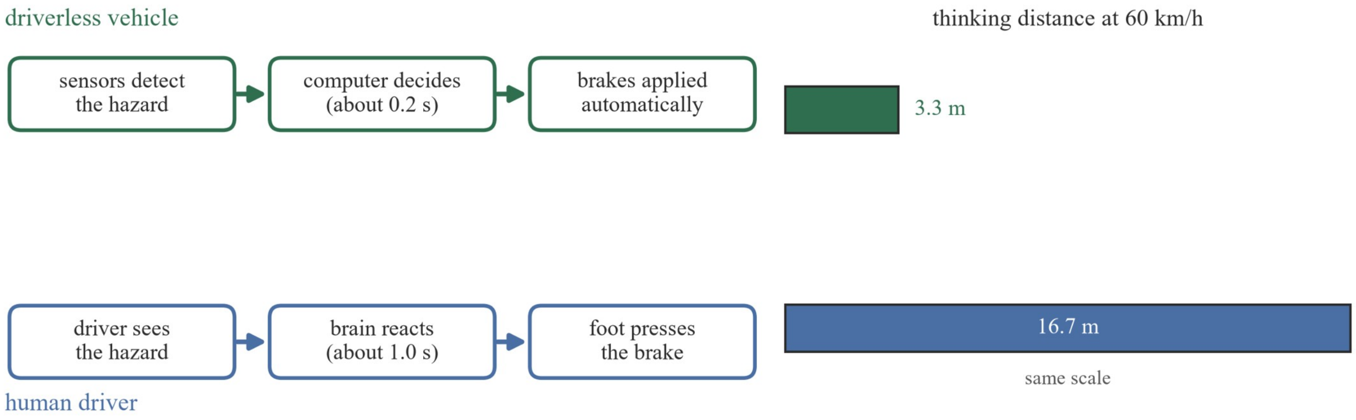


Two horizontal stopping bars drawn to the same distance scale against a child marker 25 m ahead. At 40 km/h the bar (thinking 11.1 m plus braking 9.9 m) ends at 21 m, labelled "stops — 4.0 m to spare". At 50 km/h the bar reaches the child while still braking, marked with a cross and labelled "still moving at about 27 km/h". Title: "Stopping from 40 km/h and 50 km/h when a child steps out 25 m ahead (model values)".

- At **40 km/h** (11.1 m/s) the car thinks for 11.1 m and brakes over 9.9 m, stopping in 21 m — **4.0 m short of the child**.
- At **50 km/h** (13.9 m/s) the car thinks for 13.9 m, and when it reaches the child it has braked for only 11.1 m of the 15.6 m it needs. It is **still moving at about 7.5 m/s — roughly 27 km/h — when it reaches the child**.

A 10 km/h difference in speed limit is the difference between stopping safely and striking a child at 27 km/h. The same data argue for lower limits around trucks: a loaded truck has many times the mass of a car, and the brakes can only supply a limited force, so by the second law (15B, $a = F/m$) its deceleration is smaller and its braking distance longer. Extra space and lower limits give every vehicle the distance it actually needs to stop.

Driverless vehicles brake at the right time (elaboration `VC2S10U17.E06`). A driverless car measures the same three steps a human goes through — detect, decide, brake — but runs them in a fraction of the time.



Two flow chains on a common scale. Top, "driverless vehicle": sensors detect the hazard, computer decides (about 0.2 s), brakes applied automatically — thinking distance bar of 3.3 m at 60 km/h. Bottom, "human driver": driver sees the hazard, brain reacts (about 1.0 s), foot presses the brake — thinking distance bar of 16.7 m at 60 km/h, same scale.

At 60 km/h (16.7 m/s) a human driver with a 1.0 s reaction time travels **16.7 m** before the brake is even pressed. A driverless system that detects and decides in 0.2 s travels only 16.7 × 0.2 ≈ **3.3 m** in that stage — about 13 m less, every single time, with no distraction, fatigue or phone to make the reaction slower. The brakes then do the same work, so the whole stopping distance shrinks by that thinking-distance saving. This is the quantitative case for the technology: not that the car stops "better", but that it starts stopping **sooner**.

Describing and predicting motion. Together, these tools do what the achievement standard asks: they let you *describe* motion (with graphs, speeds and accelerations) and *predict* it (with the formulas and the areas under the graphs). Given a speed and a reaction time, you can predict where a car will stop; given a speed–time graph, you can predict how far an object has gone. That is Newton's laws at work in everyday life — the same laws 15B states as $F = ma$, used here to analyse real motion quantitatively.

Activities

Activity 1 — Average speed over a marked run. Measure a straight 20 m run outside with a tape, placing markers every 5 m. In pairs, one student walks the run at their normal pace while the other times each 5 m split with a stopwatch. Calculate the average speed for the whole run (total distance ÷ total time) and for each 5 m split, and compare the splits: was the pace steady, or did the speed change? Convert the whole-run average speed to km/h and compare it with the walking bar in the reference-speeds figure.

Activity 2 — Trolley motion and a line of good fit. Using the marker-and-stopwatch setup from the theory, roll a trolley along a straight run and record the time at each marker. Plot distance against time, draw a line of good fit, and use a large gradient triangle on the line (rise ÷ run, the Maths operation) to find the trolley's speed. Repeat with a steeper ramp and compare the two gradients: which run was faster, and how does the graph show it?

Activity 3 — Reaction time and thinking distance. In pairs, run the falling-ruler test from the theory five times each and record the catch distance. Convert each catch to a reaction time using the table, and find your pair's typical value. Then calculate the thinking distance that reaction time would give at 60 km/h (16.7 m/s): thinking distance = speed × reaction time. Discuss: the simple ruler test measures only seeing and grabbing — list two extra steps in a real driving response that make a driver's full reaction time longer, and state what that does to the thinking distance.

Worked examples

Final answers in this section are given to two significant figures unless the arithmetic is exact. Model speeds converted from km/h (11.1, 13.9, 22.2, 27.8 m/s) are carried to three significant figures so they match the stopping-distance table and figures.

Example 1 — scaffolded

A cyclist covers 1.2 km along a straight road in 4.0 minutes. Calculate the average speed in m/s, and then in km/h.

Working	Comment
d = 1.2 km = 1 200 m	Work in metres and seconds.
t = 4.0 min = 240 s	One minute is 60 s.
$v = d/t$ = 1 200 ÷ 240 = 5.0 m/s	Speed is distance per unit time.
5.0 × 3.6 = 18 km/h	Multiply by 3.6 to go from m/s to km/h.

The cyclist's average speed is 5.0 m/s, or 18 km/h — a typical relaxed cycling pace, as the reference-speeds figure shows.

Example 2 — scaffolded

A car's speed–time graph is a straight line climbing from 0 to 12 m/s over the first 6.0 s, then a flat line at 12 m/s for a further 4.0 s. (a) Calculate the car's acceleration during the first 6.0 s. (b) Calculate the total distance travelled over the 10 s, using areas under the graph.

Working	Comment
(a) $a = (v - u) \div t$ = (12 − 0) ÷ 6.0 = 2.0 m/s²	The gradient of the speed–time graph is the acceleration.
(b) First 6.0 s: triangle, ½ × 6.0 × 12 = 36 m	Area under the climbing line.
Next 4.0 s: rectangle, 12 × 4.0 = 48 m	Area under the flat line.
Total = 36 + 48 = 84 m	The area under a speed–time graph is the distance.

The car accelerates at 2.0 m/s² and travels 84 m in the 10 s.

Example 3 — unscaffolded

A toy car speeds up steadily from 4.0 m/s to 16 m/s over 6.0 s, then brakes to rest in 4.0 s. Calculate the acceleration while speeding up, the distance covered while speeding up, and the acceleration while braking.

Speeding up, the acceleration is the change in speed over the time:

$$a = \frac{v-u}{t} = \frac{16-4.0}{6.0} = 2.0\,\text{m/s}^2.$$

The speed changes steadily, so the distance is the average speed × time:

$$d = 1/2\left(u+v\right) \times t = 1/2\left(4.0+16\right) \times 6.0 = 60\,\text{m}.$$

Braking, u = 16 m/s and v = 0:

$$a = \frac{0-16}{4.0} = -4.0\,\text{m/s}^2.$$

The acceleration is 2.0 m/s² while speeding up (60 m covered), and −4.0 m/s² while braking — negative because it acts against the motion.

Example 4 — unscaffolded

Using the stopping-distance model (reaction time 1.0 s, braking deceleration 6.2 m/s²), calculate the stopping distance at 50 km/h and at 100 km/h, and explain why doubling the speed much more than doubles the stopping distance.

At 50 km/h, v = 13.9 m/s. Thinking distance = 13.9 × 1.0 = 13.9 m. The braking distance is the area of the triangle under the speed–time line as the car slows: ½ × 13.9 × (13.9 ÷ 6.2) ≈ 15.6 m. Stopping distance = 13.9 + 15.6 = 29.5 m ≈ 30 m.

At 100 km/h, v = 27.8 m/s. Thinking distance = 27.8 × 1.0 = 27.8 m. Braking distance = ½ × 27.8 × (27.8 ÷ 6.2) ≈ 62.3 m. Stopping distance = 27.8 + 62.3 = 90.1 m ≈ 90 m.

Doubling the speed doubles the thinking distance (27.8 m vs 13.9 m) but **quadruples** the braking distance (62.3 m vs 15.6 m), because the car is moving twice as fast *and* takes twice as long to stop. That is why 90 m is about three times 30 m, not twice it.

Practice questions

Scaffolded questions

Question 1 Convert these speeds, showing the ×3.6 or ÷3.6 step. (a) 72 km/h to m/s. (b) 25 m/s to km/h. (c) 1.4 m/s (walking) to km/h.

Question 2 A student walks 180 m to the canteen in 2.0 minutes. (a) Calculate the average speed in m/s. (b) Convert the average speed to km/h.

Question 3 Use the distance–time graph in the gradient figure (straight line through (2 s, 3 m) and (6 s, 9 m)). (a) Confirm the gradient using the two marked points. (b) State the physical quantity the gradient represents. (c) Read from the line how far the object has moved at t = 8.0 s.

Question 4 Use the speed–time graph in the acceleration figure (straight line through (1 s, 3 m/s) and (3 s, 9 m/s)). (a) Confirm the gradient using the two marked points. (b) State the physical quantity the gradient represents. (c) Read from the line the speed at t = 4.0 s.

Question 5 Use the two shaded area figures (rectangle: 6.0 m/s for 5.0 s; triangle: rest to 10 m/s over 5.0 s). (a) Calculate the distance for the rectangle journey. (b) Calculate the distance for the triangle journey. (c) State which journey covers more distance, and by how much.

Question 6 Use the stopping-distance model (reaction time 1.0 s, braking deceleration 6.2 m/s^2) and its bar chart. (a) Write down the thinking distance at 40 km/h. (b) Explain why the thinking distance at 80 km/h is double the thinking distance at 40 km/h. (c) Compare the braking distances at 40 km/h and 80 km/h and state the pattern.

Unscaffolded questions

Question 7 A student walks 600 m to a friend's house at 1.5 m/s, then runs the last 600 m home at 5.0 m/s. Calculate the average speed for the whole 1 200 m, and explain why it is not the average of 1.5 m/s and 5.0 m/s.

Question 8 A sprinter runs 100 m in 12.5 s. (a) Calculate the average speed. (b) The sprinter starts from rest. Explain why their top speed in the race must be greater than the average speed.

Question 9 Use the trolley data table and graph (line of good fit, gradient 0.80 m/s). (a) Read from the line the distance at t = 2.0 s. (b) Confirm the gradient using the marked triangle (rise 1.2 m, run 1.5 s). (c) Predict the time at which the trolley reaches the 2.4 m marker.

Question 10 A car accelerates from rest at 2.0 m/s^2 for 4.0 s, holds that speed for 4.0 s, then brakes to rest in 2.0 s. (a) Calculate the car's maximum speed. (b) Calculate the total distance travelled, using areas under a speed–time graph. (c) Calculate the acceleration during braking.

Question 11 A car travelling at 25 m/s brakes with a deceleration of 6.2 m/s^2. Given the formula $v^2 = u^2 + 2ad$ (where a is negative while slowing), calculate the braking distance.

Question 12 A driver sees a hazard at 80 km/h (22.2 m/s). Using the stopping-distance model (reaction time 1.0 s, braking deceleration 6.2 m/s^2), calculate the thinking distance, the braking distance (using the area of the braking triangle), and the total stopping distance. Compare your total with the bar chart.

Question 13 A child steps out 25 m ahead of a car the moment the driver sees them. Using the model, show that at 40 km/h the car stops with about 4 m to spare, and calculate the car's speed when it reaches the child at 50 km/h. (At 50 km/h the car thinks for 13.9 m, then brakes with deceleration 6.2 m/s² over the remaining 11.1 m; use $v^2 = u^2 + 2ad$.) Convert your answer to km/h and comment on what the comparison shows.

Question 14 In the ruler-drop test, a catch at 5 cm corresponds to a reaction time of 0.10 s and a catch at 20 cm to 0.20 s. Explain, using the idea that a falling ruler accelerates steadily, why doubling the reaction time makes the catch distance four times as long, not twice as long.

Question 15 At 60 km/h (16.7 m/s), a human driver's reaction time is about 1.0 s and a driverless system's detect-and-decide time is about 0.2 s. (a) Calculate each thinking distance. (b) Calculate the distance saved by the driverless system before braking begins. (c) Give one reason, other than raw speed of response, why a driverless system's reaction time is more reliable than a human driver's.

Question 16 A council is debating whether the street outside a school should keep its 50 km/h limit or become a 40 km/h zone. Using the stopping-distance model and the 25 m child scenario, write a short data-backed argument for your position. Your argument must quote at least two calculated or modelled distances and must address what happens at the child's position in each case.

Answers

Question 1 (a) 20 m/s; (b) 90 km/h; (c) 5.0 km/h. **Question 2** (a) 1.5 m/s; (b) 5.4 km/h. **Question 3** (a) 6 m ÷ 4 s = 1.5 m/s; (b) speed; (c) 12 m. **Question 4** (a) 6 m/s ÷ 2 s = 3.0 m/s²; (b) acceleration; (c) 12 m/s. **Question 5** (a) 30 m; (b) 25 m; (c) the steady-speed journey, by 5 m. **Question 6** (a) 11 m; (b) thinking distance = speed × a fixed reaction time, so it is proportional to speed; (c) 9.9 m vs 39.7 m — about four times, not two. **Question 7** 2.3 m/s; the slower leg takes much longer, so it weighs more heavily. **Question 8** (a) 8.0 m/s; (b) see solution. **Question 9** (a) 1.6 m; (b) 1.2 m ÷ 1.5 s = 0.80 m/s; (c) 3.0 s. **Question 10** (a) 8.0 m/s; (b) 56 m; (c) −4.0 m/s². **Question 11** 50 m (50.4 m). **Question 12** thinking 22 m; braking 40 m; total 62 m, matching the chart's 61.9 m. **Question 13** 40 km/h: 21 m < 25 m, so 4 m to spare; 50 km/h: about 7.5 m/s ≈ 27 km/h at the child. **Question 14** distance grows with the square of the time; see solution. **Question 15** (a) 16.7 m and 3.3 m; (b) about 13 m; (c) see solution. **Question 16** see solution for marking points.

Fully-worked solutions

Question 1 (a) 72 ÷ 3.6 = 20 m/s. (b) 25 × 3.6 = 90 km/h. (c) 1.4 × 3.6 = 5.04 ≈ 5.0 km/h.

Question 2 (a) t = 2.0 min = 120 s; average speed = 180 ÷ 120 = 1.5 m/s. (b) 1.5 × 3.6 = 5.4 km/h.

Question 3 (a) Rise = 9 − 3 = 6 m; run = 6 − 2 = 4 s; gradient = 6 ÷ 4 = 1.5 m/s. (b) The gradient of a distance–time graph is the **speed**. (c) The line is $d = 1.5t$, so at t = 8.0 s the distance is 1.5 × 8.0 = 12 m.

Question 4 (a) Rise = 9 − 3 = 6 m/s; run = 3 − 1 = 2 s; gradient = 6 ÷ 2 = 3.0 m/s². (b) The gradient of a speed–time graph is the **acceleration**. (c) The line is $v = 3.0t$, so at t = 4.0 s the speed is 3.0 × 4.0 = 12 m/s.

Question 5 (a) Rectangle: 6.0 m/s × 5.0 s = 30 m. (b) Triangle: ½ × 5.0 s × 10 m/s = 25 m. (c) The steady-speed journey covers more, by 30 − 25 = 5 m.

Question 6 (a) 11 m (11.1 m in the chart). (b) Thinking distance = speed × reaction time, and the reaction time is the same 1.0 s at every speed. Double the speed with the same time gives double the distance: 11.1 m at 40 km/h, 22.2 m at 80 km/h. (c) The braking distances are 9.9 m at 40 km/h and 39.7 m at 80 km/h — about **four times** as long when the speed doubles, because braking distance grows with the square of the speed.

Question 7 Walking: t = 600 ÷ 1.5 = 400 s. Running: t = 600 ÷ 5.0 = 120 s. Total distance = 1 200 m; total time = 520 s. Average speed = 1 200 ÷ 520 = 2.307… ≈ **2.3 m/s**. The average of the two speeds, (1.5 + 5.0) ÷ 2 = 3.25 m/s, would only be right if equal *times* were spent at each speed. Here the slow leg lasts 400 of the 520 s, so the average sits much closer to 1.5 m/s than to 5.0 m/s.

Question 8 (a) 100 ÷ 12.5 = **8.0 m/s**. (b) The sprinter starts from rest, so early speeds are below the average. For the average to be 8.0 m/s, later speeds must be above 8.0 m/s — the top speed is greater than the average.

Question 9 (a) The line gives d = 0.80 × 2.0 = **1.6 m** at t = 2.0 s. (b) Gradient = rise ÷ run = 1.2 m ÷ 1.5 s = **0.80 m/s**. (c) $t = d$ ÷ speed = 2.4 ÷ 0.80 = **3.0 s**.

Question 10 (a) $v = u + at$ = 0 + 2.0 × 4.0 = **8.0 m/s**. (b) Speeding-up triangle: ½ × 4.0 × 8.0 = 16 m; steady rectangle: 8.0 × 4.0 = 32 m; braking triangle: ½ × 2.0 × 8.0 = 8 m. Total = 16 + 32 + 8 = **56 m**. (c) a = (0 − 8.0) ÷ 2.0 = **−4.0 m/s²** (a deceleration of 4.0 m/s²).

Question 11 With $v = 0$, u = 25 m/s and a = −6.2 m/s²: 0 = 25² + 2 × (−6.2) × d, so 12.4d = 625 and d = 625 ÷ 12.4 = 50.4 m ≈ **50 m**. (At 90 km/h this is why the model's braking bar is so tall.)

Question 12 Thinking: 22.2 m/s × 1.0 s = 22.2 m ≈ 22 m. Braking: the car slows from 22.2 m/s at 6.2 m/s², taking 22.2 ÷ 6.2 = 3.58 s; the triangle area is ½ × 3.58 × 22.2 = 39.7 m ≈ 40 m. Total = 22.2 + 39.7 = 61.9 m ≈ **62 m**, the same as the chart's 80 km/h bar (61.9 m).

Question 13 At 40 km/h: thinking 11.1 m + braking 9.9 m = 21.0 m, which is less than 25 m, so the car stops with 25 − 21 = **4 m to spare**. At 50 km/h the car thinks for 13.9 m and then brakes over the remaining 25 − 13.9 = 11.1 m. With u = 13.9 m/s and a = −6.2 m/s²: $v^2 = u^2 + 2ad$ = 13.9² + 2 × (−6.2) × 11.1 = 193.2 − 137.6 = 55.6, so $v = \sqrt{55.6}$ ≈

7.5 m/s. In km/h: 7.5 × 3.6 = **27 km/h** at the child. The comparison is the whole argument for school zones: 10 km/h slower turns a 27 km/h impact into a stop four metres early.

Question 14 A falling ruler accelerates steadily at 9.8 m/s^2, so its speed grows with time and the distance it falls grows with the **square** of the time (distance = average speed × time, and both the average speed and the time double). In 0.10 s it falls 5 cm; in 0.20 s — twice the time — it falls 20 cm, four times the distance. The same square law is why braking distances quadruple when speed doubles.

Question 15 (a) Human: 16.7 m/s × 1.0 s = 16.7 m. Driverless: 16.7 m/s × 0.2 s = 3.34 ≈ 3.3 m. (b) 16.7 − 3.3 = **13.4 ≈ 13 m** saved before the brake is applied. (c) A human reaction time lengthens with distraction, fatigue, phones or alcohol, and varies from moment to moment; a sensor-and-computer system responds in the same 0.2 s every time, day and night, so its thinking distance is predictable and never balloons.

Question 16 A strong answer takes a position and backs it with the model's numbers. For the 40 km/h zone: at 40 km/h the stopping distance is 21 m, so a car stops 4 m before a child who steps out 25 m ahead; at 50 km/h the stopping distance is 29.5 m — longer than 25 m — and the car reaches the child still moving at about 27 km/h. The 10 km/h reduction therefore changes the outcome from a serious injury to a safe stop, and it also shortens every stopping distance for heavier vehicles such as trucks, whose longer braking distances make the margin tighter still. A counter-argument answer must still use the data honestly (for example, noting the model assumes an alert driver and dry road, and arguing for engineering fixes such as raised crossings) — marks are awarded for quoting the distances correctly and linking them to the outcome at the child's position.

Where this leads: this subtopic is revisited at higher precision in VCE Physics Unit 2, Area of Study 1 ("How is motion understood?"), reference-only for this book; momentum and two-dimensional motion are VCE-only and are not taught here (TOC D9). Newton's laws and $F = ma$ — the reasons the braking force sets the deceleration — belong to the owner subtopic 15B.

Test A

Topic test 6 — Physical sciences: energy transfer, waves, electricity generation, forces and motion

Science understanding and science inquiry · Chapters 14–15 · Subtopics 14A, 14B, 14C, 15A, 15B and 15C · Codes VC2S10U14, VC2S10U15, VC2S10U16 and VC2S10U17

Total: 40 marks · Section A (multiple choice): 10 marks · Section B (short/structured response): 30 marks, including $F = ma$, efficiency and motion-graph items

6 of the 40 marks are science inquiry marks, attached to the practical work of Chapters 14–15 (Section B, Q16 and Q17).

Planned for about 50 minutes. This paper is untimed — there is no time to beat.

This is a school-designed paper. It is not a VCAA instrument. Achievement at Levels 9 and 10 is reported against the Victorian Curriculum achievement standard on teacher judgement; the marks here are one source of evidence towards that judgement.

Conditions

- Completion is **untimed**. The 50 minutes is planning guidance only; take as long as you need.
- **Reading support** is permitted. Your teacher may read any question out to you if you need it. Reading is not what is being looked at, and your teacher will not help with the answer.
- **A scientific calculator is permitted.** Topic tests 4, 5 and 6 are the only papers that permit one; every calculation on this paper can also be done by hand. No formula sheet. No reading time.
- Answer every question. For multiple-choice questions, circle the letter of the best answer. There is only one best answer for each question.

In this test you will:

- explain energy transfer by conduction, convection and radiation with the particle model, including why metals conduct well (Q1, Q3, Q11)
- work with sound waves — the wave equation, echoes and ultrasound (Q2, Q12)
- apply the Law of Conservation of Energy and calculate efficiency (Q4, Q5, Q6, Q13)
- model how movement is transformed into electrical energy, and compare AC and DC (Q7, Q8, Q14)
- use $F = ma$ and read motion graphs to describe motion (Q9, Q10, Q15)
- apply inquiry skills to the practical work of Chapters 14–15 (Q16, Q17)

Section A — Multiple choice (10 marks)

Each question is worth 1 mark. Circle the letter of the best answer.

Q1 *(1 mark · VC2S10U14)* Conduction primarily transfers heat through:

A. Bulk fluid movement B. Particle vibration without bulk movement C. Radiation D. Sound

Q2 *(1 mark · VC2S10U14)* Sound CANNOT travel through:

A. Air B. Water C. Steel D. A vacuum

Q3 *(1 mark · VC2S10U14)* Why are metals such good conductors of heat?

A. Metals trap many tiny air pockets that hold heat in place B. Their shiny surfaces reflect infrared radiation efficiently C. Mobile free electrons rapidly transfer kinetic energy through the metal D. Their atoms cannot vibrate, so energy passes straight through

Q4 *(1 mark · VC2S10U15)* The Law of Conservation of Energy states that:

A. The total energy in a closed system stays constant B. Energy is destroyed whenever work is done C. Energy can be created when it is needed for work D. Energy only exists in the form of heat

Q5 *(1 mark · VC2S10U15)* Efficiency = useful energy ÷ total energy input. If useful = 40 J and input = 100 J, efficiency:

A. 60% B. 100% C. 2.5% D. 40%

Q6 *(1 mark · VC2S10U15)* Why does multi-step energy transformation typically REDUCE overall efficiency?

A. Energy is lost only at the first step, so adding more steps has little effect B. Each step has its own efficiency below 100%, and the efficiencies multiply together C. Only the final step's efficiency matters for the overall result D. Each extra step recovers some previously lost energy, raising efficiency

Q7 *(1 mark · VC2S10U16)* Rotating a coil in a magnetic field induces:

A. An alternating current in the coil B. No current, because the magnetic field strength is constant C. A direct current that flows in one fixed direction D. A steady voltage that does not depend on rotation speed

Q8 *(1 mark · VC2S10U16)* Mains electricity is supplied as:

A. DC B. Pulsed DC C. AC D. A constant high-voltage supply that never changes direction

Q9 *(1 mark · VC2S10U17)* A 2 kg object accelerating at 5 m/s^2 experiences a net force of:

A. 2.5 N B. 10 N C. 7 N D. 25 N

Q10 *(1 mark · VC2S10U17)* From a velocity-time graph with slope 4 m/s^2, the object's acceleration is:

A. 8 m/s^2 B. 2 m/s^2 C. 4 m/s^2 D. 0

Section B — Short/structured response (30 marks)

Q11 *(4 marks · VC2S10U14)* A saucepan of cold water stands on an electric hotplate. The metal base warms first, and then the water warms through.

- (a) Name the process by which energy passes through the metal base, and state the feature of metals that makes them good conductors of energy. *(2 marks)*
- (b) Explain how the water at the top of the saucepan becomes hot, and name the process involved. *(1 mark)*
- (c) A student holds her hand beside the glowing hotplate and feels warmth. Name the process by which the energy reaches her hand, and state the kind of surface that is the best absorber of this energy. *(1 mark)*

Q12 *(4 marks · VC2S10U14)* A loudspeaker produces a sound wave of frequency 680 Hz. The speed of sound in air is 340 m/s.

- (a) Write the equation linking wave speed, frequency and wavelength. *(1 mark)*
- (b) Calculate the wavelength of this sound wave. Show your working. *(1 mark)*
- (c) The sound reflects from a cliff face 170 m away and returns as an echo. Calculate the time between the shout and the echo. Show your working. *(1 mark)*
- (d) Sound above 20 000 Hz cannot be heard by humans. State the name of this range of sound, and state one use of it. *(1 mark)*

Q13 *(5 marks · VC2S10U15)* A pole-vaulter sprints down the runway, plants the pole, and the bent pole straightens and lifts the vaulter over the bar.

- (a) State the Law of Conservation of Energy. *(1 mark)*
- (b) State the main energy transformation as the straightening pole lifts the vaulter. *(1 mark)*
- (c) Write the equation linking efficiency, useful energy output and total energy input. *(1 mark)*
- (d) An old-style filament lamp receives 100 J of electrical energy and transfers 7 J as light energy. Calculate the efficiency of the lamp. *(1 mark)*
- (e) State where the rest of the lamp's energy goes. *(1 mark)*

Q14 *(5 marks · VC2S10U16)* At a Victorian wind farm, moving air turns the blades of a turbine, and the turbine spins a generator.

(a) Describe the chain of energy transformations from the moving air to the electrical energy. Name the form of energy at each step, in order. *(2 marks)*
(b) Name the effect in which a rotating coil in a magnetic field produces an electric current. *(1 mark)*
(c) State whether the generator supplies AC or DC, and state what the current does to its direction. *(1 mark)*
(d) State the voltage and the frequency of the electricity supplied by an Australian mains power point. *(1 mark)*

Q15 *(6 marks · VC2S10U17)* A cyclist and bicycle together have a mass of 80 kg. The cyclist accelerates from rest along a straight, level path. The speed–time graph for the first 4.0 s is a straight line from (0 s, 0 m/s) to (4.0 s, 6.0 m/s). *(Simulated data for practice.)*

(a) State what the gradient of a speed–time graph represents. *(1 mark)*
(b) Calculate the acceleration of the cyclist over the 4.0 s. Show your working. *(2 marks)*
(c) Calculate the net force acting on the cyclist and bicycle. Show your working. *(2 marks)*
(d) While the cyclist is accelerating, state how the forward force from the pedalling compares with the resistive forces of air resistance and friction, and give the reason. *(1 mark)*

Q16 *(3 marks · VC2S10U14 · inquiry)* In Subtopic 14A, Activity 1, a class dips the inner ends of four rods of the same size — copper, aluminium, iron and glass — into a beaker of hot water. A drawing pin is held to the outer end of each rod by a small dot of wax. The class takes care with the hot water and the hot ends of the rods, does not lift the rods out of the beaker, and leaves everything to cool before packing up, because hot metal looks the same as cold metal.

(a) State the order in which the pins fall. *(1 mark)*
(b) Identify the independent variable and the dependent variable of the investigation. *(1 mark)*
(c) Identify one control variable of the investigation, and state why it must be kept the same. *(1 mark)*

Q17 *(3 marks · VC2S10U17 · inquiry)* In Subtopic 15B, Activity 2, a class uses an elastic band to pull a dynamics trolley along a smooth bench, stretching the band by the same amount each time. They repeat the pull with masses added to the trolley. The class keeps feet clear of the trolley's path and stops the trolley before it reaches the bench edge.

(a) State how the class kept the pulling force the same each time. *(1 mark)*
(b) State the pattern observed as the mass on the trolley increased. *(1 mark)*
(c) Use $F = ma$ to explain the pattern. *(1 mark)*

Test B

Topic test 6 — Physical sciences: energy transfer, waves, electricity generation, forces and motion

Science understanding and science inquiry · Chapters 14–15 · Subtopics 14A, 14B, 14C, 15A, 15B and 15C · Codes VC2S10U14, VC2S10U15, VC2S10U16 and VC2S10U17

Total: 40 marks · Section A (multiple choice): 10 marks · Section B (short/structured response): 30 marks, including $F = ma$, efficiency and motion-graph items

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Planned for about 50 minutes. This paper is untimed — there is no time to beat.

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- **A scientific calculator is permitted.** Topic tests 4, 5 and 6 are the only papers that permit one; every calculation on this paper can also be done by hand. No formula sheet. No reading time.
- Answer every question. For multiple-choice questions, circle the letter of the best answer. There is only one best answer for each question.

In this test you will:

- explain energy transfer by convection, and how sound waves behave in different media (Q1, Q2, Q3, Q11)
- relate loudness and pitch to amplitude and frequency (Q12)
- apply the Law of Conservation of Energy, calculate efficiency, and evaluate claims about energy being "lost" (Q4, Q5, Q6, Q13, Q14)
- compare AC and DC, and the sources that supply each (Q7, Q8)
- use Newton's laws and $F = ma$ to describe and predict motion, including from graphs (Q9, Q10, Q15)
- apply inquiry skills to the practical work of Chapters 14–15 (Q16, Q17)

Section A — Multiple choice (10 marks)

Each question is worth 1 mark. Circle the letter of the best answer.

Q1 *(1 mark · VC2S10U14)* Convection transfers heat by:

A. Bulk movement of warm fluid rising and cooler fluid sinking B. Direct contact between two stationary solid objects C. Vibration of particles in a solid passed neighbour to neighbour D. Electromagnetic waves travelling through empty space

Q2 *(1 mark · VC2S10U14)* Sound waves are:

A. Transverse only B. Longitudinal mechanical waves C. Electromagnetic D. Stationary

Q3 *(1 mark · VC2S10U14)* Why does sound travel faster in solids than in gases?

A. Solid particles are further apart, giving the wave more room to move B. Solids absorb sound energy, which speeds the wave up C. Gases have stronger bonds that pull the wave along more quickly D. Particles are closer together and bonds are stiffer, allowing faster energy transfer

Q4 *(1 mark · VC2S10U15)* A bouncing ball reaches a lower height each bounce. Where does the missing energy go?

A. It is dissipated as heat, sound and deformation of the ball and floor B. It is stored permanently inside the ball as chemical energy C. It is destroyed by the force of gravity acting on the ball D. It is lost from the universe and cannot be accounted for

Q5 *(1 mark · VC2S10U15)* Why isn't the energy from a battery actually 'lost' even after the battery stops working?

A. The battery destroys energy each time current flows through it B. The energy is converted into new matter inside the battery C. The energy was transferred to other forms such as light and heat during use, not destroyed D. The battery actually still contains all of its original energy

Q6 *(1 mark · VC2S10U15)* An incandescent bulb is ~5% efficient as a light source. Most of its energy becomes:

A. More light B. Heat C. Sound D. Stored chemical energy

Q7 *(1 mark · VC2S10U16)* AC current changes direction:

A. Never B. Once C. Randomly D. Periodically (e.g. 50 times per second)

Q8 *(1 mark · VC2S10U16)* A battery typically supplies:

A. DC B. A voltage that drops to zero each cycle like mains power C. AC D. DC that reverses direction once per second

Q9 *(1 mark · VC2S10U17)* If force is constant and mass DOUBLES, acceleration:

A. Doubles B. Stays the same C. Halves D. Quadruples

Q10 *(1 mark · VC2S10U17)* A car's airbag increases the time taken for the driver to come to rest in a crash. Why does this reduce the force on the driver?

A. The airbag absorbs all of the driver's energy, so no force acts on the driver B. The airbag increases the driver's mass, and a larger mass always feels a smaller force C. The airbag pushes the driver backwards, away from the crash D. The same change in velocity happens over a longer time, so the acceleration is smaller and the force is smaller

Section B — Short/structured response (30 marks)

Q11 *(4 marks · VC2S10U14)* A class studies two waves. Wave X: the particles of the medium vibrate back and forth along the direction the wave travels. Wave Y: the particles of the medium vibrate up and down at right angles to the direction the wave travels.

(a) State which wave is longitudinal. *(1 mark)*
(b) Sound is a mechanical wave and light is an electromagnetic wave. State one difference between mechanical waves and electromagnetic waves. *(1 mark)*
(c) Place these in order of increasing frequency: microwaves, radio waves, gamma rays, visible light. *(1 mark)*
(d) State one use of X-rays. *(1 mark)*

Q12 *(5 marks · VC2S10U14)* A guitarist plucks the string of an acoustic guitar.

(a) The guitarist plucks the string harder. State the property of the wave that increases, and the property of the sound that increases as a result. *(2 marks)*
(b) The guitarist shortens the vibrating length of the string, and the frequency of the sound increases. State what happens to the pitch, and give the reason in terms of frequency. *(2 marks)*
(c) State the range of frequencies a human with healthy hearing can hear. *(1 mark)*

Q13 *(4 marks · VC2S10U15)* In Victoria's Latrobe Valley, the Loy Yang power station burns brown coal to generate electricity.

(a) State the form of energy stored in the coal. *(1 mark)*
(b) Describe the chain of energy transformations in the power station, from the coal to the electrical energy. Name the form of energy at each step, in order. *(2 marks)*

(c) The power station is well below 100% efficient. State where most of the energy that does not become electrical energy goes. *(1 mark)*

Q14 *(5 marks · VC2S10U16)* A wind turbine receives 500 kJ of kinetic energy from the wind and transfers 200 kJ as electrical energy. *(Simulated data for practice.)*

(a) Write the equation linking efficiency, useful energy output and total energy input. *(1 mark)*
(b) Calculate the efficiency of the wind turbine. Show your working. *(1 mark)*
(c) State where the other 300 kJ goes. *(1 mark)*
(d) State the form of energy the moving air carries, and name the part of the turbine that the air turns. *(1 mark)*
(e) A student writes: "The turbine destroyed 300 kJ of energy." Evaluate the claim using the Law of Conservation of Energy. *(1 mark)*

Q15 *(6 marks · VC2S10U17)* A trolley rolls down a gentle slope. A class records its motion and draws a distance–time graph. The graph is a straight line from (0 s, 0 m) to (2.5 s, 2.00 m). *(Simulated data for practice.)*

(a) State what the gradient of a distance–time graph represents. *(1 mark)*
(b) Calculate the speed of the trolley. Show your working. *(1 mark)*
(c) State how the straight-line graph shows that the trolley's speed is constant. *(1 mark)*
(d) Later, on a level bench, a student pulls the same trolley with a force of 0.60 N forwards while a friction force of 0.20 N acts backwards. Calculate the net force on the trolley. *(1 mark)*
(e) The mass of the trolley is 0.50 kg. Calculate its acceleration. Show your working. *(1 mark)*
(f) The student stops pulling, and the forces on the trolley become balanced. State what happens to the trolley's motion, and name the law that describes this. *(1 mark)*

Q16 *(3 marks · VC2S10U15 · inquiry)* In Subtopic 14C, Activity 1, a class tapes a metre ruler upright beside a smooth floor, holds a tennis ball with its bottom level with the 1.0 m mark, and drops it. They watch the top of the bounce, record the bounce height, and repeat the drop three times and average the bounce heights.

(a) State why the class repeats the drop three times and averages the results. *(1 mark)*
(b) One group records an average bounce height of 0.55 m from the 1.0 m drop height. *(Simulated data for practice.)* Calculate the efficiency of the bounce. Show your working. *(1 mark)*
(c) State where the "missing" energy goes. *(1 mark)*

Q17 *(3 marks · VC2S10U17 · inquiry)* In Subtopic 15C, Activity 3, a class runs the falling-ruler test in pairs: one student holds their thumb and finger level with the 0 cm mark of a vertical ruler and catches the ruler when their partner drops it without warning. Each student repeats the test five times, and the pair converts each catch distance to a reaction time using the table in the subtopic.

(a) State why the pair repeats the test five times and finds a typical value. *(1 mark)*
(b) One student's reaction time is 0.25 s. *(Simulated data for practice.)* Calculate the thinking distance this reaction time gives at 60 km/h (16.7 m/s). Show your working. *(1 mark)*
(c) The ruler test measures only seeing and grabbing. List two extra steps in a real driving response that make a driver's full reaction time longer than the ruler-test value. *(1 mark)*

Marking guide

This guide is written for a teacher marker — no specialist science background beyond Chapters 14–15 of this book is needed. Award a mark when the student's answer matches an acceptable response below or says the same idea in other words. Do not award half marks. The marks are a record that evidence was seen; they are not used to rank students.

Test A — Section A — Multiple choice

Q	Answer	Code	Source
Q1	**B**	`VC2S10U14`	bank item `VC2S10U14.E01.S01.D1.V01`
Q2	**D**	`VC2S10U14`	bank item `VC2S10U14.E02.S01.D2.V01`
Q3	**C**	`VC2S10U14`	bank item `VC2S10U14.E01.S01.D3.V01`
Q4	**A**	`VC2S10U15`	bank item `VC2S10U15.E01.S01.D1.V01`
Q5	**D**	`VC2S10U15`	bank item `VC2S10U15.E02.S01.D1.V01`
Q6	**B**	`VC2S10U15`	bank item `VC2S10U15.E02.S01.D3.V01`
Q7	**A**	`VC2S10U16`	bank item `VC2S10U16.E01.S01.D1.V01`
Q8	**C**	`VC2S10U16`	bank item `VC2S10U16.E02.S01.D2.V01`
Q9	**B**	`VC2S10U17`	bank item `VC2S10U17.E01.S01.D1.V01`
Q10	**C**	`VC2S10U17`	bank item `VC2S10U17.E01.S01.D3.V01`

All ten items are drawn from the MCQ bank under the codes assessed on this paper; none is drawn from a neighbouring code. Items mix easy (D1), medium (D2) and hard (D3) difficulties (D1 × 5, D2 × 2, D3 × 3). Items are printed with their stem and options word for word; only the positions of the options have changed for this paper, so that the correct answers are spread across A, B, C and D (the printed positions are A × 2, B × 3, C × 3, D × 2). Formulas are printed with true subscripts and the bank's `/` as ÷, per the book's typography. Five bank items under these codes are not used on either paper of this test: the three `VC2S10U17.E02` spearthrower items, because elaboration `VC2S10U17.E02` is withheld under D10 of the plan of record and its content is not authored in this book, and no authoring may add it back; `VC2S10U16.E01.S01.D3.V01`, which needs sinusoidal magnetic-flux content above this book's D9 scope (the book treats electromagnetic induction qualitatively); and `VC2S10U16.E02.S01.D3.V01`, which needs transformer content that this book does not teach.

Why each answer is correct, in brief:

- **Q1 B** — in conduction, vibrating particles pass kinetic energy to their neighbours without the particles changing place; bulk movement of a fluid is convection, and radiation needs no particles at all.
- **Q2 D** — sound is a mechanical wave and needs particles to carry it; a vacuum has no particles. Sound travels through air, water and steel.
- **Q3 C** — metals carry mobile (free) electrons that move through the metal and transfer kinetic energy quickly, as taught in Subtopic 14A.
- **Q4 A** — energy cannot be created or destroyed; the total energy in a closed system stays constant.

- **Q5 D** — efficiency = 40 ÷ 100 = 0.40 = 40%.
- **Q6 B** — every step is below 100% efficient, and the step efficiencies multiply, so the overall efficiency falls with every added step.
- **Q7 A** — as the coil rotates, the current reverses each half turn, so the induced current is alternating; the current does not stay in one fixed direction, and it depends on the rotation.
- **Q8 C** — Australian mains electricity is AC (230 V, 50 Hz); batteries supply DC.
- **Q9 B** — $F = ma$ = 2 kg × 5 m/s^2 = 10 N.
- **Q10 C** — the gradient of a velocity–time graph is the acceleration, so a gradient of 4 m/s^2 is an acceleration of 4 m/s^2.

Test A — Section B — Short/structured response

Q11 *(4 marks · VC2S10U14)* (a) conduction. *1 mark* Metals conduct well because they carry mobile (free) electrons that move through the metal and transfer kinetic energy. *1 mark* The name and the feature must both be there. (b) convection — the water near the base warms, expands, becomes less dense and rises, and cooler water sinks to take its place, setting up a convection current. *1 mark* The name and the rising/sinking movement must both be there. (c) radiation (infrared radiation). *1 mark* Accept either naming. A matt (dull), dark surface is the best absorber. *1 mark* Both parts needed. Marker note: this item assesses the three mechanisms of energy transfer of Subtopic 14A (elaboration `VC2S10U14.E01` for conduction and convection; the surfaces-and-radiation limb is elaboration `VC2S10U14.E05`).

Q12 *(4 marks · VC2S10U14)* (a) wave speed = frequency × wavelength ($v = f\lambda$). *1 mark* (b) $\lambda = v \div f = 340 \div 680 = 0.50$ m. *1 mark* (c) the sound travels to the cliff and back: $2 \times 170 = 340$ m; $t = d \div v = 340 \div 340 = 1.0$ s. *1 mark* (d) ultrasound. *1 mark* Any one use taught in Subtopic 14B: medical imaging (prenatal scans), sonar/echo-sounding, or cleaning. *1 mark* Award the 1 mark for (d) only when both the name and a use are there. Marker note: the wave equation, echoes and the hearing range are taught in Subtopic 14B (elaboration `VC2S10U14.E02`); the speed of sound in air (340 m/s) is the value taught there.

Q13 *(5 marks · VC2S10U15)* (a) energy cannot be created or destroyed; the total energy in a closed system stays constant — energy is only transferred or transformed. *1 mark* (b) elastic potential energy stored in the bent pole → gravitational potential energy of the vaulter. *1 mark* Accept kinetic → gravitational potential energy. (c) efficiency = useful energy output ÷ total energy input. *1 mark* Accept the × 100 version for a percentage. (d) efficiency = 7 ÷ 100 = 0.07 = 7%. *1 mark* (e) dissipated as thermal (heat) energy to the surroundings. *1 mark* Marker note: this is the efficiency item §7 requires on this paper. The Law of Conservation of Energy is elaboration `VC2S10U15.E01`; the pole-vault context is the sporting example of elaboration `VC2S10U15.E05`, taught in Subtopic 14C; the filament-lamp values (100 J in, 7 J of light) are those of Subtopic 14C, Activity 2.

Q14 *(5 marks · VC2S10U16)* (a) kinetic energy of the moving air → kinetic energy of the spinning turbine → electrical energy from the generator. *2 marks* Award 1 mark for the correct forms and 1 mark for the correct order. (b) electromagnetic induction. *1 mark* (c) AC (alternating current); the direction of the current reverses periodically (50 times per second in Australia). *1 mark* Both parts needed. (d) 230 V, 50 Hz. *1 mark* Both needed. Marker note: what turns the turbine is elaboration `VC2S10U16.E03`, the generator is elaboration `VC2S10U16.E01`, and AC and DC compared is elaboration `VC2S10U16.E02`, all taught in Subtopic 15A.

Q15 *(6 marks · VC2S10U17)* (a) the acceleration. *1 mark* (b) $a = (v - u) \div t = (6.0 - 0) \div 4.0 = 1.5\ \text{m/s}^2$. *2 marks* (1 for the correct substitution, 1 for the answer with unit.) (c) $F = ma = 80\ \text{kg} \times 1.5\ \text{m/s}^2 = 120$ N. *2 marks* (1 for the correct substitution, 1 for the answer with unit.) (d) the forward force is larger than the resistive forces — the forces are unbalanced in the direction of motion, and an unbalanced (net) force is what produces acceleration. *1 mark* Marker note: this is the $F = ma$ item and the motion-graph item §7 requires on this paper, together: the graph supplies the acceleration, and $F = ma$ supplies the force. Both limbs are elaboration `VC2S10U17.E01` (graphs and formulas for a moving object), taught across Subtopics 15B and 15C. The data are simulated data for practice.

Q16 *(3 marks · VC2S10U14 · inquiry)* (a) the pin on the copper rod falls first, then aluminium, then iron; the pin on the glass rod falls last or not at all within the time of the investigation. *1 mark* The order must be complete. (b) independent variable: the material of the rod. Dependent variable: the order (or time) in which the pins fall — how quickly the wax melts. *1 mark* Both needed. (c) any one of: the length and size of the rods; the volume or starting temperature of the hot water; the size of the wax dot. *1 mark* It must be kept the same so that only the material can affect how quickly the wax melts — otherwise the comparison is not fair. *1 mark* Accept any wording that says the variable would otherwise change the result. Marker note: the inquiry marks attach to the chapter's own practical work (D7): this item is the rod-conduction comparison of Subtopic 14A, Activity 1 (elaboration `VC2S10U14.E01`). Identifying variables uses the method taught in Chapters 2–3.

Q17 *(3 marks · VC2S10U17 · inquiry)* (a) by stretching the elastic band by the same amount each time. *1 mark* (b) the heavier trolley gained speed more slowly — the acceleration got smaller as the mass increased. *1 mark* (c) $a = F \div m$ from $F = ma$; with the same force, a larger mass gives a smaller acceleration. *1 mark* Marker note: this item is the same-force-different-mass pull of Subtopic 15B, Activity 2 — the quantitative force–mass–acceleration relationship of elaboration `VC2S10U17.E01`.

Test B — Section A — Multiple choice

Q	Answer	Code	Source
Q1	**A**	VC2S10U14	bank item VC2S10U14.E01.S01.D2.V01
Q2	**B**	VC2S10U14	bank item VC2S10U14.E02.S01.D1.V01
Q3	**D**	VC2S10U14	bank item VC2S10U14.E02.S01.D3.V01
Q4	**A**	VC2S10U15	bank item VC2S10U15.E01.S01.D2.V01
Q5	**C**	VC2S10U15	bank item VC2S10U15.E01.S01.D3.V01
Q6	**B**	VC2S10U15	bank item VC2S10U15.E02.S01.D2.V01
Q7	**D**	VC2S10U16	bank item VC2S10U16.E01.S01.D2.V01
Q8	**A**	VC2S10U16	bank item VC2S10U16.E02.S01.D1.V01
Q9	**C**	VC2S10U17	bank item VC2S10U17.E01.S01.D2.V01
Q10	**D**	VC2S10U17	new item authored against VC2S10U17.E03

Nine of the ten items are drawn from the MCQ bank under the codes assessed on this paper; none is drawn from a neighbouring code. Q10 is newly authored against its own code: the bank's `VC2S10U17` items sit only under elaboration `.E01` (its `.E02` items are withheld under D10 and are not printed on any paper), so the bank cannot supply an item on net force and vehicle safety features at any difficulty (that limb sits with elaboration `VC2S10U17.E03`); the new item is authored at hard (D3) difficulty. Items mix easy (D1), medium (D2) and hard (D3) difficulties (D1 × 2, D2 × 5, D3 × 3). Items are printed with their stem and options word for word; only the positions of the options have changed for this paper, so that the correct answers are spread across A, B, C and D (the printed positions are A × 3, B × 2, C × 2, D × 3). Between them, Test A and Test B use every usable bank item for `VC2S10U14`–`VC2S10U17` exactly once — no item is reused across the two papers, and none is left over.

Why each answer is correct, in brief:

- **Q1 A** — convection is the bulk movement of a fluid: warmed fluid rises and cooler fluid sinks, carrying the energy with it.
- **Q2 B** — sound waves are longitudinal mechanical waves: the particles vibrate along the direction the wave travels, and they need a medium.
- **Q3 D** — in solids the particles are closer together and the bonds are stiffer, so vibrations pass from particle to particle faster than in a gas.
- **Q4 A** — the energy is not destroyed; it is dissipated as heat, sound and deformation of the ball and the floor.
- **Q5 C** — by the Law of Conservation of Energy the battery's energy was transferred to other forms (light, heat) during use; it was never destroyed.

- **Q6 B** — at about 5% efficiency, about 95% of the input energy becomes heat.
- **Q7 D** — AC reverses direction periodically — 50 times per second (50 Hz) in Australia.
- **Q8 A** — batteries supply DC, which flows in one direction only.
- **Q9 C** — $a = F \div m$; the same force on twice the mass gives half the acceleration.
- **Q10 D** — the same change in velocity over a longer time is a smaller acceleration ($a = (v - u) \div t$), and $F = ma$ means a smaller acceleration is a smaller force on the driver — the reasoning behind airbags, seatbelts and crumple zones taught in Subtopic 15B.

Test B — Section B — Short/structured response

Q11 *(4 marks · VC2S10U14)* (a) wave X. *1 mark* (b) mechanical waves need a medium (particles) to travel through; electromagnetic waves can travel through a vacuum. *1 mark* (c) radio waves, microwaves, visible light, gamma rays. *1 mark* The order must be complete. (d) any one of: medical imaging (photographing bones), security scanning of luggage. *1 mark* Marker note: transverse and longitudinal waves are taught in Subtopic 14B (elaboration `VC2S10U14.E02`); the order and uses of the electromagnetic spectrum are elaboration `VC2S10U14.E06`.

Q12 *(5 marks · VC2S10U14)* (a) the amplitude of the wave increases; *1 mark* the loudness (volume) of the sound increases. *1 mark* (b) the pitch rises. *1 mark* Pitch is set by frequency — a higher frequency is a higher pitch. *1 mark* (c) 20 Hz to 20 000 Hz. *1 mark* Both limits needed. Marker note: this item is the loudness–amplitude and pitch–frequency relationship of Subtopic 14B, Activity 2 (elaboration `VC2S10U14.E03`).

Q13 *(4 marks · VC2S10U15)* (a) chemical energy. *1 mark* (b) chemical energy (coal) → thermal energy (the steam) → kinetic energy (the spinning turbine) → electrical energy (the generator). *2 marks* Award 1 mark for the correct forms and 1 mark for the correct order. (c) dissipated as thermal (heat) energy to the surroundings — to the cooling water and the air. *1 mark* Marker note: the conservation and dissipation limbs are elaboration `VC2S10U15.E01`, taught in Subtopic 14C. The transformation of energy into electrical energy sits in the achievement-standard sentence shared by `VC2S10U15` and `VC2S10U16` (quoted once under each code below, per D14). Loy Yang and its brown coal are the Victorian context taught in Subtopic 15A; no sourced figures are used here.

Q14 *(5 marks · VC2S10U16)* (a) efficiency = useful energy output ÷ total energy input. *1 mark* (b) efficiency = 200 ÷ 500 = 0.40 = 40%. *1 mark* (c) dissipated — as heat in the turbine and generator, as sound, and as the kinetic energy of air that passes through without being slowed. *1 mark* Accept heat and/or sound. (d) kinetic energy; the blades. *1 mark* Both needed. (e) the claim is wrong — energy cannot be destroyed; the 300 kJ is transferred (dissipated) to other forms, so the total is still conserved. *1 mark* Marker note: this is the efficiency item §7 requires on this paper. What turns the turbine is elaboration `VC2S10U16.E03`, taught in Subtopic 15A; the 40% figure matches the wind row of the generation-efficiency table of Subtopic 14C (Table 1 there is simulated data for practice). The data here are simulated data for practice.

Q15 *(6 marks · VC2S10U17)* (a) the speed. *1 mark* (b) speed = gradient = 2.00 ÷ 2.5 = 0.80 m/s. *1 mark* (c) the gradient is constant — equal distances are covered in equal times. *1 mark* (d) net force = 0.60 − 0.20 = 0.40 N forwards. *1 mark* (e) a = F ÷ m = 0.40 ÷ 0.50 = 0.80 m/s². *1 mark* (f) the trolley keeps moving at constant speed in a straight line; Newton's first law. *1 mark* Both parts needed. Marker note: this is the $F = ma$ item and the motion-graph item §7 requires on this paper, together: the distance–time graph supplies the speed, and the net-force calculation with $F = ma$ supplies the acceleration. The graph limb and the force–mass–acceleration limb are elaboration `VC2S10U17.E01`; the net-force modelling is elaboration `VC2S10U17.E03`, both taught across Subtopics 15B and 15C. The data are simulated data for practice, in the style of the trolley table of Subtopic 15C.

Q16 *(3 marks · VC2S10U15 · inquiry)* (a) to reduce the effect of random variation — an odd bounce or a misread height — so the average is a more reliable value. *1 mark* (b) efficiency = bounce height ÷ drop height = 0.55 ÷ 1.0 = 0.55 = 55%. *1 mark* (c) dissipated as thermal (heat) energy and sound, and in the deformation of the ball and the floor. *1 mark* Marker note: the inquiry marks attach to the chapter's own practical work (D7): this item is the bouncing-ball efficiency of Subtopic 14C, Activity 1 — systems that are not 100% efficient (elaboration `VC2S10U15.E02`). The bounce height in (b) is simulated data for practice.

Q17 *(3 marks · VC2S10U17 · inquiry)* (a) reaction times vary from try to try; repeating and taking a typical value gives a more reliable result. *1 mark* (b) thinking distance = speed × reaction time = 16.7 × 0.25 = 4.2 m (4.175 m unrounded). *1 mark* (c) any two of: deciding what to do; moving the foot from the accelerator to the brake; checking the mirrors and the surroundings. *1 mark* Both steps must be listed. Marker note: this item is the falling-ruler reaction-time test of Subtopic 15C, Activity 3; the thinking-distance calculation and the driving-response discussion are the data behind the argument for lower speed limits of elaboration `VC2S10U17.E05`. The reaction time in (b) is simulated data for practice.

Tracing the items to the achievement standard

Every item traces to the achievement-standard extract of the subtopic that owns its code (§4.1 of the plan of record). The extracts are quoted as the authority file gives them. `VC2S10U14` is split-delivered: 14A owns the energy-transfer limb (conduction, convection and radiation), and 14B is the partner for the properties and applications of waves. `VC2S10U15` is delivered whole by 14C. `VC2S10U16` is delivered whole by 15A. `VC2S10U17` is split-delivered: 15B owns the Newton's-laws and $F = ma$ limb, and 15C is the partner for the quantitative analysis of motion. `VC2S10U15` and `VC2S10U16` share one achievement-standard sentence; it is quoted against each code, per D14 of the plan of record.

Code	Subtopic	Achievement-standard extract	Test A items	Test B items
`VC2S10U14`	14A and 14B	"They explain how wave and particle models describe energy transfer, and compare the properties, features and applications of waves."	Q1, Q2, Q3, Q11, Q12, Q16	Q1, Q2, Q3, Q11, Q12
`VC2S10U15`	14C	"They analyse and represent energy conservation, including efficiency, in systems, and model how different forms of energy are transformed into electrical energy."	Q4, Q5, Q6, Q13	Q4, Q5, Q6, Q13, Q16
`VC2S10U16`	15A	"They analyse and represent energy conservation, including efficiency, in systems, and model how different forms of energy are transformed into electrical energy."	Q7, Q8, Q14	Q7, Q8, Q14
`VC2S10U17`	15B and 15C	"They use Newton's laws to describe and predict the motion of objects in a system."	Q9, Q10, Q15, Q17	Q9, Q10, Q15, Q17

Inquiry weighting: 6 of the 40 marks on each paper are inquiry items attached to the practical work of Chapters 14–15 (Section B Q16 and Q17) — meeting the required minimum of 6 inquiry-strand marks per topic test (D7). On Test A the items attach to the rod-conduction comparison of Subtopic 14A (Activity 1) and the same-force-different-mass pull of Subtopic 15B (Activity 2); on Test B, to the bouncing-ball efficiency of Subtopic 14C (Activity 1) and the falling-ruler reaction-time test of Subtopic 15C (Activity 3). Each paper's inquiry pair carries one Chapter 14 practical and one Chapter 15 practical.

Mark record — Test A

Question	Code	Worth	Given
Q1 — conduction in a solid	VC2S10U14	1	
Q2 — where sound cannot travel	VC2S10U14	1	
Q3 — why metals conduct so well	VC2S10U14	1	
Q4 — the Law of Conservation of Energy	VC2S10U15	1	
Q5 — calculating an efficiency	VC2S10U15	1	
Q6 — efficiency over many steps	VC2S10U15	1	
Q7 — the rotating coil	VC2S10U16	1	
Q8 — the current from the power point	VC2S10U16	1	
Q9 — force, mass and acceleration	VC2S10U17	1	
Q10 — reading a velocity-time graph	VC2S10U17	1	
Q11 — the saucepan on the hotplate	VC2S10U14	4	
Q12 — a 680 Hz sound wave	VC2S10U14	4	
Q13 — the pole-vaulter and the filament lamp	VC2S10U15	5	
Q14 — from wind to the power point	VC2S10U16	5	
Q15 — the accelerating cyclist	VC2S10U17	6	
Q16 — the pins on the hot rods (inquiry)	VC2S10U14	3	
Q17 — pulling the trolley (inquiry)	VC2S10U17	3	
Total		**40**	

Mark record — Test B

Question	Code	Worth	Given
Q1 — how convection moves heat	VC2S10U14	1	
Q2 — the nature of sound waves	VC2S10U14	1	
Q3 — sound in solids and gases	VC2S10U14	1	
Q4 — where the bounce energy goes	VC2S10U15	1	
Q5 — is the battery's energy 'lost'?	VC2S10U15	1	
Q6 — where a bulb's energy goes	VC2S10U15	1	
Q7 — the way AC behaves	VC2S10U16	1	
Q8 — the current from a battery	VC2S10U16	1	
Q9 — twice the mass, same force	VC2S10U17	1	
Q10 — the airbag's longer stopping time	VC2S10U17	1	
Q11 — two waves, X and Y	VC2S10U14	4	
Q12 — the guitarist's string	VC2S10U14	5	
Q13 — coal to electricity at Loy Yang	VC2S10U15	4	
Q14 — the efficiency of a wind turbine	VC2S10U16	5	
Q15 — the trolley on the slope	VC2S10U17	6	
Q16 — the bouncing tennis ball (inquiry)	VC2S10U15	3	
Q17 — the falling-ruler test (inquiry)	VC2S10U17	3	
Total		**40**	