

Course Companion

AQA · GCSE · Physics

Every topic handout in one volume

exercises.lol

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1 • Energy

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Energy: the currency of physics

A battery, a stretched spring and warm water all store **energy**. Energy can be transferred and stored, but never created or destroyed. This reference covers **AQA GCSE Physics 8463, topic 4.1 Energy**.

- Each paper is 100 marks and 1 h 45 min; energy ideas occur across both papers.
- AQA currently supplies a **Physics Equations Sheet**. Check your series' insert; practise choosing and rearranging equations and converting units.
- Show the equation, substitution and answer with units. Follow the question's precision instructions; marks depend on the question and scheme.

Energy stores and systems

A **system** is an object, or a group of objects, that you choose to think about. When a system changes, energy moves between **energy stores**. The stores you must name are:

Store	What it means	Example
kinetic	energy of a moving object	a rolling ball
gravitational potential	energy stored by an object above the ground	water behind a dam
elastic potential	energy stored in a stretched or compressed spring	a drawn bow
thermal (internal)	energy in a hot object	warm soup
chemical	energy stored in bonds	food, petrol, batteries
nuclear	energy stored in an atomic nucleus	uranium fuel
electrostatic	energy stored by separated charges	a charged cloud
magnetic	energy associated with interacting magnets	magnets attracting or repelling

Use the store name requested, such as thermal, gravitational potential or elastic potential. The June 2024 scheme accepts certain symbols in particular parts; this is not a rule that every symbol is accepted in every naming question.

Eight energy stores: examples in chosen systems

kinetic moving ball	gravitational potential raised water	elastic potential stretched spring	thermal warm water
chemical food or fuel	nuclear atomic nuclei	electrostatic separated charges	magnetic interacting magnets

Heating, mechanical work and electrical work transfer energy; they are not stores.

Say which store fills and which store empties.

■ Describing a change

Energy leaves one store and enters another. Say both halves. Practise these situations, which the specification names:

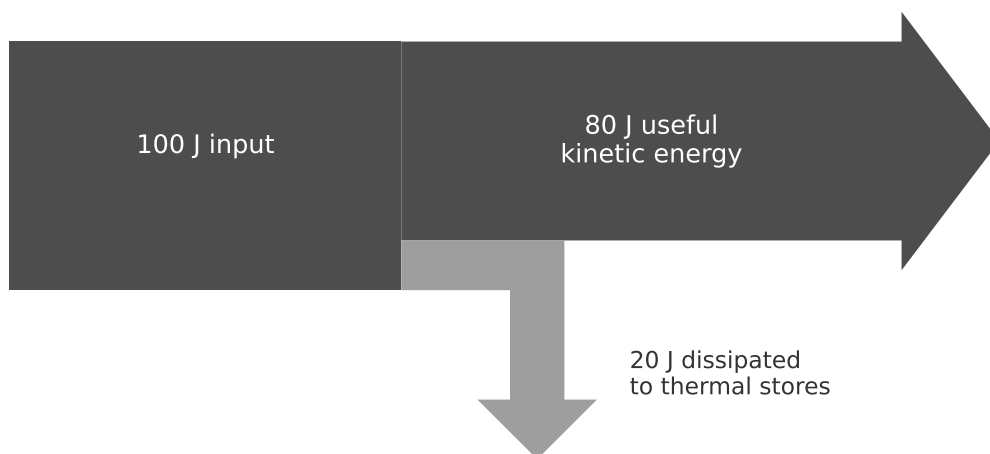
- **An object projected upwards:** the kinetic store decreases and the gravitational potential store of the object–Earth system increases. For a vertical launch, speed is zero at the highest point.
- **A moving object hitting an obstacle:** kinetic store empties; thermal stores of the object and the obstacle increase; sound can carry energy away.
- **An object accelerated by a constant force:** a source store (for example, the chemical store of a battery) decreases; work transfers energy to the vehicle's kinetic store. Electrical work is a transfer pathway, not an electrical store.
- **A vehicle slowing down:** kinetic store empties; thermal store of the brakes fills.
- **Bringing water to the boil in an electric kettle:** chemical energy in the power station's fuel (or another resource) ends in the thermal store of the water.

Energy can enter a system three ways: by **heating** (a temperature difference drives it), by **work done by forces** (a force moves something), and by **work done when a current flows** (an electrical device transfers energy). Electricity is covered in topic 4.2.

■ Sankey diagrams

A **Sankey diagram** shows energy on a common scale. The width of each arrow is drawn in proportion to the energy it carries. The left arrow is the input; it splits into a useful output and wasted outputs.

Motor model: arrow shaft widths show energy



Width, not length, shows the energy.

- The total width out always equals the width in. Energy is conserved.
- “Wasted” energy is not destroyed. It is stored in less useful ways, usually thermal.

■ Guided practice: naming stores and conserving energy

Starter – teacher-written. A motor transfers 60 J in 3.0 s. What is its power?

Worked reasoning. Power is the rate of energy transfer. The equation is $P = E/t$. Substituting gives $P = E/t = 60 \text{ J}/(3.0 \text{ s}) = 20 \text{ W}$. This means 20 joules each second; it does not establish efficiency or useful output.

Exam transfer – adapted from AQA June 2024 Paper 1H Q01.1, Q01.2 and Q06.1. Name the increasing store when water is heated, water is raised into a reservoir, and bungee cords are stretched. Try before checking: thermal/internal, gravitational potential, elastic potential. Explain each name using the temperature, height or extension change. Electrical work may transfer energy into these systems, but electrical is not an energy store.

Teacher-written motor balance. Input is 100 J and useful kinetic energy is 80 J. All the remainder reaches thermal stores. Calculate this remainder and draw proportional Sankey arrows before checking the diagram.

Worked reasoning. Conservation gives $E_{\text{dissipated}} = E_{\text{input}} - E_{\text{useful}}$. Substitution gives $E_{\text{dissipated}} = E_{\text{input}} - E_{\text{useful}} = 100 \text{ J} - 80 \text{ J} = 20 \text{ J}$. Input/useful/dissipated shaft widths have ratio $100:80:20 = 5:4:1$. Energy is conserved; the dissipated part is less useful, not destroyed. Arrow lengths and arrowhead sizes do not represent energy.

Calculating changes in energy

Choose the equation for the store that changes. Use mass in kg, speed in m/s, extension and height change in m, and the question's gravitational field strength g in N/kg.

$$E_k = \frac{1}{2}mv^2 \quad E_e = \frac{1}{2}ke^2 \quad E_p = mgh$$

- E_k **kinetic energy** in J; m mass in kg; v speed in m/s.
- E_e **elastic potential energy** in J; k **spring constant** in N/m; e **extension** in m.
- E_p **gravitational potential energy** in J; h height increase in m; g **gravitational field strength** in N/kg.

Two warnings the exam tests:

- **Extension is the change in length:** stretched length minus original length. A “7.5 m extension” already means the extra length.
- $E_e = \frac{1}{2}ke^2$ needs the **limit of proportionality** not exceeded: below it, doubling the extension quadruples the stored energy.

Teacher-written practice – extension and units. A proportional spring is 10 cm long unstretched and 22 cm long stretched, with $k = 50$ N/m. Find the extension and stored energy; predict the effect of doubling this extension while the spring remains proportional.

Worked reasoning. $e = L - L_0 = 22 \text{ cm} - 10 \text{ cm} = 12 \text{ cm} = 0.12 \text{ m}$. Then $E_e = \frac{1}{2}ke^2 = \frac{1}{2} \times 50 \text{ N/m} \times (0.12 \text{ m})^2 = 0.36 \text{ J}$. Doubling extension gives $E_{e,2} = \frac{1}{2}k(2e)^2 = 4E_e = 4 \times 0.36 \text{ J} = 1.44 \text{ J}$.

Teacher-written worked example. A 0.020 kg toy plane is launched horizontally by a proportional spring with $k = 50$ N/m and extension $e = 0.12$ m. The spring relaxes to its natural length. Assume no height change and all released elastic energy becomes the plane's kinetic energy. Find the ideal launch speed.

- Known: spring data and mass. At launch the elastic store empties into the kinetic store. For maximum speed, assume all of it arrives.

$$E_e = \frac{1}{2}ke^2 = \frac{1}{2} \times 50 \text{ N/m} \times (0.12 \text{ m})^2 = 0.36 \text{ J}$$

- Why $E_k = E_e$: the stated ideal model excludes energy transferred to other stores. In a real launch, thermal transfers can leave less kinetic energy and a lower speed.

$$E_k = \frac{1}{2}mv^2 \quad \Rightarrow \quad v = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2 \times 0.36 \text{ J}}{0.020 \text{ kg}}} = 6.0 \text{ m/s}$$

- Check: unit is m/s because $\sqrt{\text{J/kg}} = \sqrt{\text{m}^2/\text{s}^2}$.

■ Exam transfer: two cords and height

Adapted from AQA June 2024 Paper 1H Q06.2–06.3. A 240 kg pod is released upwards by two cords behaving as springs, each with $k = 735 \text{ N/m}$ and extension 8.0 m. Calculate the ideal height gain ($g = 9.8 \text{ N/kg}$), assuming all initial elastic energy becomes gravitational potential energy. Explain why the actual height is lower.

- Known: two identical cords, so the stored energy doubles.

$$E_{e,1} = \frac{1}{2}ke^2 = \frac{1}{2} \times 735 \text{ N/m} \times (8.0 \text{ m})^2 = 23\,520 \text{ J}$$

$$E_{e,\text{total}} = 2E_{e,1} = 2 \times 23\,520 \text{ J} = 47\,040 \text{ J}$$

- In this ideal model all initial elastic energy becomes gravitational potential energy at the highest point, where vertical speed is zero:

$$E_p = mgh \quad \Rightarrow \quad h = \frac{E_p}{mg} = \frac{47\,040 \text{ J}}{240 \text{ kg} \times 9.8 \text{ N/kg}} = 20 \text{ m}$$

- Air resistance opposes the upward motion. Some initial elastic energy is transferred to the surroundings instead of increasing gravitational potential energy, so the actual height gain is smaller. “Energy is wasted” alone does not explain the transfer; energy is conserved.

Keep the physical assumption and each calculation stage visible; the allocation of marks depends on the particular question.

Energy changes in systems: specific heat capacity

Warm an object and its thermal store grows. The energy needed depends on the mass, the material, and the temperature rise:

$$\Delta E = m c \Delta \theta$$

- ΔE change in thermal energy in J; m mass in kg; $\Delta \theta$ temperature change in $^{\circ}\text{C}$.
- c **specific heat capacity** in $\text{J/kg } ^{\circ}\text{C}$: the energy needed to raise the temperature of **one kilogram** of a substance by **one degree Celsius**.

For equal masses gaining equal thermal energy, a material with higher c has a smaller temperature rise. Water has c about $4200 \text{ J/kg } ^{\circ}\text{C}$; copper about $385 \text{ J/kg } ^{\circ}\text{C}$. A spoon’s heating rate also depends on its mass and energy transfer through contact; specific heat capacity alone does not establish the rate.

Teacher-written worked example. A 2.0 kg metal block gains 26 kJ (26 000 J) of thermal energy. The block’s temperature rises from 22°C to 50°C . Find c .

- Known: energy, mass, and temperatures. The temperature *change* is what enters the equation: $\Delta \theta = 50 - 22 = 28^{\circ}\text{C}$.

$$c = \frac{\Delta E}{m \Delta \theta} = \frac{26\,000 \text{ J}}{2.0 \text{ kg} \times 28^{\circ}\text{C}} = 464 \text{ J/kg } ^{\circ}\text{C} \approx 460 \text{ J/kg } ^{\circ}\text{C}$$

- Check: J divided by (kg $\times$ $^{\circ}\text{C}$) gives J/kg $^{\circ}\text{C}$.

Keep units consistent: 10.5 kJ must become 10 500 J; a time in minutes must become seconds; a mass in grams must become kg; a power in kW must become W. Write the conversion as its own line.

■ Exam transfer: rearranging for temperature change

Adapted from AQA June 2024 Paper 1H Q08.3. Air gains 0.0130 J; its mass is 2.60×10^{-8} kg and $c = 1.01$ kJ/kg $^{\circ}\text{C}$. Find the temperature change before checking.

- Convert $c = 1.01$ kJ/(kg $^{\circ}\text{C}$) = 1010 J/(kg $^{\circ}\text{C}$).
- Rearrange $\Delta E = mc\Delta\theta$ to $\Delta\theta = \Delta E/(mc)$.

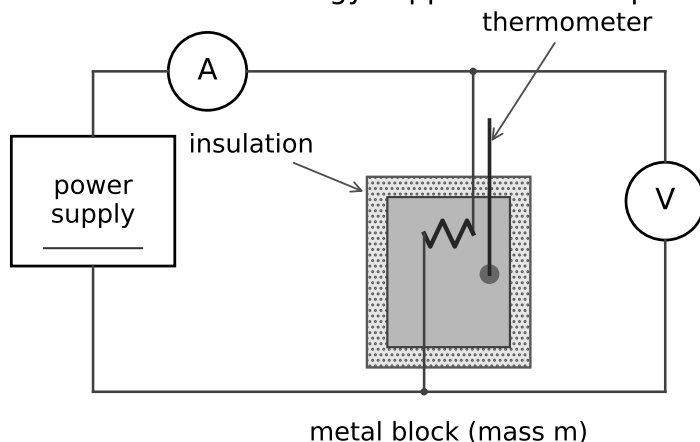
$$\Delta\theta = \frac{\Delta E}{mc} = \frac{0.0130 \text{ J}}{2.60 \times 10^{-8} \text{ kg} \times 1010 \text{ J/(kg } ^{\circ}\text{C})} \approx 495 ^{\circ}\text{C}$$

- This is the rise, not the final reading; finding final temperature also needs the initial temperature.

■ Required practical 1: specific heat capacity

You must know this investigation from memory – the exam asks you to describe or evaluate it at a desk.

RP1: measure electrical energy supplied and temperature rise



The block is lagged to reduce transfer to the surroundings; supplied electrical energy is not automatically all gained by the block.

Method:

1. Measure the mass m of the metal block with a balance.

- Put a little water in the thermometer hole for good thermal contact, and insert the heater and thermometer.
- Record the starting temperature. Switch on the power supply.
- Record the current I and potential difference V , and the time t for which the heater runs. The heater power is $P = VI$ (given in topic 4.2; some questions just give you P).
- The energy supplied is $\Delta E = Pt$.
- Record temperature at regular intervals and calculate supplied energy for each time. Plot temperature against supplied energy; the initial part may curve because of thermal lag.
- Calculate $c = \frac{\Delta E}{m\Delta\theta}$.

Measurement reasoning:

- Insulate the block** (lagging) to reduce energy transferred to the surroundings. If some supplied energy heats the surroundings, using all the supplied energy as the block's thermal-energy increase overestimates c .
- Wait for the thermometer to settle before reading the starting temperature (thermal contact takes time).
- Use the straight region of temperature against supplied energy after the initial thermal lag. In the ideal model its gradient is $1/(mc)$. Repeats help assess variation but do not remove systematic heat loss.
- State how the error changes the measured energy, mass or temperature rise. Poor thermometer contact alone does not establish an error direction; an underestimated temperature rise gives an overestimated c if energy and mass are unchanged.

■ RP1 error check: calculate before predicting

Teacher-written. A 1.0 kg block gains 6000 J and warms by 12 °C. Calculate its c . A student records only a 10 °C rise with the same energy and mass. Calculate the resulting estimate and explain the direction of the error.

$$c = \frac{E}{m\Delta\theta} = \frac{6000 \text{ J}}{1.0 \text{ kg} \times 12^\circ\text{C}} = 500 \text{ J}/(\text{kg } ^\circ\text{C})$$

$$c_{\text{measured}} = \frac{E}{m\Delta\theta_{\text{measured}}} = \frac{6000 \text{ J}}{1.0 \text{ kg} \times 10^\circ\text{C}} = 600 \text{ J}/(\text{kg } ^\circ\text{C})$$

The smaller recorded rise gives a smaller denominator and an overestimate of c . Diagnose the recorded temperature change; do not assign an error direction from “poor contact” alone.

Power

Two motors can lift the same load through the same height. The faster one is more **powerful**. **Power** is the rate of energy transfer, or the rate of doing work:

$$P = \frac{E}{t} \quad P = \frac{W}{t}$$

- P power in W; E energy transferred in J; W **work done** in J; t time in s.
- An energy transfer of 1 J per second is a power of 1 **watt**, W.

Conversions to keep at hand: 1 kW = 1000 W, 1 MW = 10^6 W, 1 GW = 10^9 W, 1 kJ = 1000 J, 1 MJ = 10^6 J.

Teacher-written worked example. A 60.0 kg athlete climbs a vertical height of 175 cm in 1.40 s ($g = 9.8$ N/kg). Find the average useful power associated with gravitational potential gain.

- Known: mass, height, time. Height must be converted: 175 cm = 1.75 m.
- Her gain of gravitational potential energy is the useful energy transferred.

$$E_p = mgh = 60.0 \text{ kg} \times 9.8 \text{ N/kg} \times 1.75 \text{ m} = 1029 \text{ J}$$

- Power divides energy by time in seconds.

$$P = \frac{E_p}{t} = \frac{1029 \text{ J}}{1.40 \text{ s}} = 735 \text{ W}$$

- Check: this is the rate of gravitational potential gain, not total chemical-energy transfer. Heating and other transfers mean more chemical energy is transferred than the useful gain.

An energy transfer stated per second is already a power: 0.343 J of gravitational potential energy gained each second is 0.343 W of useful power. A value per second is not automatically useful output; read which transfer is described.

■ Power comparison and exam transfer

Teacher-written practice. Motors A and B each lift 20 kg through 2.0 m ($g = 10$ N/kg). A takes 2.0 s; B takes 4.0 s. Find their useful power outputs before checking.

$$E_p = mgh = 20 \text{ kg} \times 10 \text{ N/kg} \times 2.0 \text{ m} = 400 \text{ J}$$

$$P_A = \frac{E_p}{t_A} = \frac{400 \text{ J}}{2.0 \text{ s}} = 200 \text{ W}$$

$$P_B = \frac{E_p}{t_B} = \frac{400 \text{ J}}{4.0 \text{ s}} = 100 \text{ W}$$

A transfers the same useful energy in half the time: twice the useful power. Efficiency cannot be compared without input data.

Adapted from AQA June 2024 Paper 1H Q02.2–02.3. A power station has output 500 MW. Find its energy output in 3600 s, in joules. Here $P = 500 \text{ MW} = 5.00 \times 10^8 \text{ W}$, and $P = E/t$ rearranges to $E = Pt$.

$$E = Pt = 5.00 \times 10^8 \text{ W} \times 3600 \text{ s} = 1.8 \times 10^{12} \text{ J}$$

The unit check is watts times seconds equals joules. Output alone does not determine efficiency.

Conservation and dissipation of energy

Energy can be transferred usefully, stored, or dissipated, but never created or destroyed. Dissipated energy is stored in less useful ways. It is often called “wasted”, but it still exists – usually spread into thermal stores of the surroundings.

- For this energy balance, a **closed system** exchanges no energy with its outside, so its total energy does not change. Name the objects included: gravitational potential energy belongs to the object–Earth interaction, not the ball alone. An ideal fall with negligible resistance transfers gravitational potential energy to kinetic energy; a vacuum by itself does not define the system boundary.

■ Follow energy through a fall and impact

Teacher-written model. Include a ball, Earth, floor and nearby surroundings. Assume no energy crosses this system’s boundary and ignore air resistance during the fall. The ball starts at rest with 20 J of gravitational potential energy relative to the floor. When that store is 5 J, what is the kinetic energy? After impact and settling, where is the energy?

Stage	Gravitational / J	Kinetic / J	Thermal gain / J
Start	20	0	0
During fall	5	15	0
After settling	0	0	20

Each row totals 20 J. After impact, energy is spread into thermal stores in this simplified model; sound may carry energy within the chosen surroundings before dissipating. Counting the ball alone gives a different system, which can exchange energy with the Earth and floor. Energy that leaves one object has not disappeared.

■ Explaining a “lower than calculated” answer

Exam questions love this shape: “the real height/speed/temperature is lower than your answer. Explain why.” The credited reasoning:

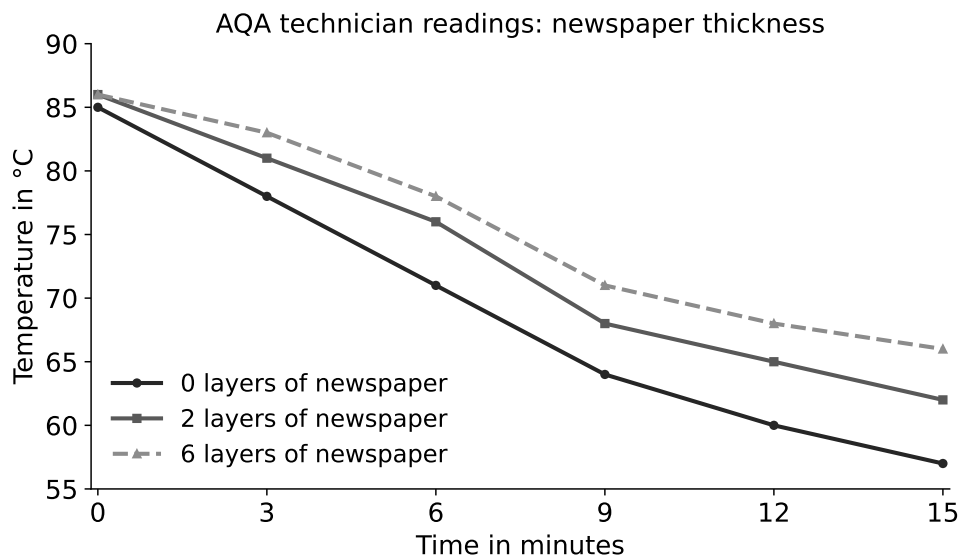
1. Name the cause: air resistance, friction between moving parts, or energy transferred to the surroundings by heating.
2. State the consequence: some energy from the input store is dissipated into thermal stores instead of the intended store.
3. Conclude: so less energy arrives in the useful store.

■ Reducing unwanted energy transfers

- **Lubrication** reduces friction between moving parts, so less energy is dissipated by heating.
- **Thermal insulation** reduces energy transfer by heating. **Thick walls**, walls made of a material with **low thermal conductivity**, or cavity insulation all slow the cooling of a building.

Compare one factor at a time. With equal wall area, thickness and temperature difference, a higher thermal conductivity gives faster transfer by conduction. With the same material and other conditions, a thicker wall reduces this rate. If both thickness and conductivity change in opposing directions, their descriptions alone do not establish the ranking.

■ Required practical 2 (physics only): thermal insulators



Replotted from the AQA practical handbook's technician data (PDF page 12, printed page 11). Initial readings are 85 °C for zero layers and 86 °C for the covered runs; check temperature falls and comparison limits.

Investigate the **effectiveness of different materials as thermal insulators**:

1. Put a fixed volume of hot water in a beaker with a lid.
2. Wrap the beaker in one material (bubble wrap, newspaper, foil, cotton wool).
3. Record the temperature as it cools for a fixed time (or the time to fall by a fixed amount).
4. Repeat for equal measured thicknesses and covered areas of different materials; equal layer counts need not give equal thicknesses.
5. Part 2: repeat for different thicknesses (layers) of one material.

Controls: same water volume, starting temperature, beaker, lid, surroundings, covered area and measurement times. Repeat to judge variation. A smaller temperature fall over a fixed time indicates less cooling under those conditions. Keep material fixed when investigating thickness; keep thickness fixed when comparing materials.

■ RP2: interpret recorded readings

The figure uses the AQA practical handbook, PDF page 12. Points are recorded values joined by lines, not a fitted cooling law. In 15 min, the zero-layer run changes from 85 to 57 °C, two layers from 86 to 62 °C, and six layers from 86 to 66 °C. Calculate the falls before checking.

$$\text{fall}_0 = \theta_i - \theta_f = 85^\circ\text{C} - 57^\circ\text{C} = 28^\circ\text{C}$$

$$\text{fall}_2 = \theta_i - \theta_f = 86^\circ\text{C} - 62^\circ\text{C} = 24^\circ\text{C}$$

$$\text{fall}_6 = \theta_i - \theta_f = 86^\circ\text{C} - 66^\circ\text{C} = 20^\circ\text{C}$$

Six layers cool 4 °C less than two layers over the same time, from the same initial temperature. This supports less cooling with greater newspaper thickness here. The zero-layer run starts 1 °C cooler. Subtracting initial temperatures does not remove all effects of unequal starting conditions; standardise them in a fresh investigation. These runs compare thickness, not different materials.

Teacher-written evaluation. Water in a beaker covered with 20 mm of cotton starts at 90 °C and finishes at 75 °C after 10 min. Water in a beaker covered with 2 mm of foil starts at 80 °C and finishes at 70 °C. Which material is the better insulator? Explain the limits and improve the method before checking.

Reasoning. Cotton falls $90 - 75 = 15^\circ\text{C}$; foil falls $80 - 70 = 10^\circ\text{C}$. Material, thickness and initial temperature all differ, so neither final readings nor temperature falls isolate the material effect. Use equal measured thickness and covered area, the same starting temperature, water volume, apparatus and surroundings; record at the same times and repeat. Conclude for the tested conditions, taking variation into account.

Efficiency

The fraction of input energy that ends up somewhere useful is the **efficiency** :

$$\text{efficiency} = \frac{\text{useful output energy transfer}}{\text{total input energy transfer}} \quad \text{efficiency} = \frac{\text{useful power output}}{\text{total power input}}$$

- Efficiency can be a **decimal** (0 to 1) or a **percentage** (0 % to 100 %). The exam may ask for either; a decimal above 1 or a percentage above 100 % is impossible – check your answer against this.
- Percentage wasted = 100 % – percentage useful.

Teacher-written worked example. A lamp takes 4.0 W of electrical power and is 0.85 efficient for useful light transfer. Find its useful light power and the remaining power.

- Known: total input and efficiency as a decimal. Rearrange before substituting.

$$\text{useful power} = \text{efficiency} \times \text{total input} = 0.85 \times 4.0 \text{ W} = 3.4 \text{ W}$$

- The remainder is $P_{\text{other}} = P_{\text{input}} - P_{\text{useful}} = 4.0 \text{ W} - 3.4 \text{ W} = 0.6 \text{ W}$. Outputs add to input; no energy is destroyed. Efficiency is a ratio without a unit.

Exam transfer – adapted from AQA June 2024 Paper 1H Q01.3. Method A heats water by 80 °C, storing 33 600 kJ per 100 kg, and wastes 40%; installation is possible anywhere in the question. Method B pumps water uphill by 500 m, storing 490 kJ per 100 kg, wastes 25%, and requires high mountains. Compare useful fractions, useful energy and practical constraints before checking.

- Percentage useful = 100 – 40 = 60 %.

$$E_{\text{useful}} = \frac{60}{100} \times 33\,600 \text{ kJ} = 20\,160 \text{ kJ}$$

Method B has useful fraction $f_B = 1 - 0.25 = 0.75$ and useful energy $E_{\text{useful,B}} = f_B E_B = 0.75 \times 490 \text{ kJ} = 367.5 \text{ kJ}$. It is more efficient than A (75% versus 60%), but A provides much more useful energy per 100 kg (20 160 kJ versus 367.5 kJ). Explain both quantities, the stated location restriction and the need to insulate heated water. Use numerical evidence alongside the stated constraints.

■ Efficiency: compare a clearly defined useful transfer

Teacher-written. Lifting devices A and B each take 2000 W of electrical input. Their useful mechanical outputs are 1700 W and 1500 W. Find both efficiencies and their difference in percentage points.

$$\eta_A = \frac{P_{\text{useful,A}}}{P_{\text{input,A}}} = \frac{1700 \text{ W}}{2000 \text{ W}} = 0.85 = 85\%$$

$$\eta_B = \frac{P_{\text{useful},B}}{P_{\text{input},B}} = \frac{1500 \text{ W}}{2000 \text{ W}} = 0.75 = 75\%$$

The gap is $85\% - 75\% = 10$ percentage points. A transfers a greater fraction to useful lifting; the ratio's units cancel. Do not confuse a percentage-point difference with a relative percentage change.

Higher Tier reasoning. Lubrication reduces frictional dissipation in a lifting motor; insulation reduces unwanted thermal transfer from hot-water storage. At fixed input, reduced unwanted transfers can leave more useful output and a greater efficiency. At fixed useful output, $E_{\text{input}} = E_{\text{useful}}/\eta$, so greater efficiency means less required input. “Useful” depends on the intended task: heating is useful for warming a room and may be unwanted in a lifting motor.

National and global energy resources

The main energy resources are **fossil fuels** (coal, oil, gas), **nuclear fuel**, bio-fuel, wind, hydroelectricity, geothermal, tides, the Sun and water waves.

A **renewable** resource is replenished as it is used. Fossil and nuclear fuels are **non-renewable** on a human timescale. Replenishment, availability when needed, and environmental impact are different questions. Renewable does not mean continuous or harmless. Compare uses in transport, electricity generation and heating. Descriptions of generating machinery are not required here.

■ Fuel resources: uses and trade-offs

- **Coal, oil and gas:** electricity or heating; oil-derived fuels are widely used in transport. Generation depends on fuel supply and maintenance. Combustion releases carbon dioxide; sulfur in fuel can produce sulfur dioxide, contributing to acid rain.
- **Nuclear fuel:** electricity, using a finite fuel. Maintenance and outages affect availability. There is no fuel-combustion CO_2 during generation, but radioactive waste needs safe management.
- **Bio-fuel:** transport, heating or electricity. Its biological source can be replaced, but production takes land and time. Burning releases CO_2 . Regrowth can absorb CO_2 , but the overall balance also depends on cultivation, processing and land-use change; carbon neutrality is not automatic.

■ Six other renewable resources

Resource	Availability / example use
wind	electricity; variable wind
Sun	electricity or heating; daylight and clouds matter
hydroelectricity	electricity; stored water helps, but supply is limited
geothermal	heating or electricity; suitable sites matter
tides	electricity; predictable timing, variable output
water waves	electricity; variable sea conditions

Wind turbines can affect wildlife and cause noise; solar installations need space and materials. Reservoirs can flood land and alter river habitats. Geothermal development involves local drilling. Tidal and wave installations can affect marine habitats and are costly to build and maintain. Distinguish environmental impacts from technical constraints and economic costs. Claims about no fuel-combustion emissions during operation do not mean zero impact over manufacture, construction and disposal.

■ Worked example: actual operating time

AQA GCSE Physics June 2024 Paper 1H Q02.5 gives one nuclear station generating for 92% of a 365-day year. With f the generating fraction:

$$t_{\text{operating}} = f t_{\text{year}}$$

$$t_{\text{operating}} = 0.92 \times 365 \text{ days} = 335.8 \text{ days}$$

About 336 days (this question's scheme accepts 335 or 336). The station did not generate all year; do not generalise its percentage to every station. This time fraction alone gives neither electrical energy output nor efficiency.

■ Interpret a trend: attempt, then check

Teacher-written fictional data, with only two categories contributing to each total:

Period	Fossil / TWh	Renewable / TWh
A	80	20
B	90	60

TWh is an energy unit. Find each total and fossil-fuel share. Did the amount of fossil energy fall?

Check:

$$E_A = E_{\text{fossil,A}} + E_{\text{renewable,A}} = 80 \text{ TWh} + 20 \text{ TWh} = 100 \text{ TWh}$$

$$E_B = E_{\text{fossil,B}} + E_{\text{renewable,B}} = 90 \text{ TWh} + 60 \text{ TWh} = 150 \text{ TWh}$$

$$s_A = E_{\text{fossil,A}}/E_A = 80 \text{ TWh}/(100 \text{ TWh}) = 0.80 = 80\%$$

$$s_B = E_{\text{fossil,B}}/E_B = 90 \text{ TWh}/(150 \text{ TWh}) = 0.60 = 60\%$$

The share fell by 20 percentage points, but fossil energy rose by 10 TWh. A decreasing share alone cannot establish decreasing emissions.

■ Make a decision with evidence

Teacher-written task: a clinic needs electricity all night. Solar panels produce no output at night; a maintained gas generator can run when fuel is supplied. Solar generation has no fuel-combustion CO_2 ; gas combustion releases CO_2 . Explain the trade-off, propose a possible supply and identify missing evidence.

Check: solar alone does not meet the night-time requirement. Solar with charged storage or another backup could work if power and stored energy meet demand. Gas can supply power at night, with fuel and maintenance, but releases CO_2 . Check demand, storage capacity, charging conditions, fuel supply, costs and the site before choosing. Funding is an economic constraint; access to reliable care is a social concern. Planning rules are political constraints, and sharing costs and benefits fairly raises ethical questions. Science identifies and measures problems; decisions also depend on these constraints. A conclusion should follow the evidence and stated priorities; no stock final sentence guarantees credit.

Checklist before you call this topic done

■ Retrieval 1: connect the equations

Teacher-written: a motor takes 5.0 J in 2.0 s. It starts a 0.50 kg cart from rest on a level track. The cart gains 4.0 J of kinetic energy; the remainder heats the system and surroundings. Find final speed, efficiency for accelerating the cart, mean input power, and the remaining energy transfer. Attempt before checking.

Check: because the initial speed is zero, final kinetic energy is 4.0 J.

$$E_k = \frac{1}{2}mv^2 \quad \Rightarrow \quad v = \sqrt{2E_k/m}$$

$$v = \sqrt{2E_k/m} = \sqrt{2 \times 4.0 \text{ J}/(0.50 \text{ kg})} = 4.0 \text{ m/s}$$

$$\eta = E_{\text{useful}}/E_{\text{input}} = 4.0 \text{ J}/(5.0 \text{ J}) = 0.80 = 80\%$$

$$P_{\text{input}} = E_{\text{input}}/t = 5.0 \text{ J}/(2.0 \text{ s}) = 2.5 \text{ W}$$

$$E_{\text{other}} = E_{\text{input}} - E_{\text{useful}} = 5.0 \text{ J} - 4.0 \text{ J} = 1.0 \text{ J}$$

That 1.0 J is transferred by heating. Energy is conserved.

■ Retrieval 2: diagnose three claims

1. RP1: all heater input is used as the block's energy gain, though some heats the room. With mass and measured temperature rise fixed, what happens to calculated specific heat capacity?
2. RP2: both insulation layers and water volume change. Why is the conclusion about layers insecure? State controls.
3. Solar panels are called a guaranteed night-time supply because solar is renewable. What is wrong and what extra provision is needed?

Check:

1. $c = E_{\text{gained}}/(m\Delta\theta)$. Using the larger input overestimates c in the stated case.
2. Two changed variables confound the result. Keep volume, container, starting temperature, timing and surroundings fixed; repeat measurements and compare temperature falls over the same time.
3. Replenishment does not ensure power when needed. Adequate charged storage or another supply is required at night.

Use the terms requested, show equations and units, and follow the question's precision instruction. A cause and its physical consequence are more useful than a memorised checklist.

2 · Electricity

AQA · GCSE · Physics

Electricity: energy on demand

Press a switch and a lamp lights. Behind that instant is a chain: charge pushed by a potential difference, through wires and components, transferring energy from power station to bulb. This reference covers **AQA GCSE Physics 8463, topic 4.2 Electricity**.

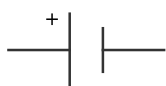
Start with a simple question: a cell, switch and lamp form a series loop. Why does opening the switch stop sustained current? When it is closed, does the lamp use up charge?

The switch must complete a conducting path, and the cell provides a **potential difference**. In a steady series loop the current is the same before and after the lamp. The lamp transfers energy; charge is not consumed. Later calculations link $Q = It$, $E = QV$, $P = VI$ and $E = Pt$.

This reference uses standard **circuit symbols** and the **Physics Equations Sheet** when supplied for the examination. Use the sheet issued for your examination series; practise choosing and rearranging equations rather than assuming every future paper has the same support. AQA uses “potential difference” in questions and accepts correct use of “voltage”. Static electricity and electric fields are physics-only content.

Circuit diagrams, charge and current

A circuit diagram uses standard symbols. Know these: cell, battery, switch (open, closed), lamp, resistor, variable resistor, ammeter, voltmeter, diode, LED, thermistor, LDR and fuse. Ammeters sit **in series**; voltmeters sit **in parallel** across the component.



cell



battery



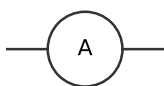
switch (open)



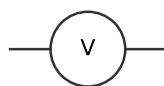
switch (closed)



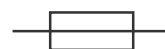
lamp



ammeter



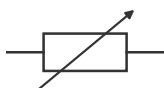
voltmeter



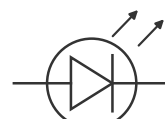
fuse



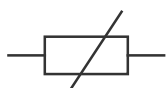
resistor

variable
resistor

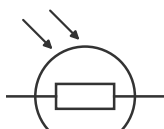
diode



LED



thermistor



LDR

Use repeated long/short plate pairs for a battery; light arrows enter an LDR and leave an LED.

For charge to flow, the circuit must be **closed** and include a source of potential difference. **Electric current** is a flow of electrical **charge**, and its size is the rate of flow:

$$Q = It$$

- Q charge flow in coulombs, C; I current in amperes, A; t time in **seconds**, s.
- Current has the same value at every point of a single series loop.
- Conventional current flows from + to –; electrons flow the opposite way.

■ **Worked reasoning: charge is not current**

Teacher-written: 4.0 C passes a point in 2.0 s in a steady series circuit. Current is charge flow per second:

$$Q = It \quad \Rightarrow \quad I = Q/t$$

$$I = Q/t = 4.0 \text{ C}/(2.0 \text{ s}) = 2.0 \text{ A}$$

One ampere means one coulomb per second. The same 4.0 C passes another point of that steady loop in the same 2.0 s. If the same charge takes 4.0 s instead:

$$I = Q/t = 4.0 \text{ C}/(4.0 \text{ s}) = 1.0 \text{ A}$$

Doubling the time for the same charge halves the current.

■ **Charge-flow practice: attempt before checking**

Teacher-written: a charger supplies a constant 0.90 A for 25 minutes. Find charge in coulombs, then predict the effect of doubling the time at the same current.

Check: use seconds, because amperes measure coulombs per second.

$$t = 25 \text{ min} \times 60 \text{ s/min} = 1500 \text{ s}$$

$$Q = It$$

$$Q = It = 0.90 \text{ A} \times 1500 \text{ s} = 1350 \text{ C}$$

$$Q = It = 0.90 \text{ A} \times 3000 \text{ s} = 2700 \text{ C}$$

Twice the time gives twice the charge, at the same current.

■ **Actual exam calculation: current from charge flow**

AQA GCSE Physics June 2024 Paper 1H Q10.3 gives a fuse wire melting when 2.0 C flows in 400 ms. Calculate current before checking.

Check: known charge and time mean use $Q = It$, rearranged for current.

$$t = 400 \text{ ms} \times 0.001 \text{ s/ms} = 0.400 \text{ s}$$

$$Q = It \quad \Rightarrow \quad I = Q/t$$

$$I = Q/t = 2.0 \text{ C}/(0.400 \text{ s}) = 5.0 \text{ A}$$

This agrees with the official scheme. **Teacher extension:** treating 400 ms as 400 s would make the denominator 1000 times too large and current 1000 times too small. Check the time unit before substituting.

Current, resistance and potential difference

The current through a component depends on both the potential difference across it and its **resistance** :

$$V = IR$$

- V potential difference in volts, V; I current in amperes, A; R resistance in ohms, Ω .
- The greater the resistance, the smaller the current for a given potential difference.

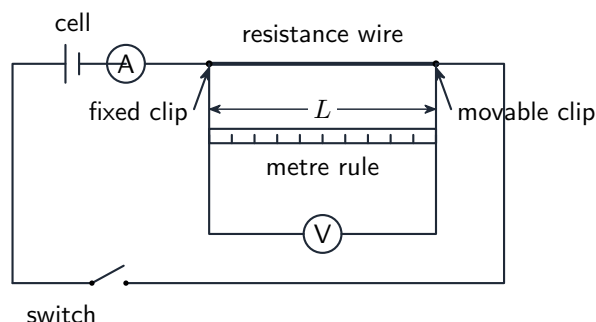
Worked example. A 0.45 V potential difference drives 0.0075 A through a coin. Find the coin's resistance.

- Known: V and I ; rearrange before substituting.

$$R = \frac{V}{I} = \frac{0.45 \text{ V}}{0.0075 \text{ A}} = 60 \Omega$$

■ Required practical 3: resistance of a wire and resistor combinations

Attach a resistance wire (nichrome or constantan) along a metre rule. Measure the selected length between the actual contact points of a fixed clip and a movable clip. The ammeter is in series with that length; the voltmeter is connected across the same two contact points.



Use a low potential difference and switch off between readings to limit heating. Change length only: keep the wire material, cross-sectional area and temperature constant. For each length record the measured potential difference and current, then calculate $R = V/I$. Repeat readings and investigate inconsistent results.

For example, these **teacher-written ideal data** illustrate the calculation; they are not experimental measurements:

Length / cm	Potential difference / V	Current / A	Resistance / Ω
20	0.60	0.30	2.0
40	0.80	0.20	4.0
60	0.90	0.15	6.0

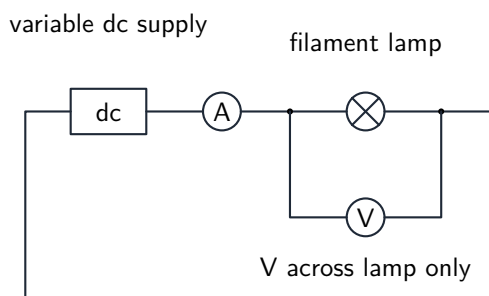
At constant temperature, for the same material and cross-sectional area, resistance is directly proportional to wire length. Plot calculated resistance against length; a straight line through the origin supports this relationship. The measured potential difference need not be identical at each length, so calculate each resistance from its own paired readings.

A non-zero intercept needs investigation. Check that length was measured between the contact points; contact and lead resistance can also affect results. Do not force the graph through the origin or subtract every intercept as a **zero error** without identifying its cause.

In the second part of this practical, connect two equal resistors in series, then in parallel. With the ammeter measuring total current and the voltmeter across the whole combination, measure total potential difference and current and calculate total resistance. Compare with one resistor: series has greater total resistance; parallel has smaller total resistance. For two identical $10\ \Omega$ resistors, ideal totals are $20\ \Omega$ in series and $5\ \Omega$ in parallel. The parallel result can be explained from the doubled total current at the same potential difference, without needing a reciprocal-resistance formula.

Resistors and I–V characteristics

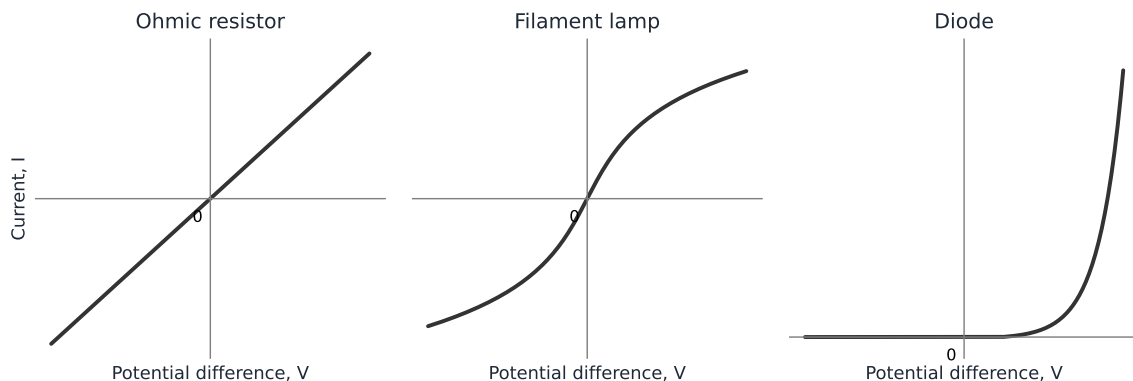
Required practical 4 measures current through a resistor, filament lamp and diode at a range of measured potential differences across each component. Connect an ammeter in series and a voltmeter in parallel with the component. Vary the pd using a variable dc supply, or a variable resistor in series. Start at zero and stay within component ratings. Record paired readings across a suitable range; repeat and investigate inconsistent readings. Switch off before reversing the supply connections to obtain negative values, using meters that can read the reversed polarity. Plot current vertically against potential difference horizontally.



For the lamp investigation in AQA June 2023 8463/1H Q06.1, Figure 6 covers -6 V to $+6\text{ V}$ with readings at 1 V intervals. Collect positive values, then reverse the supply to obtain the negative values; these settings belong to that lamp investigation, rather than every possible component.

For a diode, use a suitable protective resistor in series to limit current and a milliammeter to measure the small current. The **protective resistor**, not the milliammeter,

protects the diode. Measure pd across the diode alone, excluding the protective resistor. Keep the ohmic resistor near constant temperature; the lamp's changing filament temperature is part of the effect being investigated.



Qualitative shapes, not numerical measurement graphs. Current is the vertical axis in all three panels.

- **Ohmic conductor** (fixed resistor at constant temperature): current is directly proportional to potential difference; resistance is constant. Straight line through the origin.
- **Filament lamp** : resistance increases as its filament temperature rises. The current increases less than proportionally with pd, so the I–V curve flattens away from the origin in both directions.
- **Diode** : conducts in the forward direction; reverse current is negligible in this model, so reverse resistance is very high. Do not assume every diode has exactly the same forward voltage.

At a chosen operating point, calculate resistance using $R = V/I$. On a current-against-voltage graph, resistance is not the gradient. For a straight line through the origin, the gradient is $I/V = 1/R$; for a curved characteristic use the coordinates of the chosen point, rather than a tangent gradient.

Worked example, adapted from AQA June 2023 8463/1H Q06.2. At +3.0 V, the official lamp graph gives approximately 0.16 A:

$$R = \frac{V}{I} = \frac{3.0 \text{ V}}{0.16 \text{ A}} = 18.75 \, \Omega \approx 19 \, \Omega$$

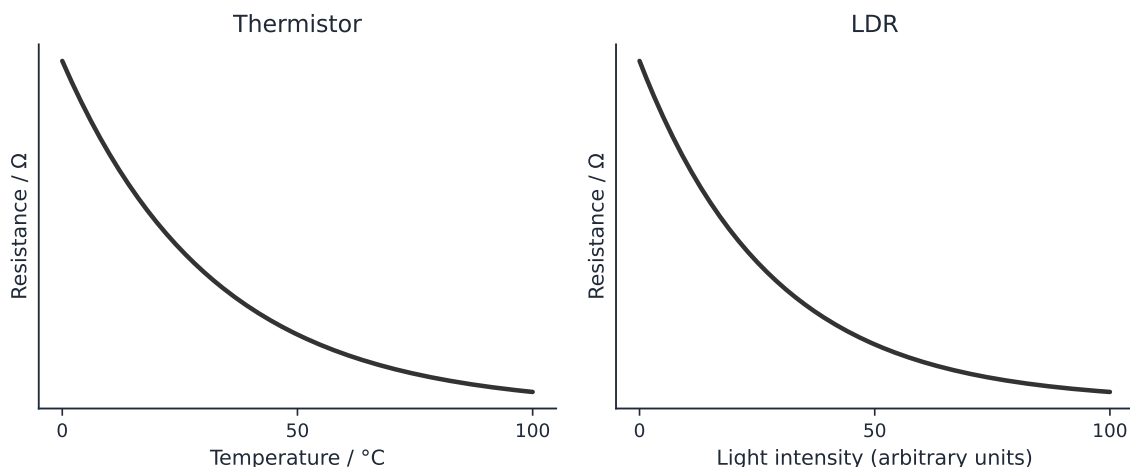
At 6.0 V the same paper gives 0.21 A (Q06.3). As a teacher extension, compare the resistance:

$$R = \frac{V}{I} = \frac{6.0 \text{ V}}{0.21 \text{ A}} \approx 29 \, \Omega$$

The larger resistance is consistent with a hotter filament: increased lattice vibrations

make electron motion more difficult. Current still increases, but by a smaller proportion than pd.

- **Thermistor** : in the type required here, resistance falls as temperature rises – used as a temperature sensor in a thermostat.
- **LDR** : resistance falls as light intensity rises – used as a light sensor in an automatic lighting circuit.

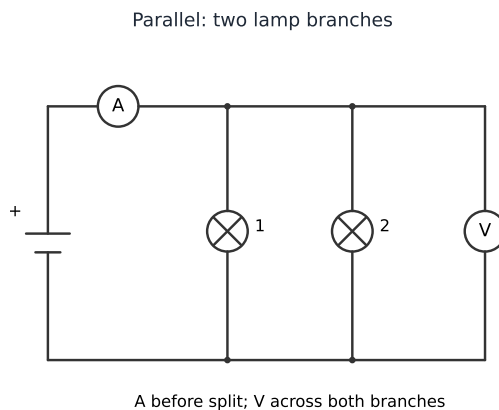
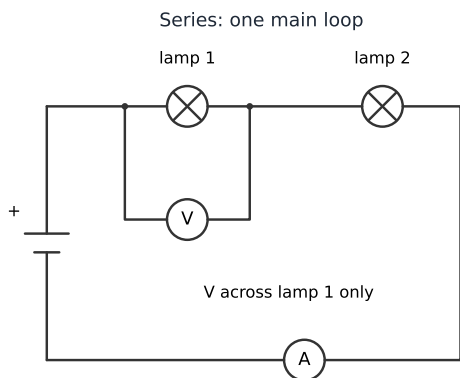


These are resistance-versus-environment graphs, not I – V characteristics.

A sensor does not by itself specify when an appliance switches on. For example, a controller set to switch a lamp on when LDR resistance is high will turn it on in darkness. A cooling controller can be arranged to switch on as thermistor resistance falls with rising temperature. State the given controller rule and trace the change through it. Only for the same pd across the sensor does falling resistance imply rising current by $I = V/R$; a fixed supply does not guarantee fixed sensor pd in a series circuit.

Series and parallel circuits

In series, the components share one unbranched loop. In parallel, components are connected on separate branches between the same two junctions. Trace these paths in the diagram before applying the current and potential-difference rules.



Same components, very different rules.

For components in **series**:

- the current is the same through each component;
- the supply potential difference is **shared** between components;
- total resistance is the **sum**: $R_{total} = R_1 + R_2$.

For components in **parallel**:

- the potential difference across each component is the **same**;
- the total current is the **sum** of the branch currents;
- the total resistance of two resistors is **less than the smallest** single one.

You must explain both directions: adding resistors in series puts extra opposition in the same unbranched conducting path, so total resistance rises; in parallel each resistor opens an extra path for charge, so more current flows for the same potential difference and the total resistance falls.

You are **not** required to calculate the combined resistance of two parallel resistors – only to compare and explain.

Worked example. A 6.0 V battery drives a lamp in series with a variable resistor set to 6.0 Ω . The lamp has a resistance of 12 Ω at this operating point.

- Known: supply pd and both resistances at this operating point. Keep the unrounded current when finding the voltage shares.

$$R_{total} = R_{lamp} + R_{resistor} = 12 + 6.0 = 18 \, \Omega$$

$$I = \frac{V}{R_{total}} = \frac{6.0}{18} = \frac{1}{3} \, \text{A} \approx 0.33 \, \text{A}$$

$$V_{lamp} = IR_{lamp} = \frac{6.0}{18} \times 12 = 4.0 \, \text{V}$$

$$V_{resistor} = IR_{resistor} = \frac{6.0}{18} \times 6.0 = 2.0 \, \text{V}$$

The shares add to 6.0 V. Equal shares occur only for equal resistances at the operating point; series components do not always share voltage equally.

Teacher-written comparison with fixed resistors. Two $8.0\ \Omega$ resistors are connected to an ideal 12 V supply. In series, $R_{total} = R_1 + R_2 = 16\ \Omega$ and $I = V/R_{total} = 0.75\ \text{A}$; each resistor has $V = IR = 6.0\ \text{V}$. In parallel, each branch has 12 V, so each branch current is $I = V/R = 1.5\ \text{A}$ and $I_{total} = I_1 + I_2 = 3.0\ \text{A}$. Adding another parallel resistor gives another current path and increases total current at the same supply pd. No reciprocal-resistance formula is needed here.

For independent parallel branches on an ideal fixed-pd supply, opening one branch stops current in that branch; the other branch still has the same pd. Opening the only series path stops current through both components. If the supply pd changes under load, do not assume the other branch's current is unchanged.

Integrated worked example, adapted from AQA June 2024 8463/1H Q05.5.

At $20\ ^\circ\text{C}$ the question's thermistor graph gives about $80\ \Omega$. It is in series with a $400\ \Omega$ resistor across 12 V. Find the pd across the thermistor.

$$R_{total} = R_{fixed} + R_{thermistor} = 400 + 80 = 480\ \Omega$$

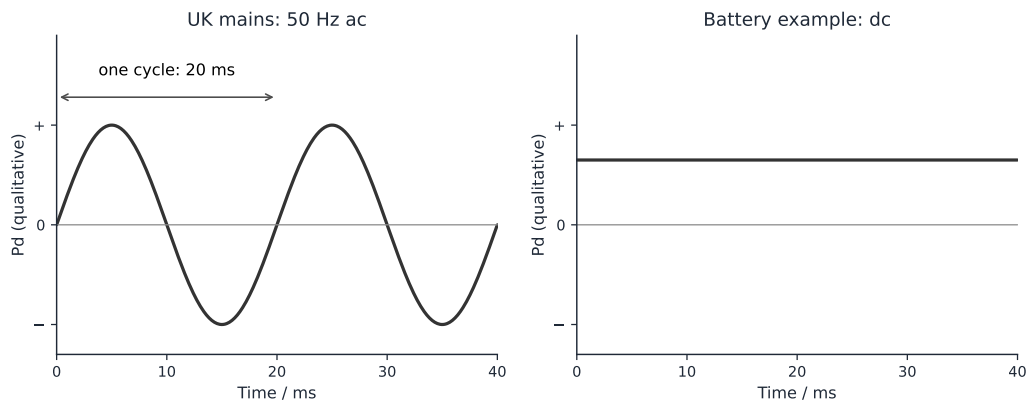
$$I = \frac{V_{supply}}{R_{total}} = \frac{12}{480} = 0.025\ \text{A}$$

$$V_{thermistor} = IR_{thermistor} = 0.025 \times 80 = 2.0\ \text{V}$$

The fixed resistor has the remaining 10 V. This example uses the graph reading supplied above; the complete exam question also requires reading that resistance from the graph. A fixed supply pd does not make the thermistor pd equal to the supply pd.

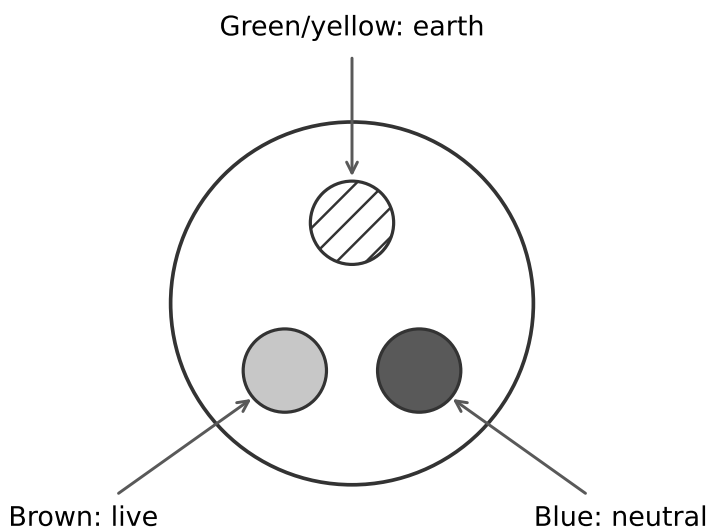
Domestic uses and safety

The UK mains supply is **alternating** (ac): the potential difference repeatedly changes polarity. Its frequency is **50 Hz**, meaning 50 complete cycles per second, and its quoted potential difference is **about 230 V**. Batteries provide **direct** (dc) potential difference with one polarity. A dc potential difference need not be perfectly constant in magnitude; its direction does not reverse.



Qualitative voltage scale: the curve does not plot 230 V as its peak. One complete 50 Hz cycle lasts 20 ms.

Actual exam recall: AQA June 2024 8463/1H Q05.1 asks for UK mains frequency and pd: 50 Hz and 230 V respectively. Fifty cycles per second does not mean only fifty direction changes per second: a sinusoidal cycle includes a positive and a negative half-cycle.

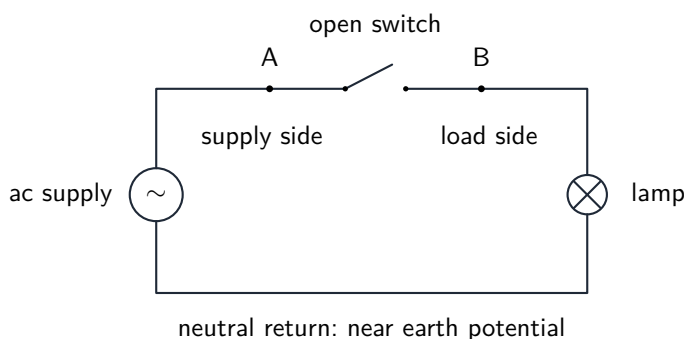


The insulation colours are named on the leaders.

Wire	Insulation colour	Normal role and potential
live	brown	Supplies alternating pd; about 230 V relative to earth.
neutral	blue	Completes the normal circuit; at or near earth potential, about 0 V.
earth	green and yellow stripes	Protective connection to an exposed metal case; near 0 V in the normal model, carrying no normal load current.

Neutral and earth have different jobs despite both normally being near earth potential. Neutral carries normal load current; the protective earth provides a fault-current path.

■ Why an open switch does not make all live wiring harmless



The open switch stops the lamp current in this ideal circuit. Point A remains connected to the live supply, at about 230 V relative to earth. A person making a conducting connection from that live point to earth can receive an electric shock. Do not infer from an unlit appliance that every part of the circuit is isolated. This does not mean that point B after a correctly wired open live switch must also remain live.

The danger depends on the current through the body, its path and duration. A human body is not a zero-resistance wire, but a current much smaller than a typical appliance fuse rating can still cause severe injury. An appliance fuse does not guarantee protection against touching live wiring.

■ Protective earth and fuse in a metal-case fault

For the classroom fault model, suppose the live wire touches an exposed metal case that has a sound protective-earth connection. The earth conductor supplies a low-resistance fault path; the resulting large current heats and melts a suitably rated fuse in the live wire, breaking the live supply. Without that earth connection, a case can become live without enough current to operate the fuse. A fuse's protection against excessive current is different from a claim that every possible shock current will blow it.

■ Evaluate a broken-neutral fault

Teacher-written ideal model: a lamp is connected to a single-phase live and neutral supply. The neutral connection breaks between the lamp and the supply. The downstream neutral terminal remains connected to live through the lamp; there is no other return path. No normal load current flows, but that downstream terminal can be at live potential.

Condition	Live-to-earth pd	Load-side neutral-to-earth pd	Pd across lamp
normal	about 230 V	about 0 V	about 230 V
neutral return broken	about 230 V	about 230 V	about 0 V

This ideal model explains an unlit lamp with a dangerous downstream terminal. Both lamp terminals are at approximately the same potential, so the lamp pd is near zero; either can still have a large pd relative to earth. It is inconsistent to assign 230 V both across this unlit ideal lamp and from each of its terminals to earth in the stated single-phase model.

Energy transfers: power and appliances

Electrical appliances transfer energy from batteries or the mains. A motor transfers energy mechanically to moving objects; a heater transfers energy to the thermal store of its surroundings. **Power is the rate of energy transfer:** 1 W means 1 J each second. A rating states this rate at the specified working potential difference; it is not the total energy used.

Known quantities	Equation	Target
pd and current	$P = VI$	power in W
current and resistance	$P = I^2R$	resistive power in W
power and time	$E = Pt$	energy in J
charge and pd	$E = QV$	energy in J

Use seconds with watts to obtain joules. Use amperes, volts, ohms and coulombs with these equations. For a resistive model, substituting $V = IR$ into $P = VI$ gives $P = (IR)I = I^2R$. If current is unknown, rearrange $I^2 = P/R$ and take the square root: $I = \sqrt{P/R}$, not P/R .

Worked example – AQA June 2023 8463/1H Q06.3. A lamp carries 0.21 A at 6.0 V for 30 minutes. Calculate the energy transferred. Current and pd give power; power and time give energy.

Convert time: 30 min = 30×60 s = 1800 s.

$$P = VI = 6.0 \text{ V} \times 0.21 \text{ A} = 1.26 \text{ W}$$

$$E = Pt = 1.26 \text{ W} \times 1800 \text{ s} = 2268 \text{ J} \approx 2300 \text{ J}$$

Alternative route using charge. The same current and time give charge; each coulomb transfers 6.0 J across the lamp.

$$Q = It = 0.21 \text{ A} \times 1800 \text{ s} = 378 \text{ C}$$

$$E = QV = 378 \text{ C} \times 6.0 \text{ V} = 2268 \text{ J}$$

Both routes agree and are accepted in the official scheme. Retain intermediate values until the final answer; write J for energy, not W.

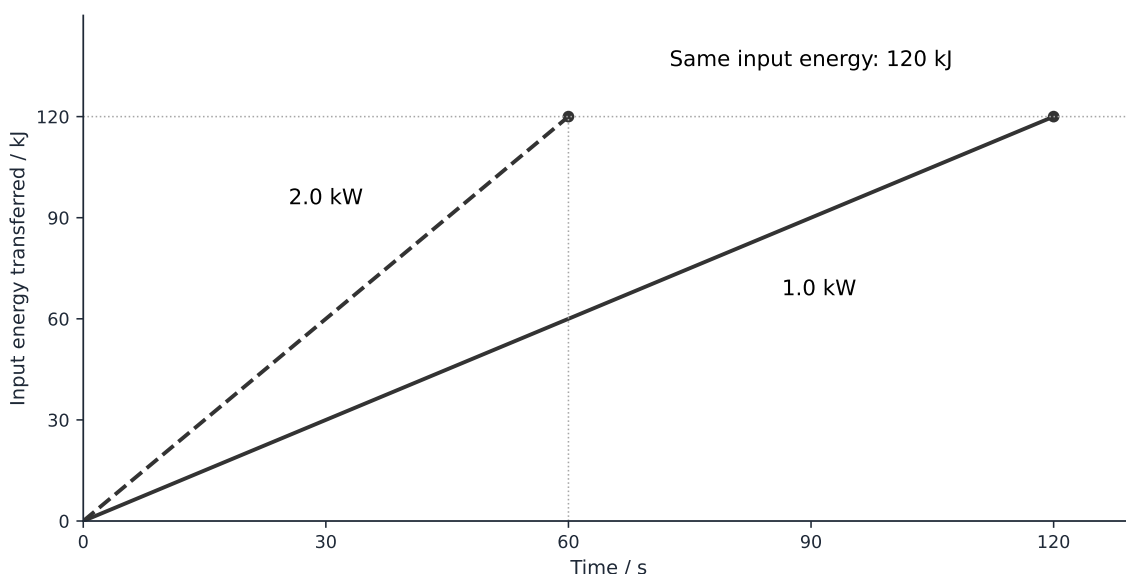
Worked example – AQA June 2025 8463/1H Q09.2. The question gives pump-motor power 4.86 W and resistance 6.0Ω and asks for charge flow in 30 minutes. Use the question's prescribed $P = I^2R$ model; this is not a general statement that all electrical input to a real running motor is resistance heating. Power and resistance give current; current and time give charge.

$$I^2 = \frac{P}{R} = \frac{4.86 \text{ W}}{6.0 \Omega} = 0.81 \text{ A}^2$$

$$I = \sqrt{\frac{P}{R}} = \sqrt{\frac{4.86 \text{ W}}{6.0 \Omega}} = 0.90 \text{ A}$$

$$Q = It = 0.90 \text{ A} \times 1800 \text{ s} = 1620 \text{ C}$$

Compare power ratings – teacher-written. Two devices transfer the same 120 kJ of input energy at constant powers 1.0 kW and 2.0 kW. Convert 120 kJ to 120 000 J and kW to W before using $t = E/P$.



The steeper line transfers energy faster. The endpoints show equal energy, with different times.

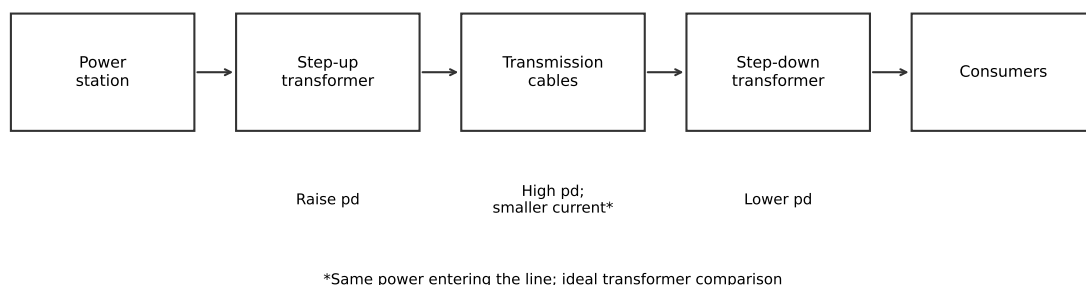
$$t_1 = \frac{E}{P_1} = \frac{120\,000\text{ J}}{1000\text{ W}} = 120\text{ s}$$

$$t_2 = \frac{E}{P_2} = \frac{120\,000\text{ J}}{2000\text{ W}} = 60\text{ s}$$

At the same run time, the 2.0 kW device transfers twice the energy. For the stated equal input energy, it takes half the time. A greater rating alone does not prove a greater total energy use or total cost for a job: duration and, for useful output, efficiency matter. For the same material and amount of water, a larger useful heating power raises temperature faster when losses are comparable.

The National Grid

The **National Grid** transfers electrical energy from power stations to consumers through cables and transformers.



Arrows show the system's energy-transfer route, not individual circuit wires.

A **step-up transformer** raises the pd before transmission. For the same power entering the line, a higher sending-end pd means a smaller current: $I = P_{\text{in}}/V$. With the same cable resistance, heating loss $P_{\text{loss}} = I^2R$ is smaller. More of the input energy reaches consumers, so efficiency increases. Loss is reduced, not eliminated.

A **step-down transformer** lowers the transmission pd for consumers; UK domestic appliances use about 230 V. This is a lower and more suitable value than transmission pd; it can still cause a dangerous electric shock. Transformer construction and operation are taught in topic 4.7; this section explains their system-level roles.

Actual exam explanation – AQA June 2022 8463/1H Q06.1–06.2. The paper places transformer X before the overhead transmission cables and Y before consumers. X raises pd, reduces current, reduces heating transfer to surroundings and increases transmission efficiency. Y lowers pd to a safer value for consumers. Do not replace the X explanation with only “it is more efficient”: state the physical chain.

■ Compare two sending potential differences

Teacher-written simplified comparison. Hold sending-end input power at 500 kW and total cable resistance at $2.0\ \Omega$. Compare sending-end pd 10 kV with 20 kV. Use a simplified single-line resistive model and ideal transformers; this is not a calculation of the real three-phase UK network. Convert kW and kV to W and V.

At 10 kV:

$$I_1 = \frac{P_{\text{in}}}{V_1} = \frac{500\,000\ \text{W}}{10\,000\ \text{V}} = 50\ \text{A}$$
$$P_{\text{loss},1} = I_1^2 R = (50\ \text{A})^2 \times 2.0\ \Omega = 5000\ \text{W}$$

At 20 kV:

$$I_2 = \frac{P_{\text{in}}}{V_2} = \frac{500\,000\ \text{W}}{20\,000\ \text{V}} = 25\ \text{A}$$
$$P_{\text{loss},2} = I_2^2 R = (25\ \text{A})^2 \times 2.0\ \Omega = 1250\ \text{W}$$

Twice the sending pd gives half the current and one quarter of the cable loss. Input power is unchanged; output power increases because less is lost. A current-and-resistance calculation gives the loss, but cannot by itself give efficiency: total input power or energy is also needed.

Sheet2.7 comparison. At 2000 A through $40\ \Omega$, $P_{\text{loss}} = I^2 R = (2000\ \text{A})^2 \times 40\ \Omega = 1.6 \times 10^8\ \text{W}$. At 500 A through the same resistance, $P_{\text{loss}} = I^2 R = (500\ \text{A})^2 \times 40\ \Omega = 1.0 \times 10^7\ \text{W}$. Current is one quarter, so loss is one sixteenth. Without a stated input, do not claim these losses are a small percentage of the total.

Actual efficiency calculation – AQA June 2023 8463/1H Q01.5. Input energy is 34.2 GJ and efficiency is 0.992. Use $\eta = E_{\text{useful}}/E_{\text{in}}$ and rearrange before substituting. Both energies use GJ here, so the ratio needs no conversion to J.

$$E_{\text{useful}} = \eta E_{\text{in}} = 0.992 \times 34.2\ \text{GJ} = 33.9264\ \text{GJ} \approx 33.9\ \text{GJ}$$

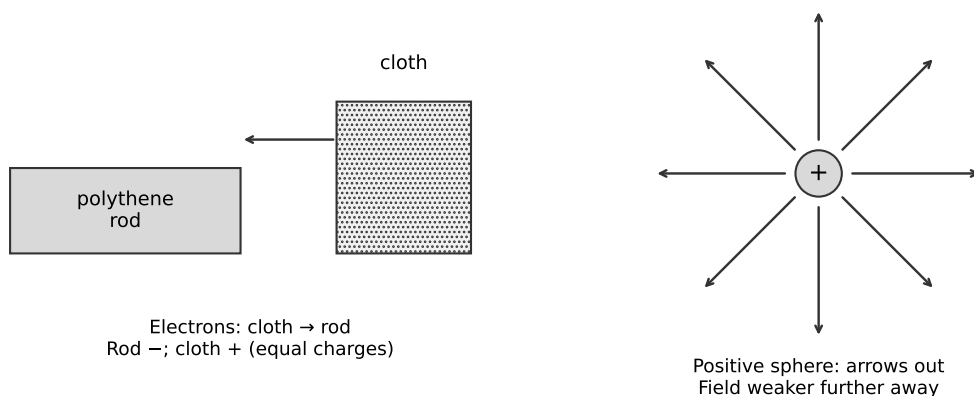
Static electricity (physics only)

When two insulating materials are rubbed together, **electrons** – negative charges – are rubbed off one and onto the other:

- the material gaining electrons becomes **negatively charged**;
- the material losing electrons is left with an equal **positive charge**.

Charged objects exert forces without contact: **like charges repel; unlike charges attract** – a non-contact force. A large potential difference can create a strong **electric field** across a small air gap. If the field is strong enough, the air becomes conducting (electrical breakdown), and charge flows briefly across the gap as a **spark**. An earthed conductor can receive a spark; earthing does not remove a nearby high-voltage source.

A charged object creates an electric field around itself: a region where another charge feels a force.



Electrons move; the field tells the force. The field is strongest close to the object and weaker further away.

You must draw the field pattern for an isolated charged sphere: straight radial lines pointing **away** from a positive charge (or towards a negative one), spaced wider as they get further from the sphere.

■ Link the explanation to real exam questions

AQA June2022 8463/1H Q05.1: electrons move from cloth to rod; electrons are negative, so the cloth is left with excess positive charge. Do not describe positive charge transferring. **Q05.4:** the large pd can cause air breakdown; electrons flow through the air from the negative rod to the earthed conductor.

AQA June2024 8463/1H Q04.1–04.3: electrons transfer to the student, her hairs gain the same negative charge, and like charges repel. The electric field is a region where another charged object experiences a force; its strength decreases with distance.

Q04.4: a spark transfers 0.60 J with 2.0 microcoulombs of charge. Convert $Q = 2.0 \times 10^{-6}$ C. Choose $E = QV$ and rearrange:

$$V = E/Q = 0.60 \text{ J}/(2.0 \times 10^{-6} \text{ C}) = 3.0 \times 10^5 \text{ V}$$

Neutral-object extension for sheet2.8. A charged rod can attract neutral paper because it slightly separates positive and negative charge within the paper. The nearer opposite charges feel stronger attraction than the repulsion of the further like charges. In an insulating wall, bound charges shift slightly; do not assume electrons flow freely through it. Attraction alone does not prove opposite net charges. In the sheet's rod question, all rods are stated to be charged, so the unlike-charge rule applies.

Checklist before you call this topic done

- Draw the standard symbols; place ammeters in series, voltmeters in parallel.
- Use $Q = It$, $V = IR$, $P = VI$, $P = I^2R$, $E = Pt$, $E = QV$ – chosen from the words of the question.
- Describe RP3: $R \propto L$, controls, intercept and heating checks; RP4: circuits and I–V shapes.
- State series/parallel current, pd and resistance rules; explain the resistance trends.
- Recall mains: 230 V, 50 Hz, ac; wire colours and jobs; explain live-wire dangers.
- Explain the National Grid's efficiency with $P = I^2R$.
- (physics only) Explain charging by friction with electrons, and draw the radial field of a charged sphere.

3 · Particle model of matter

AQA · GCSE · Physics

The particle model: matter from the inside

Why does a metal spoon sink while a huge ship floats? Why does sweat cool you down? Both answers live in the particle model. This reference covers **AQA GCSE Physics 8463, topic 4.3 Particle model of matter**.

How the exam treats this topic:

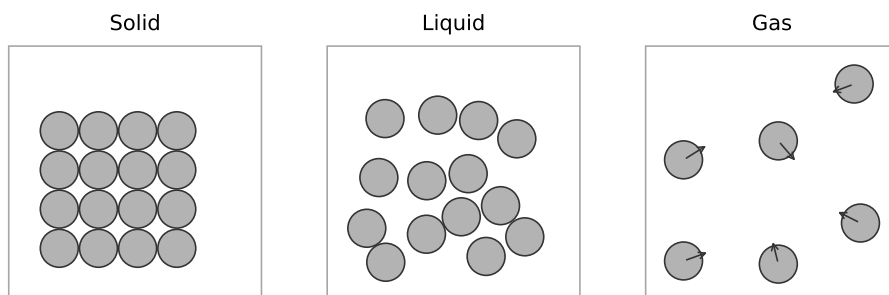
- Paper 1 (4.1–4.4) carries this topic. Practise choosing and rearranging $\rho = m/V$, $\Delta E = mc\Delta\theta$, $E = mL$ and $pV = \text{constant}$. Use the Physics Equations Sheet supplied for your examination series when one is provided.
- Pressure in gases and doing work on a gas are **physics only** (work on a gas also Higher Tier).
- You must **interpret heating and cooling graphs** that include changes of state.
- You must distinguish **specific heat capacity** from **specific latent heat** in words and in calculations.

Density of materials

$$\rho = \frac{m}{V}$$

- ρ **density** in kg/m^3 ; m mass in kg; V volume in m^3 .
- Use consistent units. To express a result in kg/m^3 , convert g/cm^3 . $1 \text{ g/cm}^3 = 1000 \text{ kg/m}^3$ (multiply by 1000: a cm^3 is a millionth of a m^3 and a gram is a thousandth of a kg).

The particle model explains the states of matter:



Same-sized schematic particles; equal viewing volumes

Pattern, contact, spacing.

State	Arrangement	Motion
solid	close, regular	vibrate about fixed positions
liquid	close, irregular	move past each other
gas	far apart	random; straight paths between collisions

- Solids and liquids have similar densities because their particles are similarly packed; a gas is mostly empty space.
- Ice is unusual: water **expands** on freezing, so ice is slightly *less* dense than water.

Worked example. A ring has mass 9.46 g and volume 0.44 cm³. Find its density in kg/m³.

- Convert both first: $m = 9.46 \text{ g} = 9.46 \times 10^{-3} \text{ kg}$; $V = 0.44 \text{ cm}^3 = 4.4 \times 10^{-7} \text{ m}^3$.

$$\rho = \frac{m}{V} = \frac{9.46 \times 10^{-3} \text{ kg}}{4.4 \times 10^{-7} \text{ m}^3} = 21\,500 \text{ kg/m}^3$$

■ Actual exam demands: density

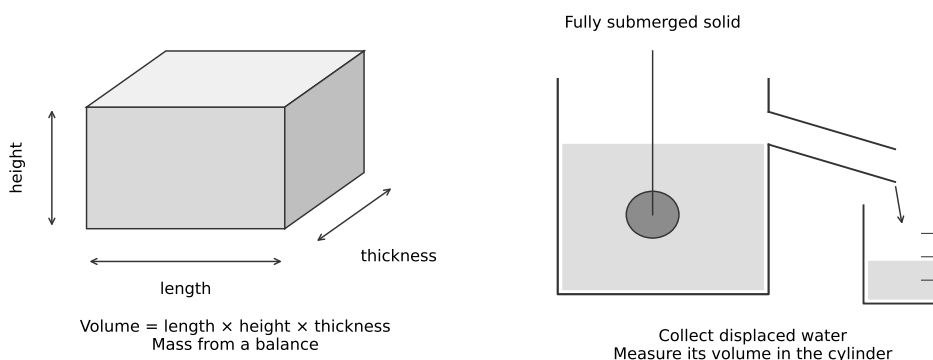
AQA June 2025 8463/1H Q01.3: 824000 kg of seawater passes a turbine each second; density is 1030 kg/m³. Choose $\rho = m/V$, then rearrange:

$$V = m/\rho = 824000 \text{ kg}/(1030 \text{ kg/m}^3) = 800 \text{ m}^3$$

This is the volume passing in each second. **AQA June 2024 Q07.5** reverses the ring example: given density 21500 kg/m³ and volume 0.44 cm³, calculate mass. Convert the volume, then use $m = \rho V = 21500 \text{ kg/m}^3 \times 4.4 \times 10^{-7} \text{ m}^3 = 0.00946 \text{ kg}$.

Teacher-written liquid example. The empty cylinder is 42 g; cylinder plus 60 cm³ of liquid is 90 g. Subtract $m = 90 \text{ g} - 42 \text{ g} = 48 \text{ g}$, then $\rho = m/V = 48 \text{ g}/60 \text{ cm}^3 = 0.80 \text{ g/cm}^3$.

■ Required practical 5: density



Regular shapes from dimensions; irregular shapes by displacement.

- **Regular solid:** measure length, width and thickness with a ruler (or micrometer/Vernier callipers), multiply for V ; find m on a balance; $\rho = m/V$.
- **Irregular solid:** fill a displacement (eureka) can to the spout, wait for dripping to stop, lower the object in on thin string; the volume of water collected in a measuring cylinder equals the object's volume.
- **Liquid:** find the mass of an empty measuring cylinder, then the mass with a known volume inside; subtract for m .
- Accuracy points: read the measuring cylinder at eye level on a flat surface (avoid parallax); use thin string so it displaces almost no water; repeat and average.

AQA June 2022 8463/1H Q02.1–02.4: describe a complete rock-density method, then interpret $2.55 \pm 0.10 \text{ g/cm}^3$ as the interval 2.45–2.65 g/cm³. Repeated readings allow a mean and reduce random-error effects; they do not remove a systematic calibration error. In a cylinder-displacement method, subtract initial volume from final volume, fully submerge the rock and avoid trapped bubbles.

Changes of state and internal energy

When a substance **melts, freezes, boils, evaporates, condenses or sublimates** :

- **Mass is conserved** in a closed system: the number of particles does not change. If vapour leaves an open container, the remaining material loses mass, but the total including the escaped vapour is conserved.
- Changes of state are **physical changes** : reverse the change and the material recovers its original properties. (A chemical change makes new substances; melting does not.)

Internal energy is the **total kinetic and potential energy of all the particles** that make up a system. Heating a system increases the particles' energy, and that energy goes one of two ways:

1. it **raises the temperature** – the particles' kinetic energy grows;
2. it **produces melting or boiling** – the particles' potential energy increases as their arrangement changes. For a pure substance changing state at constant pressure, temperature stays constant. During freezing or condensation, energy is released and potential energy decreases.

Specific heat capacity and temperature changes

While the temperature changes, the energy needed follows (also met in topic 1):

$$\Delta E = m c \Delta \theta$$

Specific heat capacity c (J/kg °C) is the energy needed to raise the temperature of **one kilogram** by **one degree Celsius**.

Worked example. 0.030 kg of olive oil ($c = 1800 \text{ J/kg } ^\circ\text{C}$) warms from $21 ^\circ\text{C}$ to $96 ^\circ\text{C}$.

- Temperature change first: $\Delta\theta = 96 - 21 = 75 ^\circ\text{C}$.

$$\Delta E = mc\Delta\theta = 0.030 \times 1800 \times 75 = 4050 \text{ J}$$

Teacher-written heating-pad example. A 0.20 kg pad with $c = 900 \text{ J/(kg } ^\circ\text{C)}$ warms from $22 ^\circ\text{C}$ to $46 ^\circ\text{C}$. First find $\Delta\theta = 46 - 22 = 24 ^\circ\text{C}$, then:

$$\Delta E = mc\Delta\theta = 0.20 \text{ kg} \times 900 \text{ J/(kg } ^\circ\text{C)} \times 24 ^\circ\text{C} = 4320 \text{ J}$$

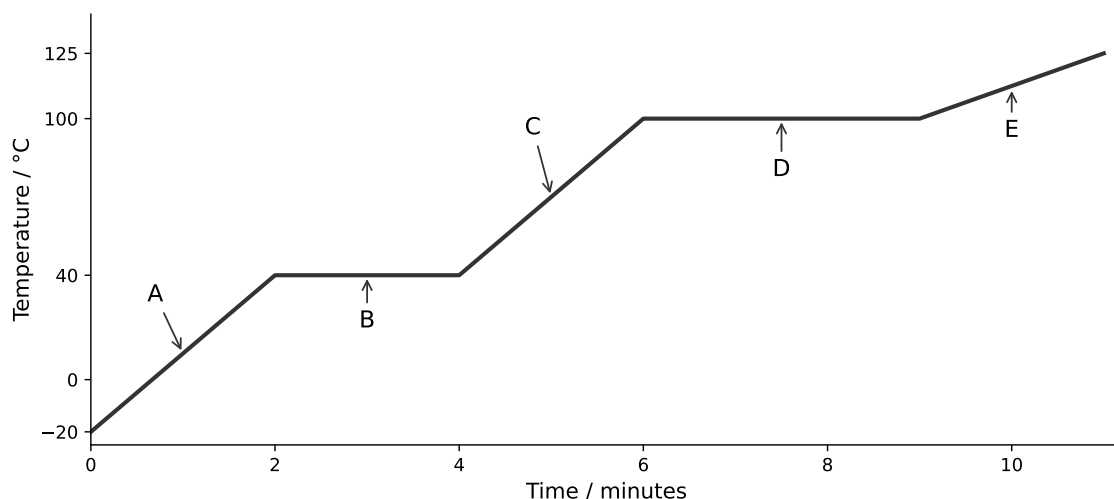
The RP1 method, error analysis and percentage-difference work are covered on sheet 1.3 – the same equation, the same practical.

Specific latent heat and heating graphs

For a pure substance **melting or boiling at constant pressure**, temperature remains constant while energy enters. Freezing and condensation release energy at constant temperature under the same conditions. The energy needed is called **latent heat** :

$$E = mL$$

- E energy for the change of state in J; m mass that changes state in kg; L **specific latent heat** in J/kg.
- **Specific latent heat** is the energy needed to change the state of **one kilogram** of a substance with **no change of temperature**.
- **Fusion** : solid to liquid. **Vaporisation** : liquid to vapour. These are different changes, with different values of L . For water, the specific latent heat of vaporisation is much greater than that of fusion; use the value for the stated material and change.



A and C warm single phases; B is melting; D is boiling; E warms the gas. The temperatures are for this generic substance, not water.

Reading the graph:

- Rising sections: energy goes into kinetic energy – the temperature climbs ($\Delta E = mc\Delta\theta$).
- Flat sections: energy goes into potential energy – the state is changing ($E = mL$). For the same material, change of state and constant net heating power, a longer plateau means more mass changed state. If L or heating power differs, time alone does not identify the mass.
- Cooling has the reverse sequence of state changes: flat while a pure substance freezes or condenses at constant pressure, releasing latent heat. Rates and durations need not mirror the heating graph.

Distinguishing the two: specific heat capacity involves a **temperature change**; specific latent heat involves a **change of state at constant temperature**.

Teacher-written worked example. A 30 W heater runs for 11 minutes and boils off 6.6×10^{-3} kg of water already at its boiling point. Estimate L assuming all heater energy reaches the boiling water, then explain the effect of heat loss.

- Convert: $E = Pt = 30 \text{ W} \times 660 \text{ s} = 19800 \text{ J}$.

$$L = \frac{E}{m} = \frac{19800 \text{ J}}{6.6 \times 10^{-3} \text{ kg}} = 3.0 \times 10^6 \text{ J/kg}$$

■ Actual exam demands: boiling and energy accounting

AQA June 2025 8463/1H Q08.1–08.2: 9950 J boils 50 g of nitrogen at its boiling point. Convert $m = 0.050$ kg, choose $E = mL$ and rearrange:

$$L = E/m = 9950 \text{ J}/0.050 \text{ kg} = 199000 \text{ J/kg}$$

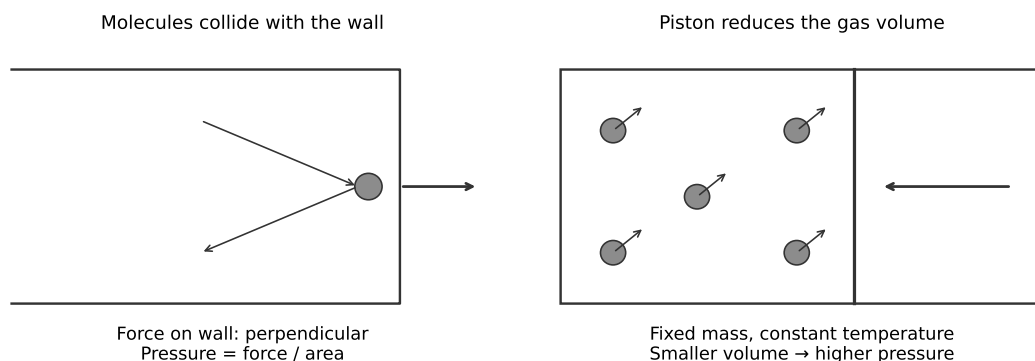
During boiling, potential energy increases while average kinetic energy and temperature remain constant; internal energy increases.

AQA June 2022 Q08.3–08.5: beaker-and-water mass falls from 0.080 kg to 0.071 kg while the heater transfers 25200 J. The evaporated mass is 0.009 kg, so $L = E/m = 25200 \text{ J}/0.009 \text{ kg} = 2.8 \times 10^6 \text{ J/kg}$. Heat transferred to the surroundings makes the heater-energy estimate of L too high. Conversely, including water lost before boiling overstates the mass associated with the measured boiling energy and makes the estimate too low. Identify which measured quantity is biased before predicting the result.

Particle motion in gases

The molecules of a gas are in **constant random motion**. Its temperature is related to the **average kinetic energy** of the molecules: hotter gas, faster particles.

Explain gas pressure using the particle model:



The force on the wall is perpendicular to it; molecules can approach obliquely.

1. the moving molecules **collide with the container walls**;
2. each collision exerts a **force at right angles** to the wall;
3. pressure is force per unit area – the total of many tiny collisions spread over the wall.

Temperature up (constant volume) → pressure up: the molecules move faster on average, so they hit the walls **more often** and **harder** (larger force each impact), so the force per unit area rises.

Actual explanation – AQA June 2025 8463/1H Q08.3: after the nitrogen has boiled, its gas temperature rises in the sealed fixed-volume container. Mean kinetic energy and mean speed increase; collisions exert greater force and occur more frequently, so pressure increases. State the fixed-volume condition.

Pressure in gases (physics only)

A gas can be compressed or expanded by pressure changes. For a **fixed mass of gas at constant temperature**:

$$pV = \text{constant}$$

- p pressure in pascals, Pa; V volume in m^3 .
- Before/after form: $p_1V_1 = p_2V_2$.

The particle explanation of each direction:

- **Volume up** → **pressure down** (constant temperature): at the same average speed, molecules collide with each unit area of wall less frequently, so force per unit area falls.
- **Volume down** → **pressure up**: at the same average speed, molecules collide with each unit area of wall more frequently, so force per unit area rises.

Worked example. A syringe holds 50 cm^3 of air at 100 kPa. It is compressed to 20 cm^3 at constant temperature.

- Convert or keep consistent: volumes in cm^3 cancel; pressures must be consistent.

$$p_1V_1 = p_2V_2 \quad \Rightarrow \quad p_2 = \frac{p_1V_1}{V_2}$$
$$p_2 = \frac{p_1V_1}{V_2} = \frac{100 \text{ kPa} \times 50 \text{ cm}^3}{20 \text{ cm}^3} = 250 \text{ kPa}$$

Doing work on a gas (physics only, Higher Tier)

Work is the transfer of energy by a force. In a rapid compression with little heat transfer to the surroundings, work done on the gas **increases its internal energy** and can raise its temperature.

The credited chain (bicycle pump): pushing the pump's handle does work on the trapped gas → energy is transferred to the gas's particles → their average kinetic energy rises → the temperature of the gas increases (the pump feels warm).

A gas doing work on its surroundings can cool if energy is not replaced by heating. Compression or expansion does not always change temperature: sufficiently slow changes with heat exchange can be approximately isothermal. Do not apply $pV = \text{constant}$ to a rapid compression that heats the gas unless constant temperature is stated or justified.

Checklist before you call this topic done

- Convert g/cm^3 to kg/m^3 , and cm^3 to m^3 , before using $\rho = m/V$.
- Describe RP5 for regular solids, displacement and liquids, with accuracy points.
- State that mass is conserved in changes of state and that they are physical changes.
- Define internal energy as total kinetic plus potential energy of the particles.
- Choose between $\Delta E = mc\Delta\theta$ (temperature changes) and $E = mL$ (state changes).
- Read heating graphs: rising = kinetic energy, plateau = latent heat.
- Explain gas pressure from wall collisions; use $pV = \text{constant}$ with consistent units.
- (physics only, HT) Explain why doing work on a gas raises its temperature.

4 • Atomic structure

AQA • GCSE • Physics

Atomic structure: the unstable nucleus

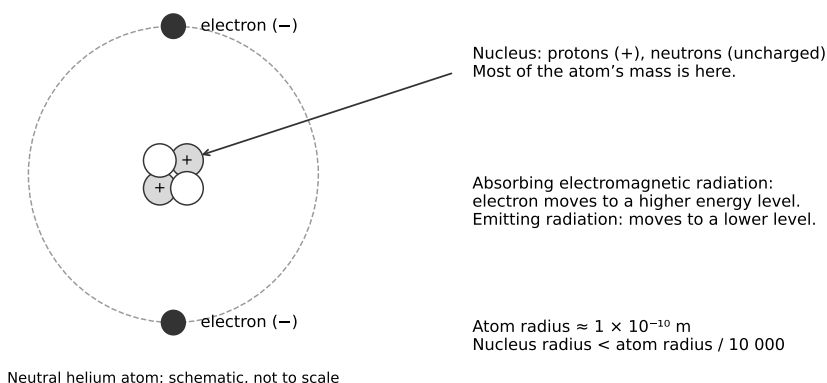
Radioactivity is over a century old, yet it still treats cancer, powers grids and demands strict safety rules. This reference covers **AQA GCSE Physics 8463, topic 4.4 Atomic structure**.

How the exam treats this topic:

- Paper 1 (4.1–4.4) carries this topic. Equation-sheet support depends on the examination series. Practise notation, balanced equations, graphs and explanations as well as calculations.
- Background radiation, half-life hazards, uses and fission/fusion are **physics only**.
- Net-decline ratios after several half-lives are **Higher Tier**.
- You must write **balanced nuclear equations** for single alpha and beta decay (balance atomic numbers and mass numbers; daughter naming not required).

The structure of an atom; isotopes

An atom is very small: radius about 1×10^{-10} m. Its structure:



- **Nucleus:** positively charged, with protons and neutrons; most of the atom's mass, but a radius **less than 1/10 000** of the atom's.
- **Electrons:** negative, arranged in energy levels. Absorbing electromagnetic radiation moves an electron to a higher level, **further** from the nucleus; emission moves it to a lower level, **closer**.

Notation: ${}^A_ZX$ where Z = **atomic number** (protons) and A = **mass number** (protons + neutrons). In a neutral atom, electrons = protons; atoms have no overall charge.

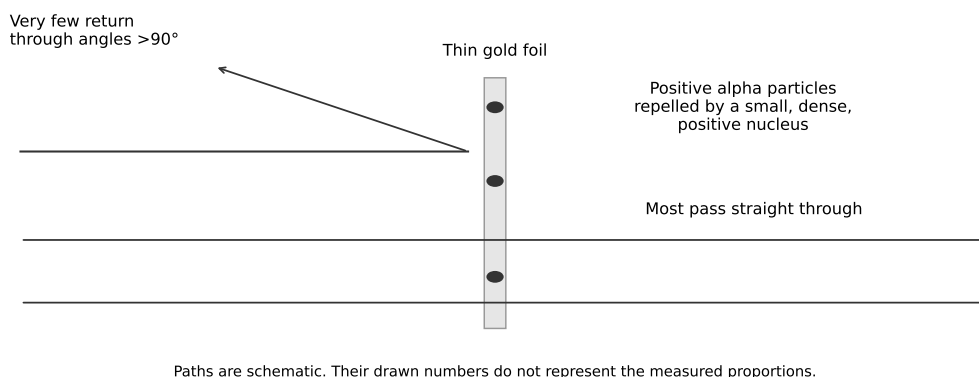
- **Isotopes** : atoms of the **same element** (same Z) with **different numbers of neutrons** (different A).
- Neutrons in the nucleus = $A - Z$.
- Atoms that lose one or more outer electrons become **positive ions**.

Worked example. Carbon-14: ${}^{14}_6\text{C}$.

- Protons = 6; electrons = 6 (neutral); neutrons = $14 - 6 = 8$.
- Carbon-12 has 6 neutrons – same element, different neutrons: isotopes.

The development of the model of the atom

New **experimental evidence** can change or replace a scientific model:



1. Before the electron's discovery: atoms were **tiny spheres** that could not be divided.
2. Electron discovered → the **plum pudding model**: a ball of positive charge with negative electrons embedded in it.
3. **Alpha scattering** (Rutherford): most alpha particles passed straight through, a few bounced back → the mass and positive charge must be concentrated in a tiny centre → the **nuclear model** replaced the plum pudding model.
4. **Bohr** adapted it: electrons orbit at **specific distances**; his calculations agreed with observations.
5. Further work showed the positive charge comes in whole-number units – the **proton**; **Chadwick's** experiments (about 20 years later) proved the **neutron**.

Explain the evidence that changed the model: if the pudding were right, alpha particles should all pass through with small deflections (B1); some bounced almost straight back (B1), which is only possible if the mass and positive charge sit in a tiny, dense, positive nucleus (B1).

Radioactive decay and nuclear radiation

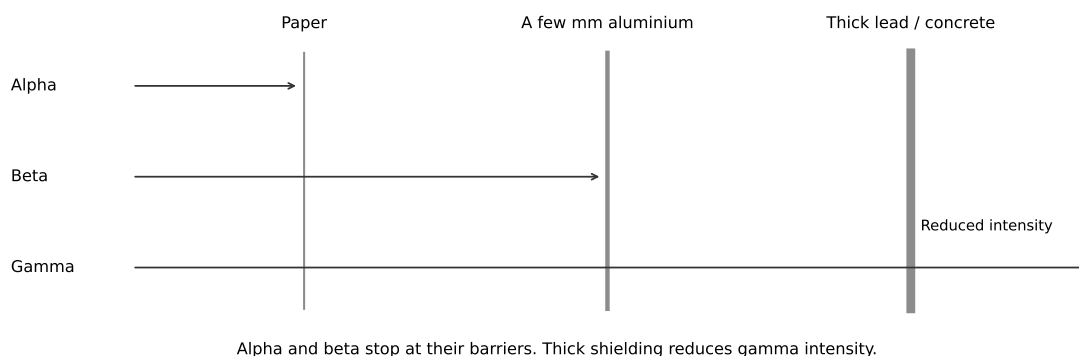
Some nuclei are **unstable**. They give out radiation as they change to become more stable – a **random** process called **radioactive decay**.

- **Activity** : the rate at which a source decays; unit **becquerel** (Bq).
- **Count-rate** : detector counts per second, after allowing for background where needed. A detector usually records only some emissions: its count rate is not automatically the source activity in Bq.

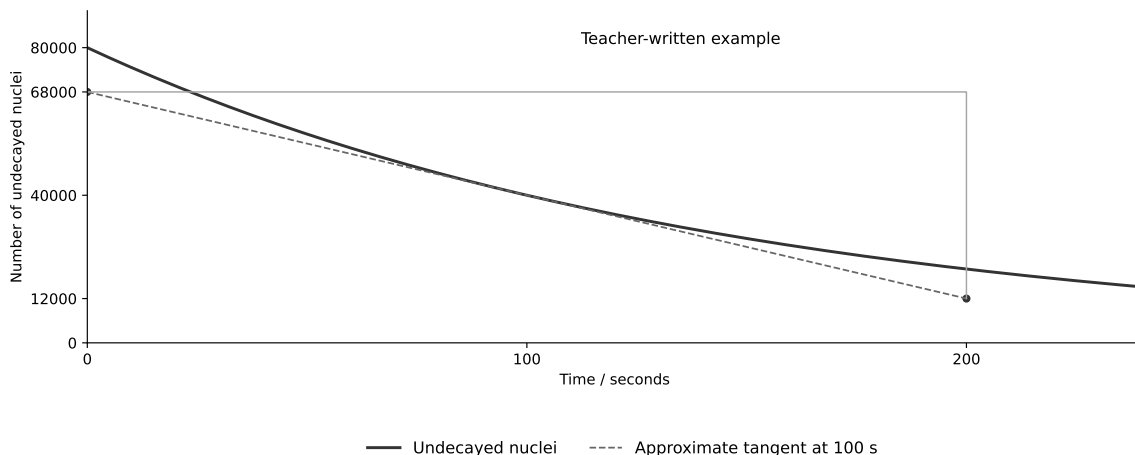
Radiation	Identity	Ionising power	Shielding
alpha α	helium nucleus	strong	paper / skin
beta β	fast electron	medium	mm of aluminium
gamma γ	EM radiation	weak	thick lead reduces it

Alpha contains two protons and two neutrons and travels only a few centimetres in air. Beta is emitted when a neutron changes into a proton; its range in air is longer. Gamma has the greatest range of these three and is reduced, not completely stopped, by thick lead or concrete. A nucleus can also emit a neutron; detailed neutron properties are not required here.

Choose a source for a use by matching these properties: alpha for ionisation smoke alarms (smoke reduces the ionisation current); beta for thickness control (partly absorbed by the sheet); gamma for tracers (escapes the body) and sterilising (penetrates packaging and damages microorganisms). A sealed source reduces contamination risk; it does not justify ignoring handling precautions.



Activity from a graph. On a graph of the number of undecayed nuclei against time, draw a tangent at the stated time. Its downward gradient is the rate of decrease in the number of nuclei; activity is the positive magnitude, in Bq. Read two widely separated points on the tangent, not two arbitrary points on the curve.



Worked example (teacher-written). The approximate tangent passes through (0 s, 68000) and (200 s, 12000).

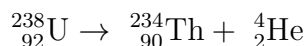
$$\text{activity} = \frac{\text{decrease in number of nuclei}}{\text{time interval}} = \frac{68000 - 12000}{200 \text{ s} - 0 \text{ s}} = 280 \text{ Bq}$$

This is an estimate from a drawn tangent. AQA June 2024 8463/1H Q09.5 requires the same method on its own graph at 300 s; its official answer is 7.1×10^{20} Bq. Those are different graphs and data.

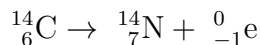
Nuclear equations

Balance **mass numbers** (top) and **atomic numbers** (bottom) on both sides:

- **Alpha decay:** the nucleus loses 4 from the top and 2 from the bottom.



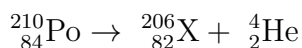
- **Beta decay:** a neutron turns into a proton; mass number **unchanged**, atomic number **+1**; the beta particle is ${}_{-1}^0\text{e}$.



- **Gamma emission:** changes neither number.

Worked example. Polonium-210 decays by alpha emission. Write the equation.

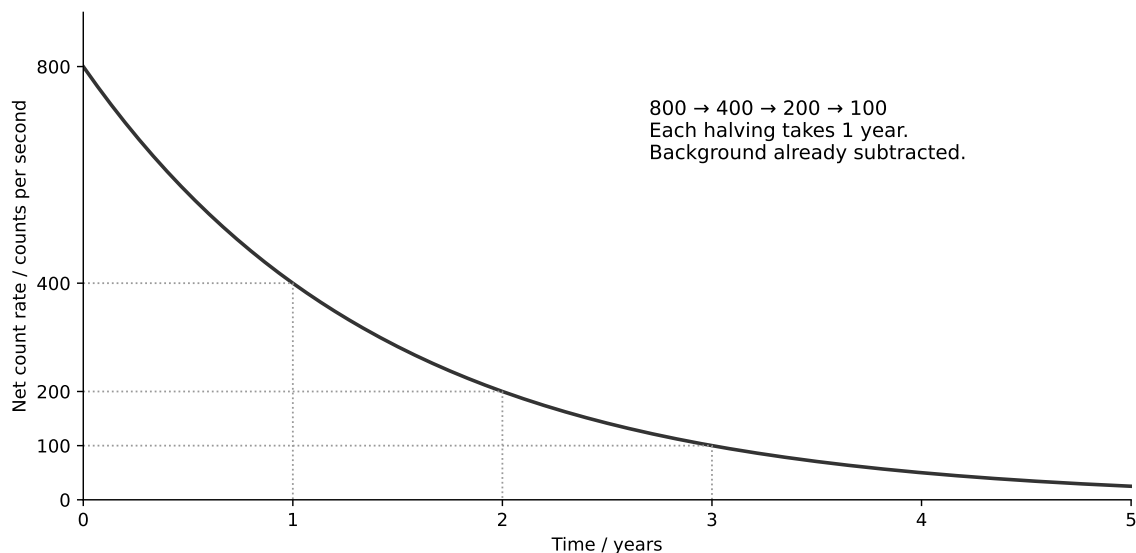
- Alpha removes 4 and 2: $A : 210 - 4 = 206$; $Z : 84 - 2 = 82$.



- Check both rows balance ✓ (the daughter's name is not required).

Half-lives and the random nature of decay

Decay is **random**: it cannot be predicted for any one nucleus; only the average behaviour of many is predictable.



Half-life : the time for (a) the number of nuclei of the isotope in a sample to halve, or (b) the net count rate / activity to fall to **half** its initial level. Subtract background from detector readings first and keep the detector geometry unchanged.

- From a graph: read the time for the count rate to halve – repeat over several halvings and average.
- After n half-lives, the fraction remaining is $1/2^n$ (HT: express as a ratio).

Worked example. A sample's activity falls from 800 Bq to 200 Bq in 12 years.

- Halvings: $800 \rightarrow 400 \rightarrow 200$ is two halvings.

$$t_{1/2} = \frac{12 \text{ years}}{2} = 6 \text{ years}$$

Actual AQA demand, June 2025 8463/1H Q07.4: polonium-210 has a half-life of 138 days. The number of atoms falls from 256 000 to 16 000: four halvings, so the time is $4 \times 138 = 552$ days. Q07.5 compares equal numbers of Po-209 and Po-210 atoms: the longer-lived Po-209 has lower activity. The equal-population condition matters.

Radioactive contamination

- **Contamination** : unwanted radioactive atoms **on or inside** an object or person. The hazard lasts as long as the atoms are there, decaying on or in the body.

- **Irradiation** : exposing an object to radiation. The irradiated object **does not become radioactive**.

Contamination can continue to irradiate tissue while the radioactive atoms remain. Exposure from an external source ends when that source is removed or effectively shielded. Compare the source activity, radiation type, distance, exposure time and whether material is inside the body; contamination is not always the larger dose. External alpha has low penetration and is stopped by skin, but internally its strong ionisation can damage nearby living tissue.

Precautions: hold sources with **tongs**, keep them at a **distance**, limit **time** near them, point them away from people, store in lead-lined boxes. Findings on radiation effects are **published and peer-reviewed** so they can be checked.

Background radiation (physics only)

Background radiation is around us all the time:

- **natural**: rocks (radon gas), cosmic rays from space, food and naturally occurring isotopes in the body;
- **man-made**: fallout from weapons testing, nuclear accidents, medical uses.

Dose depends on **occupation and location** (high altitude, certain industries). Dose unit: sieverts ($1000 \text{ mSv} = 1 \text{ Sv}$; recall not required).

Measurements of a sample must **subtract the background count-rate** first.

Half-life hazards and uses of radiation (physics only)

Half-life and hazard: for equal numbers of unstable nuclei, a shorter half-life means greater activity. Amount and exposure conditions also matter. A long-lived source may require secure storage for many years. A medical tracer should remain active long enough for the investigation, then decay quickly to reduce further dose. A smoke-alarm source must remain useful for years.

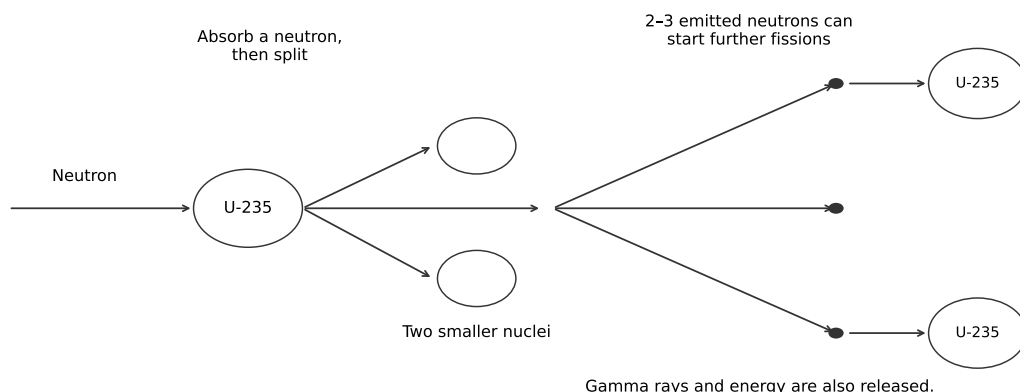
Medical uses (each = exploration or destruction):

- **Exploration**: a gamma-emitting tracer (e.g. technetium-99m) injected so organs show on a scan; gamma escapes the body; a suitable short half-life limits dose after the scan.
- **Destruction**: focused gamma beams or implanted sources kill cancer cells (radio-therapy); beta for skin conditions.

Evaluating risk: compare the dose and consequence of the procedure against the risk of the illness – with numbers from the question.

Nuclear fission and fusion (physics only)

Fission : the splitting of a **large, unstable** nucleus (uranium-235, plutonium-239).



- Spontaneous fission is rare: the nucleus usually **absorbs a neutron** first.
- It splits into **two smaller nuclei of roughly equal size**, releasing **two or three neutrons** and **gamma rays**; **energy is released** and all products carry kinetic energy.
- The released neutrons can cause further fissions – a **chain reaction**. A reactor **controls** it (control rods absorb neutrons); a weapon's explosion is an **uncontrolled** chain.
- You must draw or interpret the diagram: neutron in → two fragments + neutrons out → branching chain.

Fusion : **two light nuclei join** to form a heavier nucleus; some mass converts into the energy of radiation. To join, the positive nuclei must approach closely despite their electrical repulsion. Do not describe fusion as chemical bonding or claim that every fusion system is waste-free.

Checklist before you call this topic done

- Find protons, neutrons and electrons from A, Z ; identify isotopes and ions.
- Explain how experimental evidence changed atomic models.
- Compare $\alpha/\beta/\gamma$ properties and select suitable sources for a use.
- Balance single alpha/beta equations and check both rows.
- Find half-life and (HT) net decline; find activity from a tangent gradient.
- Subtract background; distinguish detector counts from source activity.
- Compare irradiation/contamination hazards and precautions.
- (physics only) Explain background, medical uses, half-life choices and fission/fusion.

5 • Forces

AQA • GCSE • Physics

Forces: pushes, pulls and their effects

A bridge, a brake, a bungee cord, a planet in orbit: engineers analyse them all with forces. This reference covers **AQA GCSE Physics 8463, topic 4.5 Forces** – the largest topic of Paper 2.

How the exam treats this topic:

- Paper 2 (4.5–4.8) carries this topic, and it may also draw on energy and electricity ideas. Equation-sheet support depends on the examination series. Practise choosing an equation, rearranging it and using SI units; check the sheet supplied for your examination.
- Moments, levers and gears and fluid pressure are **physics only**. Interpreting terminal-velocity graphs is also physics only. Momentum is **Higher Tier**; collision calculations and changes in momentum are physics only.
- Free-body diagrams, vector diagrams (scale drawing) and resolution of forces are **HT only**.
- Required practicals: RP6 (force–extension of a spring) and RP7 (force and mass effect on acceleration).

Scalars, vectors and forces

Scalar : magnitude only – distance, speed, mass, energy. **Vector** : magnitude **and** direction – displacement, velocity, force, weight, momentum. A vector is drawn as an arrow: length = magnitude, direction = direction.

A **force** is a push or pull from the interaction with another object:

- **contact** forces (touching): friction, air resistance, tension, normal contact force;
- **non-contact** forces (separated): gravitational, electrostatic, magnetic.

Gravity: weight of mass is the force on an object due to gravity; it acts at the **centre** and is measured with a calibrated spring-balance (newtonmeter):

$$W = mg$$

- W weight in N; m mass in kg; g gravitational field strength in N/kg (given, usually 9.8 near Earth).
- Weight and mass are directly proportional ($W \propto m$).

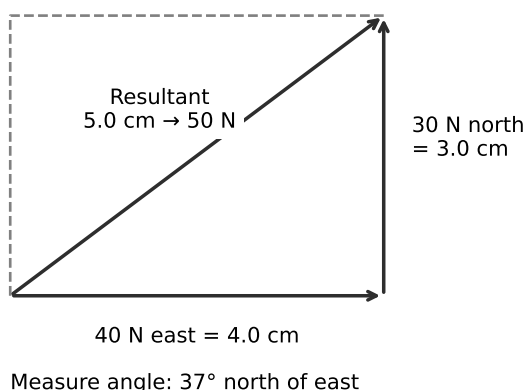
Resultant force : the single force replacing several forces with the same effect. Collinear: add same-direction forces, subtract opposite ones. (HT) Use **free-body**

diagrams (only the forces on the chosen object), resolve a force into perpendicular components, and find resultants by **scale drawing**.

Worked example. A 65 kg person stands on Mars where $g = 3.7 \text{ N/kg}$.

$$W = mg = 65 \times 3.7 = 240 \text{ N (2 s.f.)}$$

Scale: 1.0 cm represents 10 N



Worked scale drawing (HT; teacher-written). Use 1 cm for 10 N. Draw 4.0 cm east, then 3.0 cm north. The resultant joins the first tail to the last head: 5.0 cm represents 50 N, about 37° north of east. The equilibrant has equal magnitude in the opposite direction.

Exam demand. AQA June2025 8463/2H Q05.5 uses 240 N upwards and 200 N left. A scale triangle or parallelogram gives about 310 N, 40° left of vertical (official ranges 300–320 N and $38\text{--}42^\circ$). The diagram, arrow directions and scale are part of the method.

Work done and energy transfer

A force does **work** when it moves its point of application through a distance:

$$W = Fs$$

- W work done in J; F force in N; s distance **moved along the line of action of the force**, in m.
- **1 J = 1 N · m**: one joule is the work of one newton over one metre.
- Work done against friction raises the object's temperature – the energy transfers to thermal stores.

Worked example. A child pushes a baby walker 2.8 m with a horizontal force of 25 N.

$$W = Fs = 25 \text{ N} \times 2.8 \text{ m} = 70 \text{ J}$$

Forces and elasticity (RP6)

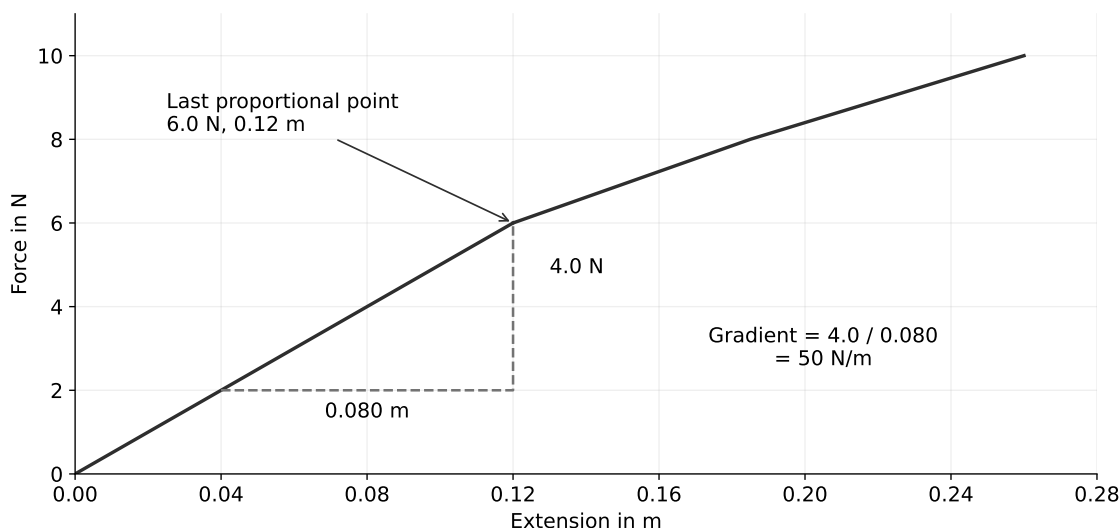
More than one force is needed to stretch, bend or compress a **stationary** object (a single force would just move it). **Elastic** deformation is recovered when the forces are removed; **inelastic** is not.

Below the **limit of proportionality**:

$$F = ke \quad E_e = \frac{1}{2}ke^2$$

- k spring constant in N/m (stiff spring $\rightarrow$ large k); e extension = stretched length – original length (or compression).
- Work done on the spring = elastic energy stored (if not inelastically deformed).

Required practical 6: hang masses on a spring, measure extension for each (ruler at eye level), plot force against extension. The linear section's **gradient is k** ; beyond the limit of proportionality the line curves. Hooke's-law reasoning: doubling the force doubles the extension only below the limit.



Worked example (AQA June2025 Q02.7). A force of 4.0 N produces extension 0.064 m. Choose $F = ke$ in the proportional region, then rearrange:

$$k = \frac{F}{e} = \frac{4.0 \text{ N}}{0.064 \text{ m}} = 62.5 \text{ N/m}$$

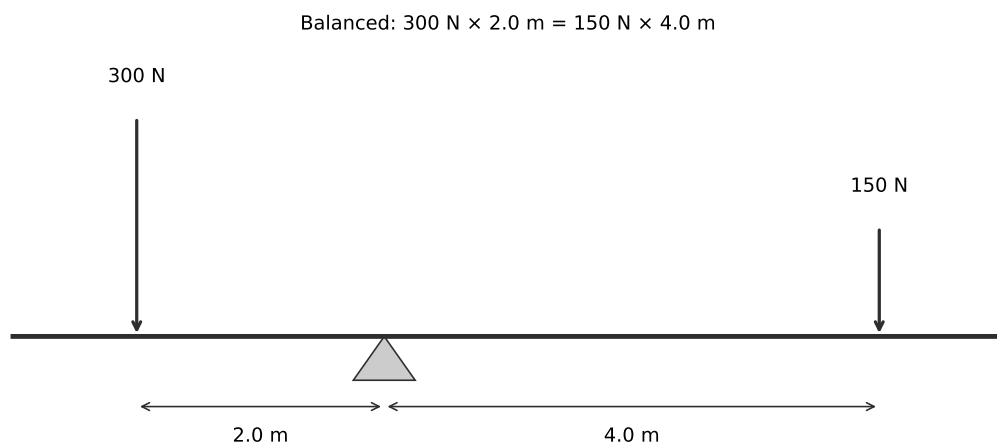
A plot of total **length** has a non-zero intercept because the unloaded spring has a non-zero length. A curve away from the proportional line means F and e are no longer proportional; unload the spring to test for permanent deformation. Secure the stand, limit loading, keep the ruler vertical and close, and use a pointer at eye level.

Moments, levers and gears (physics only)

$$M = Fd$$

- M moment in $\text{N} \cdot \text{m}$; d is the **perpendicular distance from the pivot to the line of action** of the force.
- **Balance:** total clockwise moment = total anticlockwise moment.

Levers and **gears** transmit the rotational effect of a force. A longer lever arm produces a larger moment for the same perpendicular force. In an ideal pair of meshed gears, the teeth exert equal forces at the contact: a larger driven gear turns more slowly with a larger moment. The meshed gears turn in opposite directions.



Worked example. Choose the pivot and equate clockwise and anticlockwise moments:

$$F_R d_R = F_L d_L$$

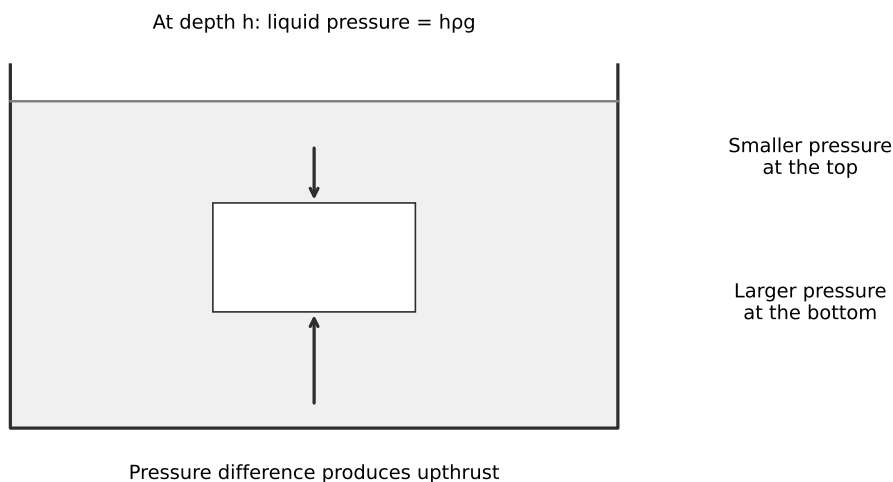
$$F_R = \frac{F_L d_L}{d_R} = \frac{300 \text{ N} \times 2.0 \text{ m}}{4.0 \text{ m}} = 150 \text{ N}$$

For AQA June2024 Q02.6, convert the perpendicular distance 7.5 cm to 0.075 m: $M = Fd = 2.0 \text{ N} \times 0.075 \text{ m} = 0.15 \text{ N m}$. In a pair of meshed gears, the teeth produce a force and moment on the other gear; adjacent gears rotate in opposite directions.

Pressure and fluids (physics only)

$$p = \frac{F}{A} \quad (\text{HT only}) \quad p = h\rho g$$

- p pressure in Pa; F force **normal** to the surface; A area in m^2 .
- (HT) h column height in m, ρ liquid density in kg/m^3 . Pressure grows with depth and density.
- A submerged object feels greater pressure on its bottom than its top $\rightarrow$ a resultant **upthrust**. Floating at rest: upthrust = weight. If weight initially exceeds upthrust, a released object accelerates downwards; a sinking object can later move at constant speed when upthrust plus drag balances its weight.
- **Atmospheric pressure** decreases with height: fewer air molecules above a surface as you climb, so less weight of air; the atmosphere gets less dense with altitude.



Worked example (teacher-written; HT). A 2.0 m water column has density $1000 \text{ kg}/\text{m}^3$; $g = 9.8 \text{ N}/\text{kg}$. Its pressure, additional to that at the free surface, is:

$$p = h\rho g = 2.0 \text{ m} \times 1000 \text{ kg}/\text{m}^3 \times 9.8 \text{ N}/\text{kg} = 19600 \text{ Pa}$$

Floating at rest requires a complete force balance. A sinking object can reach constant velocity when **upthrust + drag = weight**; sinking does not always mean downward acceleration.

Describing motion along a line

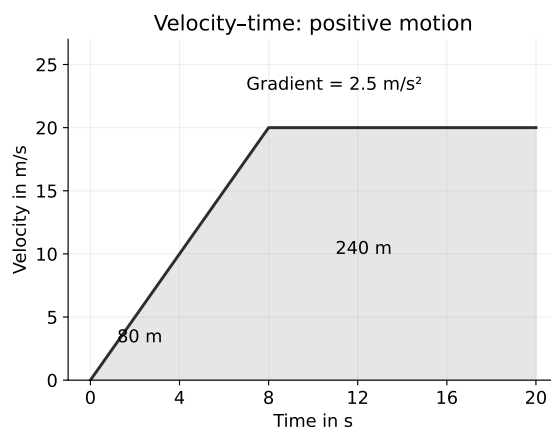
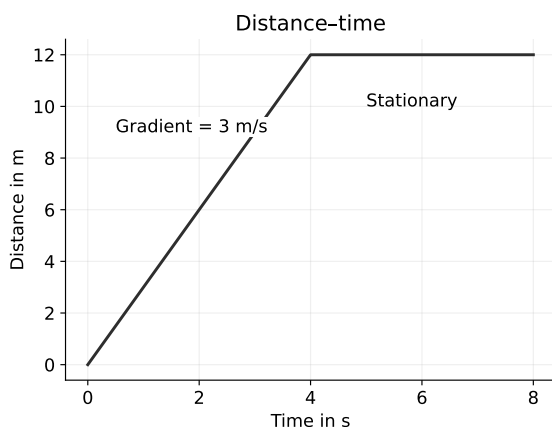
- **Distance** (scalar): how far. **Displacement** (vector): straight-line distance **and direction**.

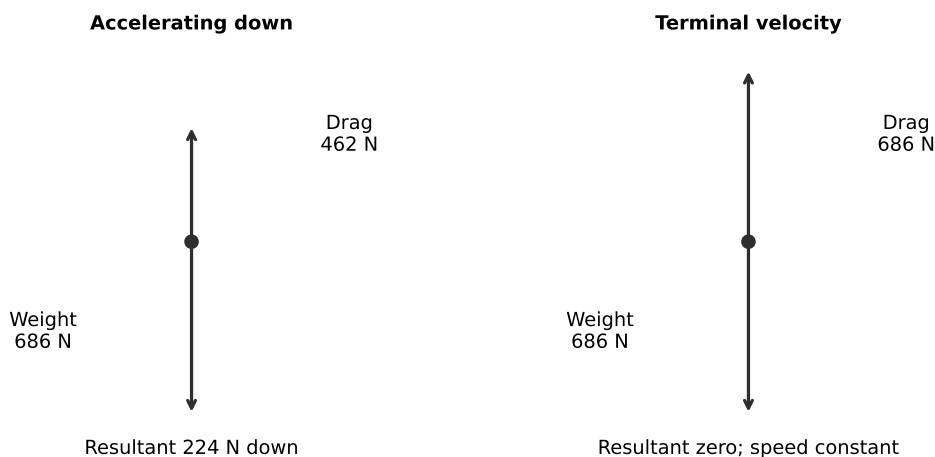
- **Speed** (scalar) – typical values: walking ≈ 1.5 m/s, running ≈ 3 m/s, cycling ≈ 6 m/s, sound in air ≈ 330 m/s. **Velocity** (vector): speed in a given direction.
- $s = vt$ (constant speed); average speed = total distance $\div$ total time.
- **Distance–time graph**: gradient = speed; (HT) a tangent gives instantaneous speed of an accelerating object.
- **Acceleration** : $a = \Delta v/t$, in m/s^2 ; deceleration means slowing down. With the initial direction chosen positive, its acceleration is negative. Estimate everyday accelerations.
- **Velocity–time graph**: gradient = acceleration; (HT) signed area gives displacement. Add the magnitudes of areas above and below zero to find total distance. If velocity stays positive, area also gives distance.
- Uniform acceleration: $v^2 - u^2 = 2as$. Free fall near Earth: $a \approx 9.8$ m/s^2 .

Worked example (graph). A v - t graph rises straight from 0 to 20 m/s in 8 s, then stays flat for 12 s.

- Acceleration (gradient): $a = \Delta v/\Delta t = (20 - 0)/8 = 2.5$ m/s^2 .
- (HT) Positive-velocity areas: $s = s_1 + s_2 = \frac{1}{2}\Delta t_1 v + v\Delta t_2 = \frac{1}{2} \times 8 \times 20 + 20 \times 12 = 320$ m.

Terminal velocity : a falling object accelerates (weight > drag); as speed grows, drag grows until resultant force = 0 – constant speed = **terminal velocity**. Skydiver: fast terminal before the chute, slow after; interpret the v - t curve shape.





Worked tangent example (HT; teacher-written). At a chosen instant, a tangent to a distance–time curve passes through (2 s, 3 m) and (6 s, 15 m):

$$v = \frac{\Delta s}{\Delta t} = \frac{(15 - 3) \text{ m}}{(6 - 2) \text{ s}} = 3.0 \text{ m/s}$$

This is instantaneous speed at the point of tangency. A chord over a time interval instead gives an average rate.

Exam demand. AQA June2025 Q05.2 gives mean acceleration 0.64 m/s^2 from rest for 2.5 minutes. Convert time to 150 s, then:

$$v = u + a\Delta t = 0 + 0.64 \text{ m/s}^2 \times 150 \text{ s} = 96 \text{ m/s}$$

Q05.3 needs the linked terminal-velocity explanation: speed rises $\rightarrow$ drag rises $\rightarrow$ drag equals weight $\rightarrow$ resultant and acceleration become zero. On opening a parachute, drag initially exceeds weight: upward acceleration slows the still downward-moving skydiver.

Newton's laws (RP7)

- **First law:** zero resultant force $\rightarrow$ stationary stays stationary; moving keeps the same velocity. For motion in a straight line at steady speed, driving force = resistive forces. (HT) **Inertia** : the tendency to keep the state of motion.
- **Second law:** $a \propto F$, $a \propto 1/m$, so:

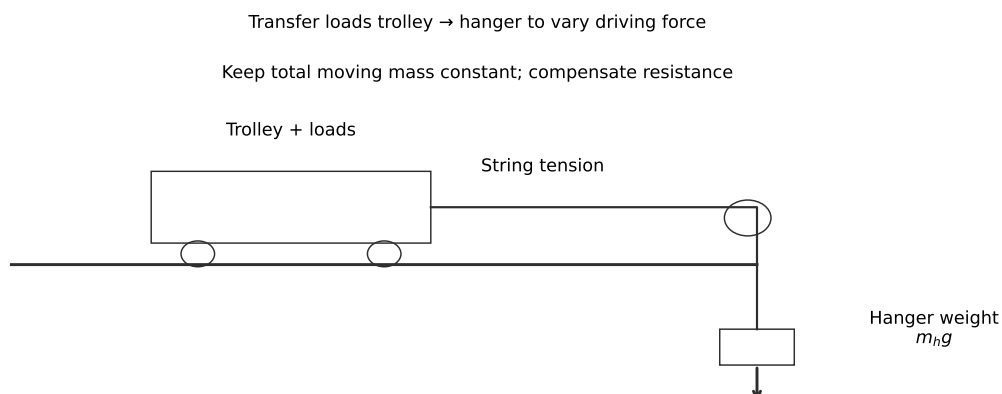
$$F = ma$$

(HT) **Inertial mass** = force $\div$ acceleration – resistance to change of velocity.

Required practical 7: trolley on a runway – vary the driving force by transferring masses from the trolley to its hanging holder, keeping the **total moving mass**

constant. For the combined trolley–hanger system, the driving force is the hanger’s weight when resistance is negligible or compensated; the string tension on the trolley is a different force. Then keep hanger mass constant and add mass to the trolley. Measure acceleration with light gates; plot a against driving force at fixed total mass, or a against $1/m$ where m is total moving mass.

- **Third law:** two interacting objects exert **equal and opposite** forces on **each other** – same type, opposite directions, on different objects.



Worked uncertainty example (AQA June2024 Q05.4). Three accelerations are 1.36, 1.39 and 1.33 m/s². The range is 0.06 m/s²; using half the range, report uncertainty ± 0.03 m/s². Repeats reveal spread; a mean reduces random variation but does not remove a common calibration error.

From rest under uniform acceleration, acceleration can also be found from distance and time: average speed is s/t , final speed is twice the average, and acceleration is final speed divided by time. State the rest/uniform-acceleration assumptions.

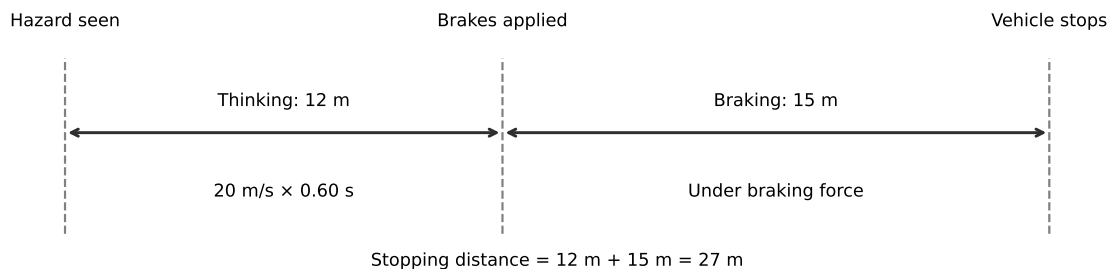
Forces and braking

Stopping distance = thinking distance + braking distance.

- **Thinking** (reaction) distance = reaction time $\times$ speed. Reaction time 0.2–0.9 s typically; affected by tiredness, drugs, alcohol, distractions. Measure it: drop a ruler between a partner’s fingers – distance fallen $\rightarrow$ time from $s = \frac{1}{2}at^2$ (or electronic timers).
- **Braking distance:** grows with speed (for a given braking force); wet or icy roads, worn brakes or tyres lengthen it.
- Braking physics: friction between brake and wheel does work on the kinetic energy store; the brakes’ temperature rises; a higher speed or shorter stop $\rightarrow$ larger force needed $\rightarrow$ larger deceleration $\rightarrow$ **overheating brakes, loss of control**. (HT) Estimate deceleration forces with $F = ma$.

Worked example. A 1500 kg car brakes from 30 m/s to rest in 60 m.

- Choose initial motion positive. From $v^2 - u^2 = 2as$, $a = (v^2 - u^2)/(2s) = (0 - 30^2)/(2 \times 60) = -7.5 \text{ m/s}^2$.
- Braking-force magnitude: $|F| = m|a| = 1500 \times 7.5 = 11250 \approx 11000 \text{ N}$, opposite the initial motion.



Worked exam example (AQA June 2025 Q06.3). A 1400 kg car slows uniformly from 18 m/s to rest over 24 m of **braking**. Choose the initial direction positive:

$$a = \frac{v^2 - u^2}{2s} = \frac{0 - (18 \text{ m/s})^2}{2 \times 24 \text{ m}} = -6.75 \text{ m/s}^2$$

$$F = ma = 1400 \text{ kg} \times (-6.75 \text{ m/s}^2) = -9450 \text{ N}$$

The force has magnitude 9450 N, opposite the initial motion. Do not insert thinking distance into the braking equation.

Momentum (HT; calculations physics only)

$$p = mv \quad F = \frac{m\Delta v}{\Delta t}$$

- p momentum in kg m/s (a vector); conservation: in a **closed system**, total momentum before = total momentum after an event (collisions).
- $F = m\Delta v/\Delta t$: force = **rate of change of momentum** (this is $F = ma$ restated).
- Safety features explained by it: air bags, seat belts, crash mats, cycle helmets, cushioned playgrounds – all **increase the time** over which momentum changes, so $\Delta v/\Delta t$ falls and the force falls.

Worked example. A 1000 kg car at 20 m/s hits a barrier and stops in 0.25 s.

- Magnitude of momentum change: $|\Delta p| = m|\Delta v| = 1000 \times 20 = 20\,000 \text{ kg m/s}$.
- Mean force magnitude: $|\bar{F}| = |\Delta p|/\Delta t = 20\,000/0.25 = 80\,000 \text{ N}$, opposite the motion. With a crumple zone ($\Delta t = 0.50 \text{ s}$), the mean force magnitude halves to 40 000 N for the same momentum change.

Worked collision example (sheet 5.9). A 2.0 kg trolley moving right at 3.0 m/s sticks to a stationary 1.0 kg trolley. With negligible external horizontal impulse, take right positive:

$$p_i = m_A u_A + m_B u_B = 2.0 \times 3.0 + 1.0 \times 0 = 6.0 \text{ kg m/s}$$

$$v = \frac{p_i}{m_A + m_B} = \frac{6.0 \text{ kg m/s}}{3.0 \text{ kg}} = 2.0 \text{ m/s right}$$

Momentum conservation does not require kinetic energy conservation. For a rebound, keep signed velocities: a 0.16 kg ball changes from +12 to -8.0 m/s, so $\Delta p = m(v - u) = -3.2 \text{ kg m/s}$. Over 0.020 s, mean force is $\bar{F} = \Delta p / \Delta t = -160 \text{ N}$ (160 N left). The wall experiences the equal, opposite mean force.

Air-bag explanation (AQA June2025 Q06.2). For the same driver and momentum change, the bag lengthens stopping time, reducing the rate of momentum change and mean force. This reduces injury risk; it does not guarantee a harmless collision.

Checklist before you call this topic done

- Classify scalar/vector, contact/non-contact; compute $W = mg$; find collinear resultants; (HT) draw free-body and scale-diagram resultants.
- $W = Fs$ with energy transfer story; $F = ke$, $E_e = \frac{1}{2}ke^2$; RP6 with gradient = k .
- (physics only) Moments balance; levers and gears trade force for distance; $p = F/A$, (HT) $p = h\rho g$; upthrust and floating; atmospheric pressure vs height.
- Distance vs displacement; typical speeds; read d-t and v-t graphs (gradient, tangent, area); $v^2 - u^2 = 2as$; terminal velocity story.
- Newton's three laws with examples; RP7 method and graphs.
- Stopping distance split; reaction-time measurement; braking energy and deceleration dangers.
- (HT) $p = mv$, conservation in collisions, $F = m\Delta v / \Delta t$, safety features via longer Δt .

6 • Waves

AQA • GCSE • Physics

Waves: energy that travels

Ripples on a pond, the sound of a voice, the light of a distant star – all are waves carrying energy from a source to an absorber. This reference covers **AQA GCSE Physics 8463, topic 4.6 Waves**.

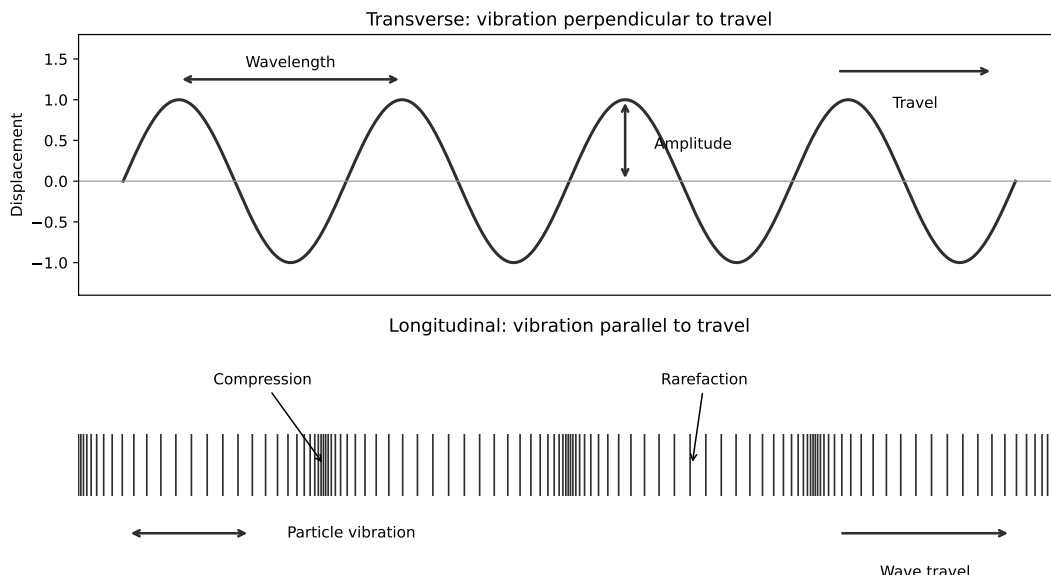
How the exam treats this topic:

- Paper 2 carries this topic. $T = 1/f$, $v = f\lambda$ and magnification may be supplied on the equation sheet; check the examination series.
- Reflection (RP9), sound, detection waves, lenses, visible light and black-body radiation are **physics only**; sound and detection are also **HT only**; parts of EM properties are **HT only**.
- Required practicals: RP8 (wave speed in a ripple tank and a solid) RP9 (reflection and refraction, physics only), and RP10 (infrared absorption and emission by surfaces).
- You must **construct ray diagrams** for reflection, refraction and lenses.

Transverse and longitudinal waves

Type	Vibration direction	Examples
transverse	across the travel direction	water ripples, all electromagnetic waves
longitudinal	along the travel direction	sound in air

Longitudinal waves show **compressions** (particles squashed) and **rarefactions** (particles spread).



Evidence that the wave travels, not the material: a ripple moves across a pond but particles oscillate about their equilibrium positions, with no net transport of the medium in this model. A floating ball bobs as ripples pass; air particles vibrate as sound passes.

Properties of waves and the wave equation

Quantity	Meaning	Unit
amplitude	maximum displacement from the undisturbed position	m
wavelength	distance from a point on one wave to the equivalent point on the next	m
frequency	number of waves passing a point each second	Hz
period	time for one wave	s

$$T = \frac{1}{f} \quad v = f\lambda$$

- Wave speed is the speed at which **energy is transferred** through the medium.
- Read amplitude and wavelength straight off a labelled diagram.

Worked example. A water wave has frequency 2.0 Hz and wavelength 0.35 m.

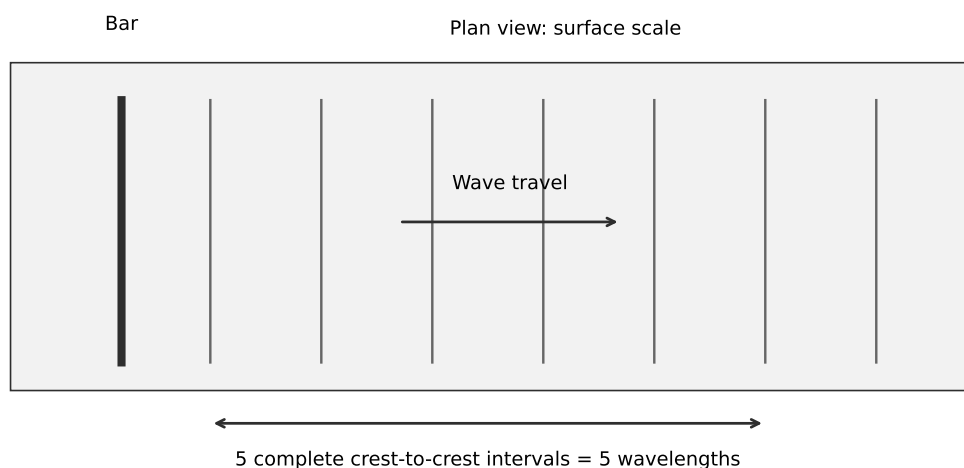
$$v = f\lambda = 2.0 \times 0.35 = 0.70 \text{ m/s}$$

Worked example (kHz). Sound of frequency 4.0 kHz travels at 330 m/s.

- Convert: $f = 4000 \text{ Hz}$.

$$\lambda = \frac{v}{f} = \frac{330}{4000} = 0.0825 \approx 8.3 \times 10^{-2} \text{ m}$$

■ Measuring wave speeds (RP8)



- **Ripples:** a straight-bar motor makes straight wavefronts. Measure the distance across several complete crest-to-crest intervals at the water surface using a calibrated scale, then divide by the number of intervals. If measuring a projected pattern, correct for its magnification. Time several complete cycles at a fixed point: $f = N/t$, then $v = f\lambda$. Keep water depth fixed and repeat.
- **Waves in a solid:** drive a stretched string with a signal generator. Adjust frequency to give clear stationary loops; each loop is half a wavelength. For n loops over length L , $\lambda = 2L/n$. Read f from the generator and calculate $v = f\lambda$; control tension and string type.
- **Speed of sound:** measure perpendicular distance d from a large wall. Time the interval t from a sharp sound to its echo; the sound travels $2d$, so $v = 2d/t$. Repeat and average; electronic recording reduces reaction-time error. Alternatively use two electronic detectors a measured distance apart for a one-way time.

(Physics only) Sound changing medium: at a stationary boundary with a stationary source, frequency stays the same. If speed changes, wavelength changes in the same ratio because $\lambda = v/f$.

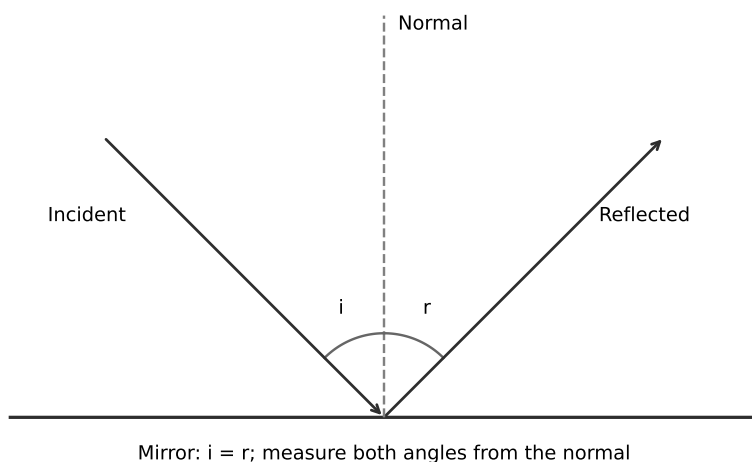
Reflection (physics only)

At a boundary parts of the incident energy may be **reflected**, **absorbed** and **transmitted**:

- **specular reflection** : from a smooth surface, one direction;
- **diffuse reflection** : from a rough surface, scattered;
- **absorption**: energy stays in the material; **transmission**: passes through.

Construct the reflection ray diagram: the **normal** at right angles to the surface at the point of incidence; the angle of incidence equals the angle of reflection – both measured

from the normal.



RP9: shine a ray box at plane mirror / rough surfaces; trace incident and reflected rays with a pencil, measure angles with a protractor; for refraction, pass light through a glass block and trace the bent path at each boundary.

Sound waves and hearing (physics only, HT)

Sound travels through solids as vibrations. In the ear, sound waves vibrate the ear drum and other parts – the vibrations are passed through ear structures and converted into signals that the brain interprets. This works only over a limited frequency range: **human hearing spans 20 Hz to 20 kHz**. Examples of conversion: a microphone's diaphragm, a drum skin, windows rattling near a bass speaker.

Waves for detection (physics only, HT)

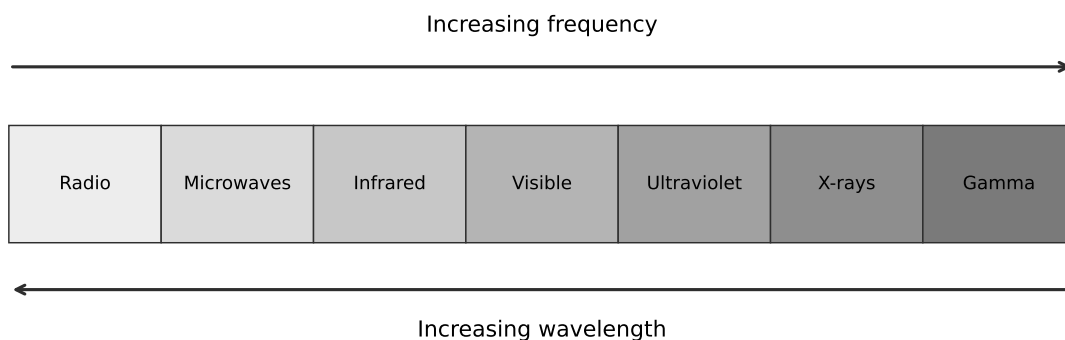
- **Ultrasound:** frequency above 20 kHz; **partially reflected at boundaries** between media; the echo time gives the distance to a boundary ($s = vt$, with the path often there-and-back). Uses: medical prenatal scanning (non-ionising, avoiding the ionisation risk of X-rays), industrial flaw detection.
- **Seismic waves:** earthquakes produce **P-waves (longitudinal)** and **S-waves (transverse)**, travelling at different speeds through the Earth; P-waves pass through liquids, S-waves do not – the shadow zones reveal the Earth's layered structure. **Echo sounding** with ultrasound/sound pulses maps seabeds.

Electromagnetic waves

All EM waves are **transverse**, transferring energy from source to absorber. They form a **continuous spectrum** and all travel at the **same speed in vacuum (approximately the same in air)** (3×10^8 m/s). From long to short wavelength:

radio → microwave → infrared → visible (red to violet) → ultraviolet → X-ray → gamma

Eyes detect only visible light – a tiny band.



Wave	Typical use	Why (HT)
radio	TV and radio	(HT) circuit oscillations produce radio waves; reception induces alternating currents of the same frequency
microwave	satellite TV, cooking	passes through the atmosphere; absorbed by water in food
infrared	heaters, night vision, remote controls	emitted by warm bodies; absorbed as heat
visible	vision, fibre optics, photography	detected by eyes and cameras
ultraviolet	fluorescence lamps, tanning, sterilising	energises chemicals;
X-ray	medical imaging of bones	penetrates flesh, absorbed by bone
gamma	sterilising medical equipment, cancer treatment	kills bacteria and cells

Hazards: UV ages skin prematurely and raises skin-cancer risk; **X-rays and gamma rays are ionising** – they can mutate genes and cause cancer. **Radiation dose** in sieverts measures the risk of harm ($1000 \text{ mSv} = 1 \text{ Sv}$; recall of the unit not required). Draw conclusions from dose data.

■ Infrared surfaces (RP10)

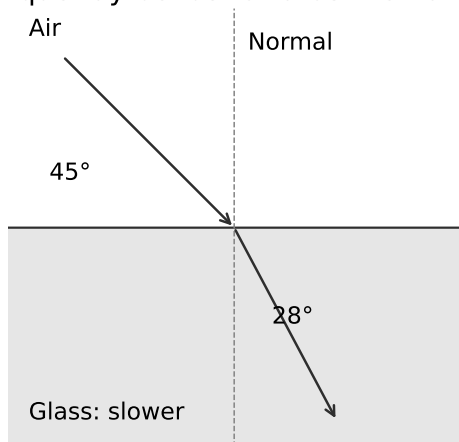
Compare infrared emission from different surfaces of a Leslie cube containing hot water. Use a non-contact infrared detector at the **same distance and angle** from each face; keep the water temperature as constant as possible, subtract the background reading where needed, repeat and compare mean readings. Avoid touching hot surfaces. Matt black and shiny metal surfaces differ in infrared emissivity; visible colour alone does not determine infrared emission.

To compare **absorption**, expose otherwise identical containers with different surfaces to the same infrared source. Keep source distance, exposure time, starting temperature, water mass and container material the same; record the temperature rise and repeat. A larger rise under these controls indicates greater absorption. The emission and absorption experiments measure different quantities; do not treat detector readings as temperatures.

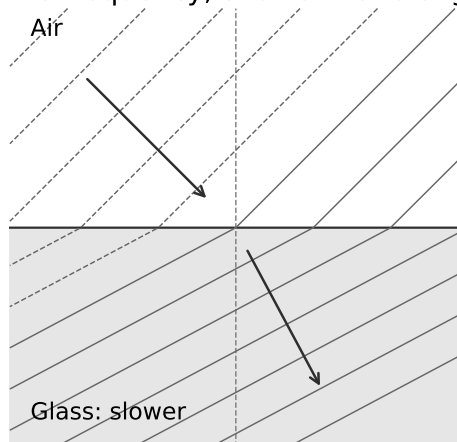
(HT) Oscillations in an electrical circuit produce radio waves. Absorbed radio waves induce an alternating current of the **same frequency** in a receiving circuit. Changes in atomic nuclei can produce gamma radiation.

(HT) Substances absorb, transmit, refract or reflect EM waves **in ways that vary with wavelength**; refraction comes from the **change of speed** between substances. Show refraction on a ray diagram (bending towards the normal when slowing at oblique incidence; no direction change at normal incidence) and on **wavefront diagrams** (wavefronts closer together in the slower medium).

Oblique ray bends towards the normal



Same frequency; shorter wavelength

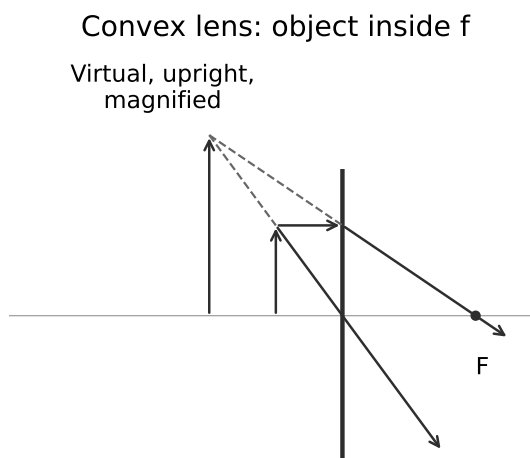
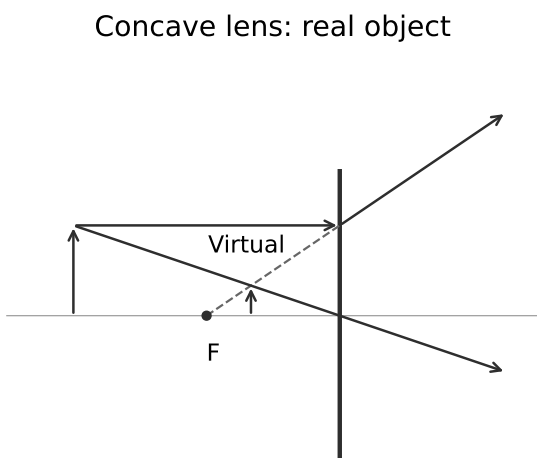
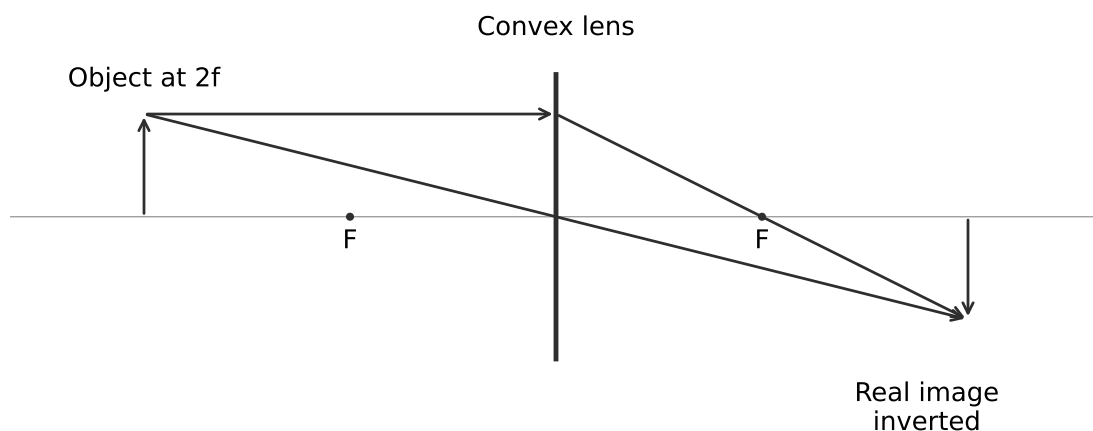


Lenses (physics only)

A lens forms an image by **refracting** light:

- **convex** : parallel rays converge at the **principal focus**; focal length = lens-to-focus distance; images real or virtual.
- **concave** : rays spread; for a real object, the image is **virtual, upright and diminished**.

Ray-diagram rules (two rays locate the image): a ray parallel to the axis refracts through the focus (convex) or appears to come from it (concave); a ray through the centre of the lens goes straight on.



$$\text{magnification} = \frac{\text{image height}}{\text{object height}}$$

- A ratio, **no units**; both heights in mm or both in cm.

Worked example. An object 5.0 mm high forms an image 20 mm high.

$$m = \frac{20}{5.0} = 4.0 \text{ (no unit)}$$

Visible light and colour (physics only)

Spectral colours correspond to ranges of wavelength (red longest, violet shortest in the visible band). Mixtures of wavelengths can also produce perceived colours.

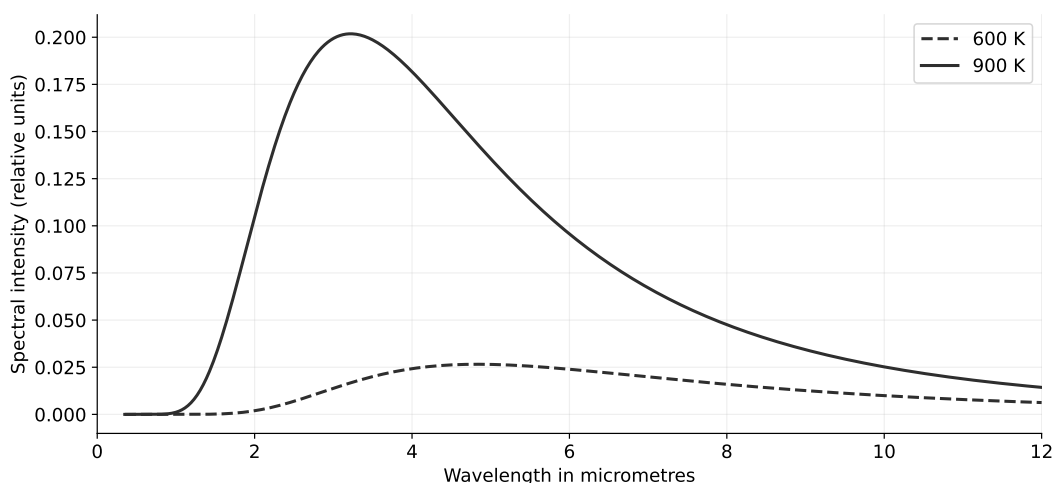
- **Filters** absorb some wavelengths and transmit others (a red filter transmits red).
- An **opaque** object's colour = the wavelengths it **strongly reflects**; the rest are absorbed. Under white illumination, a surface reflecting all visible wavelengths strongly appears white; one absorbing nearly all appears black. Predict coloured-light cases from the wavelengths actually present.
- **Transparent/translucent** objects transmit light.
- Specular vs diffuse reflection (from the reflection section) explains why a smooth red surface looks glossy but paper looks matt.

Black body radiation (physics only)

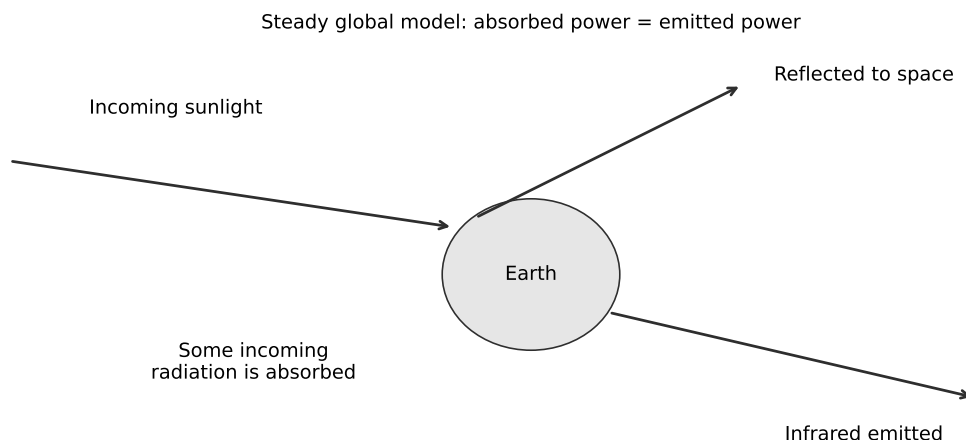
Bodies above absolute zero **emit thermal radiation** and can absorb infrared. At everyday temperatures much of their emission is infrared. The hotter the body, the more radiation it emits per second.

A **perfect black body** absorbs all incident radiation – no reflection, no transmission – and (good absorber = good emitter) is also the **best possible emitter**.

The **intensity and wavelength distribution** of the emitted radiation depend on the body's temperature: hotter → more intense, and the peak shifts to shorter wavelength.



(HT) In a model where radiation is the only net energy transfer, a body at constant temperature **absorbs at the same rate as it emits**. In real objects, also consider conduction and convection.



In the radiation-only model, absorbing faster than emitting $\rightarrow$ temperature rises.

The **Earth's temperature** depends on the balance of absorbed and emitted radiation and on reflection back to space – use it to explain warming and ice-albedo style examples, and read the standard diagram.

Checklist before you call this topic done

- Define amplitude, wavelength, frequency, period; use $T = 1/f$ and $v = f\lambda$ with prefixes.
- Describe RP8 in a ripple tank and on a string; describe a speed-of-sound method.
- (physics only) Draw reflection and refraction ray diagrams with the normal; RP9.
- Describe RP10 with controlled distance, temperature and exposure; distinguish emission from absorption.
- Recite the EM spectrum order; match uses and hazards with reasons; compare dose data.
- (physics only) Draw lens ray diagrams (convex/concave); magnification as a unitless ratio.
- (physics only) Explain colour by reflection, filters by transmission.
- (physics only) Black-body emission, absorption and the Earth's radiation balance (HT).

7 · Magnetism and electromagnetism

AQA · GCSE · Physics

Magnetism and electromagnetism: movement from current

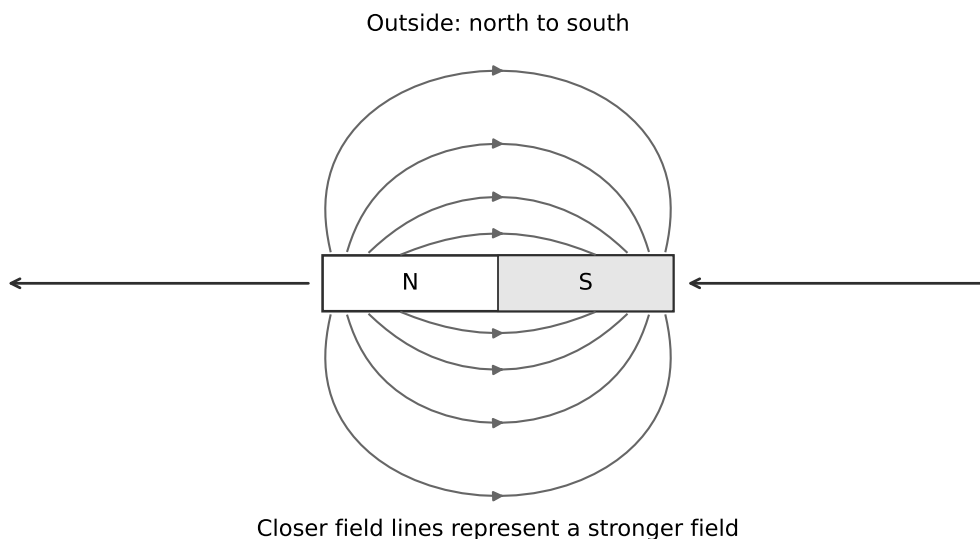
A changing magnetic field can induce a potential difference; a complete circuit can then carry current. Current in a magnetic field can cause movement. Every motor, generator, power station and loudspeaker lives in this topic. This reference covers **AQA GCSE Physics 8463, topic 4.7 Magnetism and electromagnetism**.

How the exam treats this topic:

- Paper 2 carries this topic. $F = BIl$ and the two transformer equations may be supplied on the equation sheet; check the examination series.
- Fleming's left-hand rule, motors, loudspeakers, the generator effect, alternators/dynamos, microphones and transformers are **HT only**; everything from 4.7.3 onwards is also **physics only**.
- You must **draw field patterns**: bar magnet, straight wire, solenoid.

Permanent and induced magnets, magnetic fields

- **Poles** : where the magnetic force is strongest.



Like poles repel; unlike poles attract – a non-contact force.

- A **permanent magnet** produces its own field. An **induced magnet** becomes magnetised in an external field; induced magnetism causes **attraction** to the magnet producing that field. It loses most or all of this magnetism quickly

when the field is removed. Soft iron loses it readily; steel can retain more.

- The **magnetic field** is the region where a force acts on another magnet or magnetic material (iron, steel, cobalt, nickel). A magnet attracts initially unmagnetised magnetic material. Another permanent magnet can attract or repel, depending on its poles.
- Field is **strongest at the poles**; direction = the force on a **north pole** at that point. Field lines run **north → south outside the magnet**; they form closed loops, returning through the magnet.
- A **compass** is a small bar magnet; it points along the Earth's field – evidence the Earth has a magnetic field. The field is associated with processes in the core; a bar magnet is a model, not a literal magnet inside the Earth.

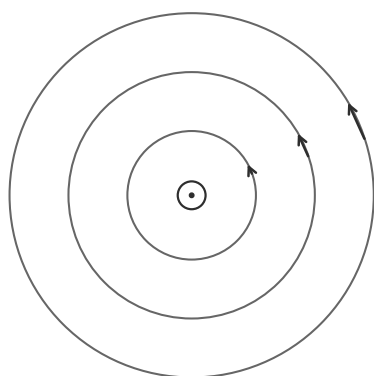
Plotting a field: put a small plotting compass near the magnet, mark both needle ends, identify the north-seeking end, then move the other end to the previous north-tip mark. Repeat, join smoothly and add arrows in the north-tip direction; start again elsewhere for several lines. Iron filings show a pattern but not its direction.

Electromagnetism

A **current-carrying wire** has a magnetic field around it (concentric circles; right hand grip – thumb with the current, fingers curl with the field). The field is **stronger with more current** and **weaker further from the wire**.

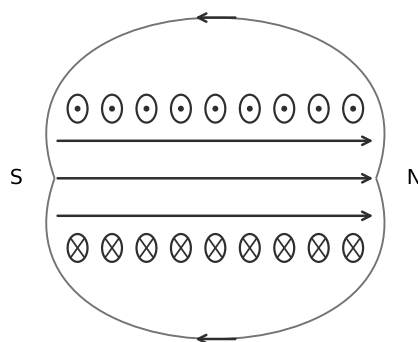
Bending the wire into a **solenoid** :

Wire: anticlockwise field



Dot: current out of page

Solenoid: uniform field inside



Dots out; crosses into page

- the fields of the loops add – the field inside is **strong and uniform**;
- outside, the shape matches a **bar magnet**'s;
- adding an **iron core** increases the strength further – this is an **electromagnet**

An electromagnet can be switched on and off and its strength changed with the current – that is why it beats a permanent magnet in scrapyards and relays.

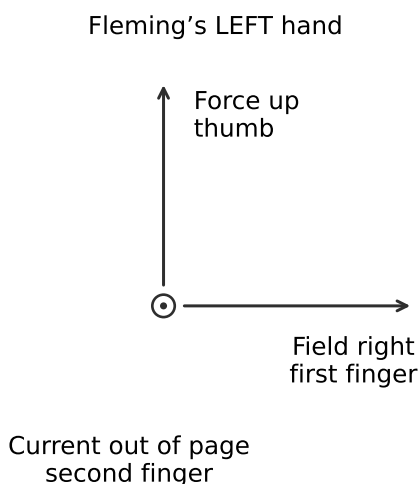
Demonstrating the field: place a compass near a straight wire, switch the current on, observe deflection, then reverse the current and observe the reversed field direction. Compare equal positions at different currents; switch off before moving apparatus.

Relay model (physics only): a small control current magnetises an iron-cored coil. It attracts an iron armature, closing a separate load-circuit contact. On switching off, a spring returns the armature. Identify the control coil and load circuit separately; the magnetic action operates the contact without joining the two circuits.

The motor effect (HT)

A conductor carrying a current across a magnetic field feels a force (the **motor effect** – the field, the magnet and the conductor push on each other).

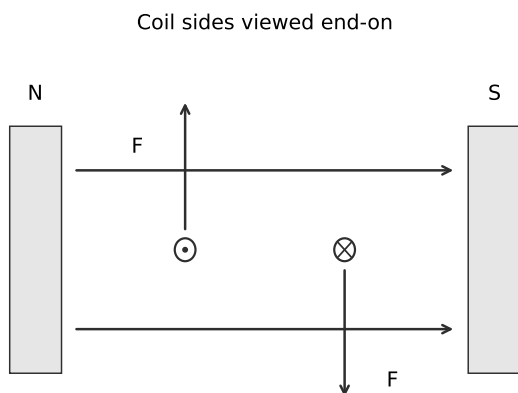
Fleming's left-hand rule: thumb = **force**, first finger = **field** (N→S), second finger = **current** – all three at right angles.



$$F = BIl$$

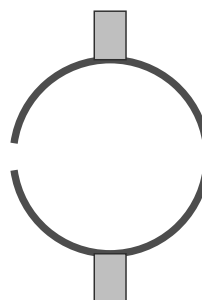
- F force in N; B **magnetic flux density** in tesla, T; I current in A; l length of conductor **in the field**, in m.
- Bigger force with: stronger field (larger B), larger current, longer conductor in the field. Use $F = BIl$ when the current is at **right angles** to the field; a current parallel to a uniform field has zero motor force.

Electric motor: a current-carrying **coil** in a field rotates because the two sides feel forces in opposite directions.



Opposite forces create a turning effect

Split-ring commutator



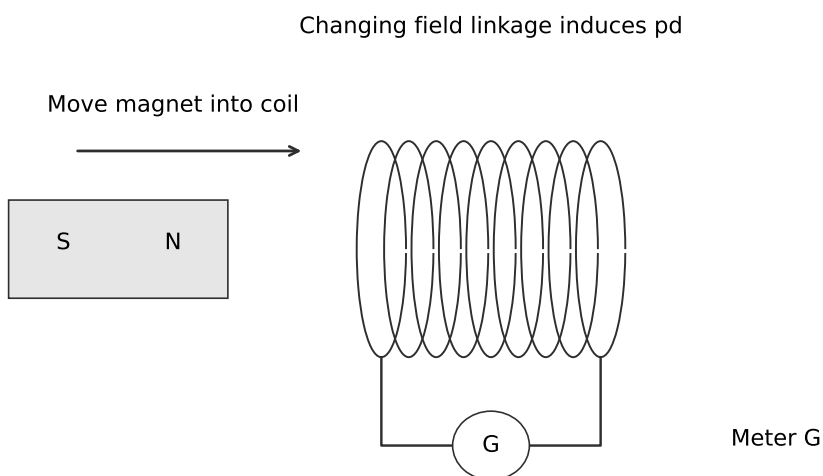
Fixed brushes

Fixed brushes contact a **split-ring commutator**, which swaps the coil connections each half-turn. Current reverses in each physical coil side, keeping the turning effect in the same sense. When the brushes meet insulating gaps, current and magnetic force briefly fall to zero. Inertia can carry an already rotating coil through this position; an ideal single coil at a dead spot does not start itself.

Loudspeaker (physics only): an alternating current through a coil in a field makes the coil vibrate in and out; the cone pushes the air into **pressure variations** – **sound waves** whose frequency matches the signal's.

The generator effect (physics only, HT)

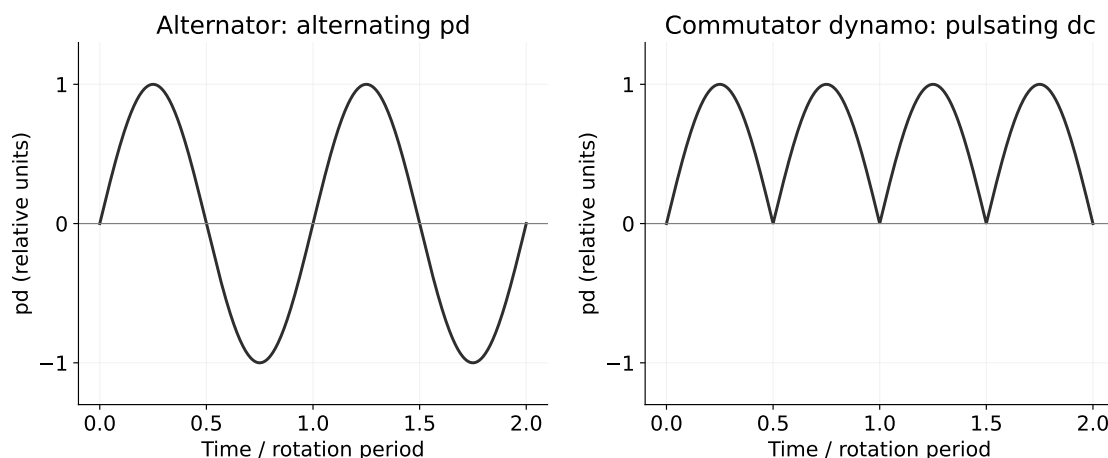
If a conductor **cuts magnetic field lines**, or the magnetic field linking it changes, a **potential difference is induced**; if the circuit is complete, a current flows – the **generator effect**.



- The **induced current's own field opposes the change** that made it.
- Bigger induced pd with: **faster** movement, **stronger** field, more turns of wire.
Reversed direction with: reversed movement or reversed field polarity.

When no pd is sustained: a stationary magnet and coil have no changing field linkage. Motion parallel to uniform field lines does not cut them. In a transformer, steady dc gives a steady field after switching; brief switching transients are different from sustained ac operation.

Alternator (ac generator): a coil rotates in a field – the induced pd **reverses direction** every half-turn, so the pd–time graph is a repeating wave crossing zero.

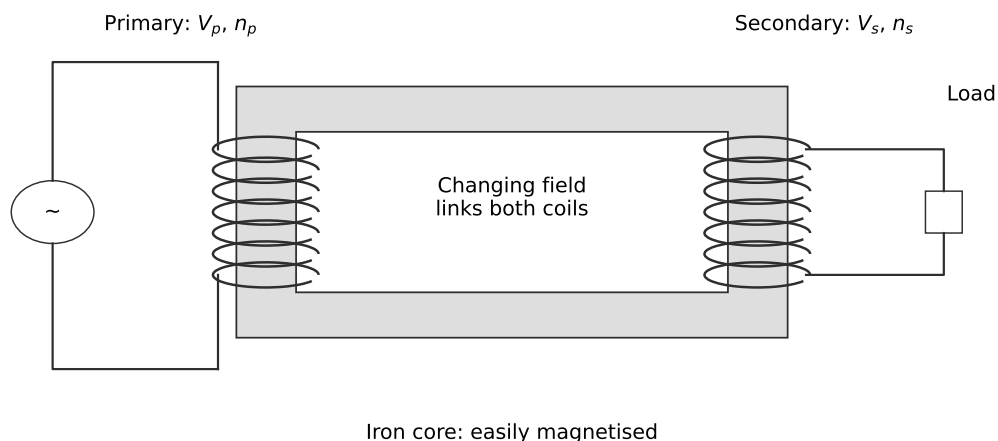


Dynamo (dc): a split-ring commutator flips the connections each half-turn, so the output stays on one side of zero (pulsating dc). Reversing the terminal labels reverses the sign; dc is one-directional, not necessarily positive. A real bicycle device called a “dynamo” can be an alternator; use its stated construction.

Microphone: the reverse of a loudspeaker – sound pressure variations move a coil in a field, **inducing a varying potential difference**. In a complete circuit this drives a varying current corresponding to the sound.

Transformers (physics only, HT)

A **transformer** : primary and secondary coils wound on an **iron core** (easily magnetised; laminations not required).



An **alternating current** in the primary makes a changing magnetic field in the core; that changing field **induces an alternating pd** in the secondary.

$$\frac{V_p}{V_s} = \frac{n_p}{n_s} \quad V_s I_s = V_p I_p \text{ (100\% efficient)}$$

- **Step-up:** $V_s > V_p$ (more secondary turns). **Step-down:** $V_s < V_p$.
- The second equation is power in = power out **only for the ideal, 100% efficient model**; use it to find the current drawn from the input supply.

Worked example. A transformer has 345 primary turns and 6000 secondary; the input is 230 V.

$$\frac{230}{V_s} = \frac{345}{6000} \Rightarrow V_s = 230 \times \frac{6000}{345} = 4000 \text{ V (a step-up)}$$

Worked example (power). Assume that transformer is 100% efficient and supplies 50 mA at 4000 V.

- Power out: $P = V_s I_s = 4000 \times 0.050 = 200 \text{ W}$.
- Input current: $I_p = P/V_p = 200/230 = 0.87 \text{ A}$.

The National Grid story closes the loop: **step-up before transmission** (at the same transferred power, larger pd means smaller current; for the same cable resistance, $P_{\text{loss}} = I^2 R$ falls), **step-down** for homes (see topic 2.7).

Checklist before you call this topic done

- State the pole rules; distinguish permanent from induced magnets.
- Draw bar-magnet, straight-wire and solenoid field patterns with directions; explain the compass/Earth link.
- (HT) Use Fleming's left-hand rule and $F = BIl$; explain the motor and the commutator.

- (physics only, HT) State the generator-effect conditions and the opposing induced field; distinguish alternator and dynamo graphs; explain the microphone.
- (physics only, HT) Use both transformer equations; explain induction between coils and the Grid advantage.

8 · Space physics (physics only)

AQA · GCSE · Physics

Space physics: the biggest picture

Stars form, release energy by nuclear fusion and evolve; light from most distant galaxies is red-shifted; and the light they send us carries the news. This reference covers **AQA GCSE Physics 8463, topic 4.8 Space physics**.

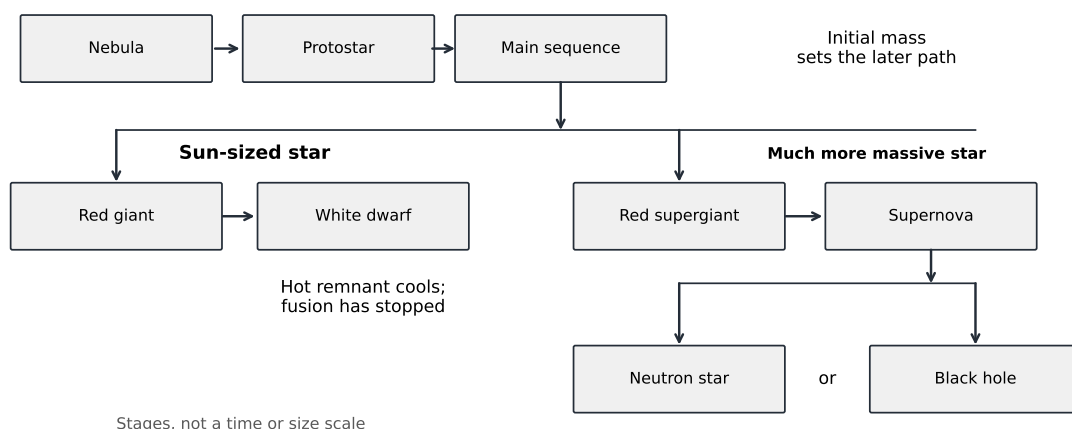
How the exam treats this topic:

- The **whole topic is physics only**, sitting on Paper 2.
- Gravity as the cause of circular orbits and comparisons of planets and satellites are common-tier content. **HT only**: explain changing velocity at constant speed and compare the radii of stable circular orbits at different speeds.
- Facts must be exact: the life-cycle sequence, the fusion story of the elements, and the red-shift chain.

Our solar system and the Sun

The solar system: **one star (the Sun)**, **eight planets**, the **dwarf planets** orbiting the Sun, and **natural satellites (moons)** orbiting planets. Our solar system is a small part of the **Milky Way** galaxy.

The Sun's formation: a cloud of dust and gas (a **nebula**) was pulled together by **gravitational attraction**. As it collapsed:



1. the dense centre heated until **fusion** began – a star lit;
2. energy released by fusion maintains the outward pressure that balances the inward gravitational pull – an **equilibrium** during the main sequence.

The life cycle of a star

The life cycle depends on the star's initial **mass**; compare a Sun-sized star with one much more massive than the Sun.

Sun-sized star: nebula → protostar → **main sequence** (fusion of hydrogen; equilibrium) → **red giant** (core hydrogen becomes depleted; the star expands and later fuses helium) → **white dwarf** (the hot remnant core; sustained fusion has stopped) → eventual cooling towards a **black dwarf**. A black dwarf is a predicted cooled remnant, not an observed present-day stage. The Sun will not fuse elements all the way to iron.

Massive star (much more massive than the Sun): nebula → protostar → **main sequence** → **red supergiant** → **supernova** (explosion) → **neutron star**, or – for the most massive – a **black hole**.

Where the elements come from (a favourite sequence):

- Fusion joins light **nuclei** to make heavier nuclei: hydrogen forms helium, and later fusion stages in sufficiently massive stars build elements up to **iron**.
- In the AQA GCSE model, elements **heavier than iron** are produced in a **supernova**. This is the exam explanation; it is not a claim that every heavy atom forms only in supernovae.
- The supernova **distributes** the elements throughout the universe – the stuff of planets and people.

■ Worked data reading: mass, prefixes and travel time

These examples follow AQA June 2024 8463/2H Q03.2, Q03.3 and Q03.5 and their official mark scheme.

Compare mass: Betelgeuse has mass 2.2×10^{31} kg, while the Sun has mass 2.0×10^{30} kg. First compare powers of ten: Betelgeuse is the much more massive candidate in that question, so it is the star most likely to form a black hole. The ranking does not predict an exact remnant from mass alone.

Convert the prefix: $1 \text{ Gm} = 10^9 \text{ m}$, so $s = 1.1 \times 10^8 \text{ Gm} = 1.1 \times 10^{17} \text{ m}$. A unit conversion does not change the physical distance.

Find light-travel time: Arcturus is 3.6×10^{14} km away; light travels at $3.0 \times 10^8 \text{ m/s}$. Convert the distance and use the definition of speed.

$$s = 3.6 \times 10^{14} \text{ km} = 3.6 \times 10^{17} \text{ m}$$

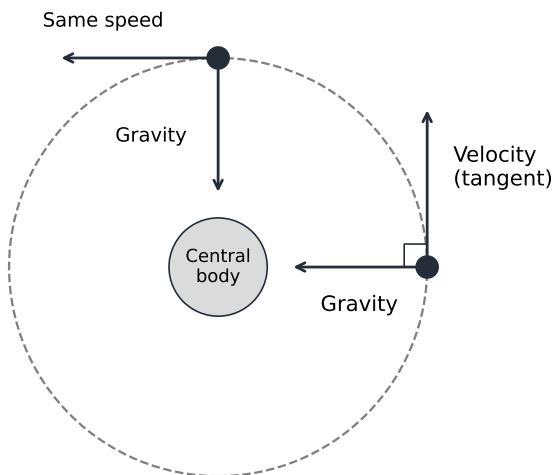
$$v = \frac{s}{t} \quad t = \frac{s}{v}$$

$$t = \frac{s}{v} = \frac{3.6 \times 10^{17}}{3.0 \times 10^8} = 1.2 \times 10^9 \text{ s}$$

The unit is seconds because metres divided by metres per second gives seconds.

Orbital motion and satellites

Gravity provides the centripetal force keeping planets and satellites in circular orbits.



HT: velocity direction changes; speed stays constant

- **Planets:** orbit the Sun. **Moons:** natural satellites orbiting planets. **Artificial satellites:** made by us, orbiting the Earth. Gravity holds all of these in orbit. Compare what they orbit and whether they formed naturally or were made by humans; artificial satellites can orbit bodies other than Earth.
- (HT) A circular orbit has **changing velocity but unchanged speed** – velocity is a vector, and the direction changes continuously; the gravitational force acts at right angles to the motion, changing direction but not speed.
- (HT) Compare **stable circular orbits around the same central body**: a smaller radius requires a higher speed; a larger radius requires a lower speed. This compares completed circular orbits. It does not mean that firing an engine to speed up instantly moves a satellite into a lower circular orbit.

Worked explanation: gravity acts towards the centre → the satellite accelerates towards the centre → its direction, and therefore its velocity, changes even if its speed stays constant.

Red-shift and the Big Bang

Light from **most distant galaxies** shows an **increase in wavelength** – a shift towards the red end: **red-shift** .



Match the same pattern on one common wavelength scale

Schematic redrawing of AQA June2024 8463/2H Q03.4

- For the distant-galaxy expansion trend, the **further away** the galaxy, the **faster** it is receding and the **bigger** the red-shift. Compare matching spectral lines on the same wavelength scale, not the apparent colour or brightness of whole galaxies.
- Red-shift means the universe is **expanding**. Played backwards, everything was once in a **very small, extremely hot and dense region** – the **Big Bang**.

No measured shift suggests no recession along the line of sight in the simple school model; it does not prove the object has no sideways motion.

The credited chain: observed red-shift → galaxies receding → further = faster → space itself expanding → Big Bang. And the scientific-method point: observations (red-shift surveys, and since **1998** supernovae supporting **accelerating expansion**) are the evidence from which the theory is built; much remains unknown, e.g. **dark matter** and **dark energy**.

Checklist before you call this topic done

- List the solar system's contents and the Sun's formation from a nebula by gravity.
- Draw or order both life cycles; state where every element forms.
- Explain orbits with gravity; (HT) explain changing velocity at constant speed and radius changes for stable orbits.
- State the red-shift chain and its Big Bang conclusion, the 1998 supernova observation, and one open unknown.