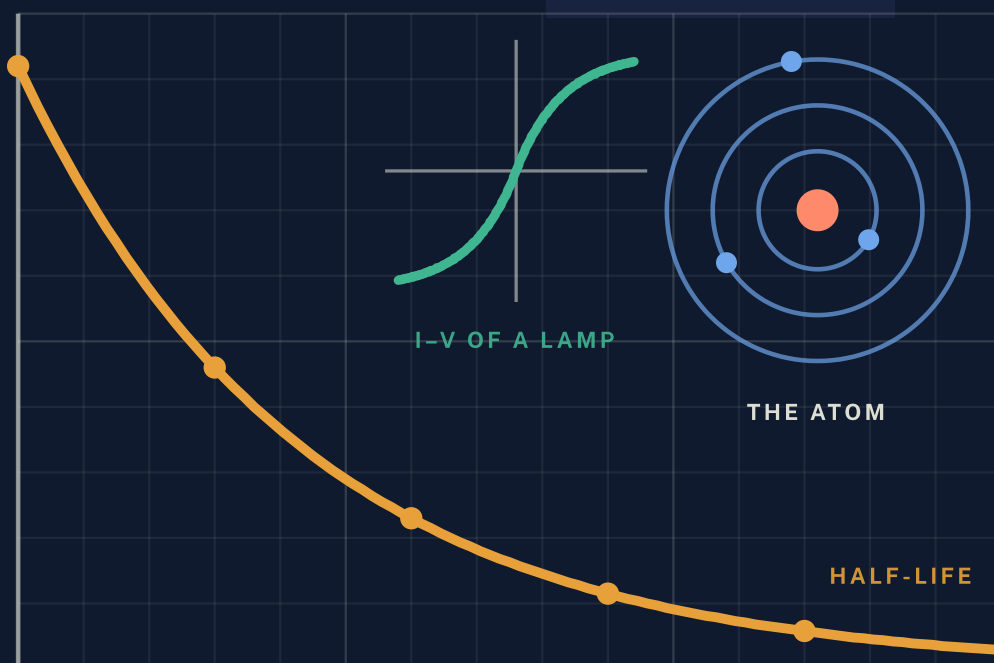


AQA GCSE PHYSICS (8463) · PAPER 1

Physics Paper 1

Energy, electricity, particles and the atom

Sixteen topics on two pages each: learn it, then use it. Exam questions marked in red pen, the equations, graphs and calculations the paper really asks for, and a practice paper to finish.

**16**TOPICS, EACH ON TWO
PAGES**128**

KEY WORDS TO OWN

5

REQUIRED PRACTICALS

90MARKS IN THE PRACTICE
PAPER

[Start here](#)

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Two pages a topic

Learn it: sixty seconds of the topic, the facts with a circle to colour, key words, and a Spot it question on a sticky note. The number under each recall box is how many facts the page has.

Use it: a diagram or table, an exam question answered and marked in red pen, a Try it question to answer yourself, a box to write from memory, and a quick-fire quiz.

Four steps, every time

Predict how much you'll remember. **Recall** with the page covered. **Check** in another colour and fill the circles. **Repair** the weakest part, then come back in two days.

Where it comes from

The facts follow AQA's specification (8463, version 1.1). The exam advice comes from AQA's own Paper 1 papers, mark schemes and examiners' reports: Higher tier for November 2020, November 2021, June 2022 and June 2023, and the Foundation report for June 2019. AQA has not published later Paper 1 papers. No AQA question or mark scheme is reproduced: marking points are paraphrased, and every question and number here was written for this guide.

HT and Physics only

A red **HT** marks content the specification gives to Higher tier students only. A green **Physics only** marks content that is in GCSE Physics but not in Combined Science: Trilogy.

A four-week plan

Week 1: energy, topics 1 to 4. **Week 2:** electricity, topics 5 to 9. **Week 3:** particles and the atom, topics 10 to 16. **Week 4:** skills and practicals (pages 36 to 45), then the practice paper (pages 49 to 52). Come back to each topic two days later and again a week later. The tracker is on page 56.

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Know the exam

Paper 1 on one page

Paper 1	
Topics	1 to 4: Energy; Electricity; Particle model of matter; Atomic structure
Exam	Written, 1 hour 45 minutes
Marks	100, which is 50% of the GCSE
Tiers	Foundation and Higher
Questions	Multiple choice, structured, closed short answer and open response

That is just over a minute a mark. Bring a ruler and a scientific calculator. Write in black ink, and use pencil only for drawing and graphs. Show your working.

What the paper looks like

The Higher papers had eleven questions in November 2021 and June 2022 (one was discounted in 2022) and nine in June 2023. Each question is set at a level: standard demand aims at grades 4 to 5, standard to high at 6 to 7, and high demand at 8 to 9.

At least 30% of the marks test maths, more than in Biology or Chemistry, and a lot test practical skills: variables, graphs, uncertainty, resolution. About 60 marks need you to **use** what you know or analyse information (AO2 and AO3), not just recall it (AO1, about 40).

In 2022 and 2023 AQA printed every equation on a sheet. The specification still lists equations to recall, and a recalled equation is accepted in any correct rearrangement (pages 36 and 37).

Paper 2 can draw on energy transfers and conservation of energy from topics 1 to 9, so they are worth knowing twice.

What the question word asks for

Word	AQA's meaning, shortened	What it looks like
Give · Name · Write	A short answer. No explanation or description.	"The earth wire."
Describe	Recall facts, events or a process accurately.	First this, then this, finally this.
Explain	Make it clear, or state the reasons.	Point, because, so.
Compare	Similarities and/or differences, not just one thing.	A does this, whereas B does that.
Calculate	Use the numbers in the question to work out the answer.	Equation, numbers with units, answer with unit.
Suggest	Apply what you know to a new situation.	Link a fact you know to the new context.
Evaluate	Use the information given and your own knowledge to weigh evidence for and against, then reach a judgement.	For, against, so overall.
Justify	Use evidence from the information supplied to support an answer.	Quote a figure, then say what it shows.
Determine · Identify	Use given data to obtain an answer. Name or otherwise characterise.	Read it off the graph or table, then show how.
Predict · Estimate	A plausible outcome. An approximate value.	Use the pattern, or round the numbers first.
Plot · Complete · Label · Draw	Mark data on a graph. Fill in a table or diagram. Name the parts.	Crosses, a ruler, a smooth line.
Plan · Design	Write a method. Set out how something will be done.	Variable, measurement, controls, steps, repeats.

Four marks or more: open response

These are worth four to six marks. Some are marked from a list of points. Others are marked by **levels**: two marks a level, and the examiner picks the level that best fits your whole answer. Level 3 wants relevant points, in detail, linked into a clear account, and for an evaluation **at least one judgement**. A statement that contradicts a correct one can stop you getting full marks, and in a list answer a wrong item can cancel a right one. Plan for twenty seconds first.

Practise: two worked six-mark answers are on page 47.

Sources: AQA command words list; AQA, Our exams explained (GCSE science from summer 2018); AQA 8463 specification, papers and mark schemes (2021 to 2023). Check your own papers.

1 Energy stores and transfers

Learn it

In sixty seconds

Energy is stored in different ways, and the ones you calculate are kinetic, gravitational potential, elastic potential and thermal. When a system changes, energy is transferred between stores by heating, by work done by forces, or by work done when a current flows. Energy is never created or destroyed, so the total stays the same, but some is always dissipated into less useful stores.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- A **system** is an object or group of objects. When it changes, its energy is stored in different ways. Energy can be transferred usefully, stored or dissipated, but it **can't be created or destroyed**.
- Energy is transferred by **heating**, by **work done by forces** and by **work done when a current flows**. Work done is the transfer of energy by a force.
- In a **closed system** the total energy doesn't change. In every real change some energy is **dissipated**: stored in less useful ways, usually as thermal energy in the surroundings ("wasted").
- **Kinetic energy**: $E_k = \frac{1}{2} m v^2$. Mass in kg, speed in m/s. The speed is squared, so doubling the speed makes the kinetic energy four times bigger.
- **Gravitational potential energy**: $E_p = m g h$. g is the gravitational field strength, in N/kg, and AQA gives its value in the question. Height is in metres.
- **Elastic potential energy**: $E_e = \frac{1}{2} k e^2$, for a stretched spring that hasn't passed its limit of proportionality. k is the spring constant in N/m and e the extension in metres. This one is on the equations sheet.
- Changes to describe: thrown upwards (kinetic to gravitational potential), hitting an obstacle (kinetic to thermal), pushed by a constant force (work done to kinetic), a braking vehicle (kinetic to thermal), a kettle (work done by the current to thermal).
- With no air resistance, a falling object's gravitational potential energy lost equals its kinetic energy gained: $m g h = \frac{1}{2} m v^2$. The mass cancels, so $v = \sqrt{2 g h}$.
- Energy is measured in **joules** (J). 1 kJ = 1000 J and 1 MJ = 1 000 000 J. Change kilojoules, megajoules, grams and centimetres to J, kg and m before you substitute.
- When you name a store in words, include the word **potential**: gravitational potential or elastic potential. The abbreviations KE, GPE and EPE are fine.

Key words

- System** an object or group of objects. ☐
- Conservation of energy** energy can't be created or destroyed, only transferred. ☐
- Dissipated** stored in a less useful way, often as thermal energy in the surroundings. ☐
- Closed system** no energy enters or leaves, so there is no net change in total energy. ☐
- Work done** energy transferred by a force. ☐
- Kinetic energy** the energy of a moving object. ☐
- Gravitational potential energy** the energy gained by raising an object above the ground. ☐
- Elastic potential energy** the energy stored in a stretched spring. ☐

Say it in stores. "The ball is thrown up. Its kinetic energy decreases and its gravitational potential energy increases. A little is transferred to thermal energy by air resistance." Say where the energy starts, where it ends up, and how it gets there.

Two things cost marks in 2022 and 2023: "no energy is lost" (say the total is conserved and some is dissipated) and leaving the word "potential" out of a store. Changing kg into g by mistake lost the marks that followed on the 2023 mass question.

Spot it Which describes this change?

A trolley rolls down a ramp and stops when it hits a wall. Which statement describes the energy transfers?

- (A) Gravitational potential to kinetic, then the kinetic energy is used up as it stops.
- (B) Gravitational potential to kinetic, then thermal in the trolley and wall.
- (C) Kinetic energy appears from nowhere as it rolls, then vanishes in the collision.
- (D) Elastic potential to kinetic, then kinetic to gravitational potential in the wall.

Cover this, choose, then read

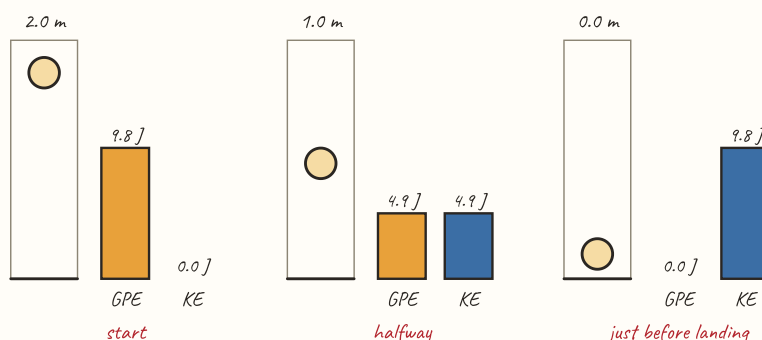
B. Energy is never created or destroyed, only transferred. On the ramp the gravitational potential store falls as the kinetic store rises. In the collision the kinetic energy is dissipated as thermal energy in the trolley, the wall and the air.

1 Part one · Energy

Energy stores and transfers

Use it

A ball dropped from 2.0 m: the stores trade places, and the total stays at 9.8 J



Mass 0.50 kg, $g = 9.8 \text{ N/kg}$, air resistance ignored. At the bottom $\frac{1}{2} m v^2 = 9.8 \text{ J}$, so $v = \sqrt{(2 g h)} = \sqrt{39.2} = 6.3 \text{ m/s}$. With air resistance a little ends up as thermal energy in the air and the ball.

Common situation	What happens to the energy
An object thrown upwards	kinetic to gravitational potential (a little to thermal in the air)
A moving object hits an obstacle	kinetic to thermal in the object and the obstacle (and some sound)
An object pushed by a constant force	work done by the force goes to kinetic energy
A vehicle slowing down	kinetic to thermal in the brakes and surroundings
A kettle heating water	work done by the current to thermal energy of the water

A car of mass 1.2 tonnes is travelling at 20 m/s. (a) Calculate its kinetic energy. (b) The brakes bring it to rest in 5.0 s. Calculate the average power of the braking. (1 tonne = 1000 kg)

[5 marks]

1.2 tonnes = 1200 kg ✓

$E_k = \frac{1}{2} \times 1200 \times 20^2 = 240\,000 \text{ J}$ ✓

(b) $P = 240\,000 \div 5.0 = 48\,000 \text{ W}$ ✓

5/5

1 for tonnes to kg. 2, 3 for the substitution and 240 000 J (or 240 kJ). 4, 5 for $P = E \div t$ and the answer in watts, which is 48 kW. Forgetting the conversion gives 240 J, a power of ten slip that AQA's reports keep naming, and 240 J for a moving car should look too small to you. Show the unit with every answer.

Try it A cyclist freewheels down a hill and then brakes to a stop at the bottom. Describe the energy changes.

[3 marks]

It could be asked as: Describe the energy transfers when a ball is thrown up, a car brakes or a kettle boils. · Calculate kinetic, gravitational potential or elastic potential energy, converting units first. · Find a speed using conservation of energy, such as a drop or a released spring. · Explain why some energy is described as dissipated or wasted.

Cover both pages, write it from memory, then count the facts

facts: predict ___ / 10 got ___ / 10

Quick-fire. Answers are on page 53

1.1 Calculate the kinetic energy of a 2.0 kg trolley moving at 3.0 m/s.

1.2 A 4.0 kg book is lifted 1.5 m. Calculate the gain in gravitational potential energy ($g = 9.8 \text{ N/kg}$).

1.3 What happens to a car's kinetic energy when it brakes?

1.4 A spring with $k = 200 \text{ N/m}$ is stretched by 0.10 m. How much elastic potential energy does it store?

2 Part one · Energy Power and efficiency

Learn it

In sixty seconds

Power is the rate of transferring energy: how many joules each second. One watt is one joule per second. Efficiency is the fraction of the input energy that is transferred usefully, and it can never be more than 1, or 100%. The wasted energy is dissipated, mostly as thermal energy. Less friction and better insulation make a transfer more efficient.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- **Power** is the rate at which energy is transferred or work is done: $P = E \div t$ and $P = W \div t$. A transfer of 1 joule per second is a power of 1 **watt**.
- Power is in watts (W), energy and work in joules (J), time in seconds (s). 3 kW = 3000 W. 2 MW = 2 000 000 W. 5 minutes = 300 s. 1 hour = 3600 s.
- Two motors lift the same weight through the same height. They do the same work, but the more powerful one does it in less time.
- **Efficiency** = useful output energy transfer $\div$ total input energy transfer. It can also be found as useful power output $\div$ total power input.
- Efficiency has no unit. Give it as a decimal (0.35) or a percentage (35%): $\times 100$ turns a decimal into a percentage, $\div 100$ turns it back. It is never more than 1 (100%).
- Energy is conserved, so total input = useful output + wasted energy. The wasted energy is dissipated, usually as thermal energy in the surroundings.
- A **Sankey diagram** draws each arrow with a width in proportion to the energy it carries. The wasted arrow leaves the main one.
- A more efficient device wastes less energy, so the same job needs less energy input. That cuts the demand for electricity and the environmental impact of generating it.
- Lubrication reduces friction between moving parts, and thermal insulation reduces unwanted transfer by heating. **HT** Describe ways to increase the efficiency of a transfer.
- Choose the version of the efficiency equation that matches the data: energies given, use the energy version. Powers given, use the power version.

Key words

- Power** the rate at which energy is transferred, in watts. ☐
- Watt** one joule transferred each second. ☐
- Efficiency** useful output divided by total input. ☐
- Useful output** the part of the energy transferred in the way you want. ☐
- Wasted energy** energy dissipated, stored in a less useful way. ☐
- Friction** a force that opposes movement and transfers energy to thermal. ☐
- Lubrication** oil or grease that reduces friction between moving parts. ☐
- Thermal insulation** material that reduces the rate of unwanted energy transfer by heating. ☐

Three numbers, any two. Total input, useful output and wasted energy are linked: wasted = input – useful. A motor wastes 30 J of every 120 J it takes in, so the useful output is 90 J and the efficiency is $90 \div 120 = 0.75$.

Unit slips (kW, MW, kJ, minutes) cost the most marks in every paper. 2023: the power version of efficiency with energies given scored zero. 2022: “saves energy” and “wastes no energy” scored nothing, say it wastes less. 2020: there is no “ $\times 100$ ” in the equation, and a right equation beside a wrong one scores 0.

Spot it Which is correct?

A machine has an efficiency of 0.80. Which statement is correct?

- (A) Its efficiency is 0.80 watts. (B) It is possible for it to be 120% efficient.
- (C) It must have a greater power than a machine with 0.60 efficiency. (D) 20% of the input energy is dissipated as wasted energy.

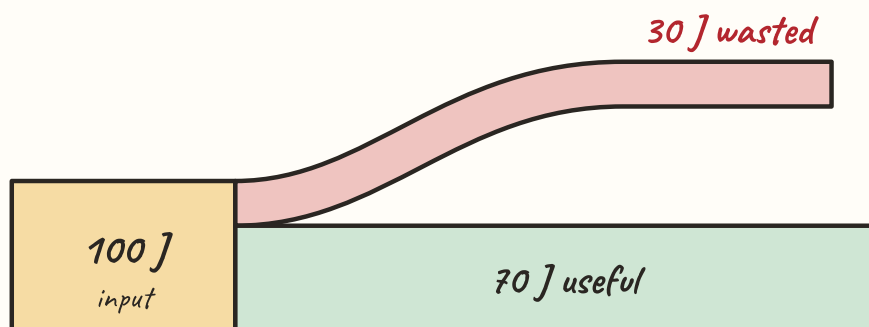
Cover this, choose, then read

D. Efficiency has no unit and can't be over 1, because a machine can't give out more useful energy than it takes in. $1 - 0.80 = 0.20$, so 20% is wasted. Efficiency compares useful output with input and says nothing about power.

2 ^{Part one · Energy} Power and efficiency

Use it

Where 100 J of electrical energy goes: a Sankey diagram, with the widths drawn in proportion



$$\begin{aligned}\text{efficiency} &= 70 \div 100 \\ &= 0.70\end{aligned}$$

The wasted 30 J is thermal energy (and some sound), dissipated into the surroundings. Efficiency = $70 \div 100 = 0.70$, or 70%. Check: $70 \text{ J} + 30 \text{ J} = 100 \text{ J}$.

A crane motor has an input power of 4.2 kW. It lifts a 500 kg load through 12 m in 20 s. Calculate the efficiency of the motor. ($g = 9.8 \text{ N/kg}$) [5 marks]

$$4.2 \text{ kW} = 4200 \text{ W} \checkmark$$

$$E_p = 500 \times 9.8 \times 12 = 58\,800 \text{ J} \checkmark$$

$$\text{useful power} = 58\,800 \div 20 = 2940 \text{ W} \checkmark$$

$$\text{efficiency} = 2940 \div 4200 \checkmark = 0.70 \checkmark$$

5/5

1 for the kW to W. 2 for the gravitational potential energy. 3 for the useful power. 4, 5 for the substitution and answer. A power efficiency needs both powers in watts, which is where a unit slip would have cost the mark. Also acceptable is 70%. The multistep 8-9 questions in 2022, like this one, were well attempted.

Try it A sign says: “our new motor wastes no energy”. Explain why this can't be true, and write a claim that could be true. [2 marks]

--

It could be asked as: Calculate power from energy and time, converting units first. · Calculate efficiency as a decimal and a percentage, from energies or from powers. · Explain why a more efficient device has less environmental impact. · Suggest how to increase the efficiency of a transfer (HT).

Cover both pages, write it from memory, then count the facts

facts: predict ___ / 10 got ___ / 10

--

Quick-fire. Answers are on page 53

2.1 A motor transfers 3600 J in 1 minute. What is its power?

2.2 A 2.5 kW heater runs for 2 hours. Give the power in W and the time in s.

2.3 A lamp wastes 45 J of every 60 J it takes in. What is its efficiency?

2.4 Why can't a machine have an efficiency of 120%?

3 Heating: specific heat capacity and insulation

Learn it

In sixty seconds

Warming a material takes energy, and how much depends on its mass, the material and the temperature change: $\Delta E = m c \Delta\theta$. The specific heat capacity is the energy needed to raise 1 kg of a substance by 1 °C. Insulation slows energy transfer by heating, and the higher the thermal conductivity of a material, the faster it transfers energy.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- The energy needed to warm something depends on its **mass**, the **material** and the **temperature change**: $\Delta E = m c \Delta\theta$. This equation is on the equations sheet.
- ΔE is the change in thermal energy in J, m is the mass in kg, c is the specific heat capacity in J/kg °C and $\Delta\theta$ is the temperature change in °C.
- **Specific heat capacity** is the energy needed to raise the temperature of 1 kg of a substance by 1 °C. A high value means a lot of energy for a small rise.
- **Required practical 1:** heat a block with an electric heater. Energy supplied = $V I t$ or $P \times t$. Measure the mass, and the start and end temperatures, then $c = \Delta E \div (m \Delta\theta)$.
- Insulate the block so less energy escapes. More of the energy supplied then warms the block, and the value of c is more accurate.
- Leave the thermometer in the block before switching on, until it shows the block's temperature. Read the highest value after switching off. $\Delta\theta$ is the final minus the starting temperature.
- The higher the **thermal conductivity** of a material, the higher the rate of energy transfer by conduction through it. Metals conduct fast, so they are poor insulators.
- A building cools more slowly through thicker walls and through walls of a material with lower thermal conductivity. Thermal insulation reduces unwanted energy transfer.
- **Physics only** **Required practical 2:** compare insulators. Use the same hot water, volume, starting temperature and container, and measure the temperature fall in a set time, or the time for a set fall.
- A smaller fall in a set time, or a longer time for a set fall, means a lower rate of energy transfer and a better insulator. Say "rate of energy transfer", not just "good insulator".

Key words

Specific heat capacity the amount of energy needed to raise the temperature of 1 kg of a substance by 1 °C. ☐

Temperature change final temperature minus starting temperature. ☐

Thermal conductivity how well a material transfers energy by conduction. ☐

Insulator a material with a low thermal conductivity. ☐

Independent variable the one thing you change. ☐

Dependent variable what you measure. ☐

Control variable something you keep the same. ☐

Thermal energy store where energy is held when a material is hot. ☐

Substitute first. In 2022's straightforward calculations the first mark was for substituting into the equation as printed on the sheet, and rearranging wrongly first scored nothing. Write $\Delta E = m c \Delta\theta$ with numbers in, then rearrange: $c = \Delta E \div (m \Delta\theta)$.

2023: the thermometer is left in the block before switching on so it shows the block's temperature, not "room temperature". Many used the wrong temperature change from the graph. 2022: the dependent variable was time, and "temperature change" was the common wrong answer.

Spot it What does this show?

A student heats 0.50 kg of water and 0.50 kg of oil with the same heater for the same time. The oil gets hotter. What does this show?

- (A) The oil has a lower specific heat capacity than the water.
- (B) The oil has a higher specific heat capacity than the water.
- (C) The water has a smaller mass than the oil.
- (D) The oil is a better thermal insulator than the water.

Cover this, choose, then read

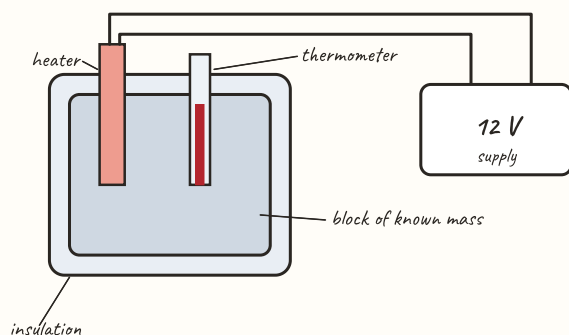
A. $\Delta E = m c \Delta\theta$. The energy and mass are the same, so the bigger temperature change means a smaller c . The oil needs less energy per kilogram for each °C. The masses were equal, and insulation isn't what is being measured.

3 Part one · Energy

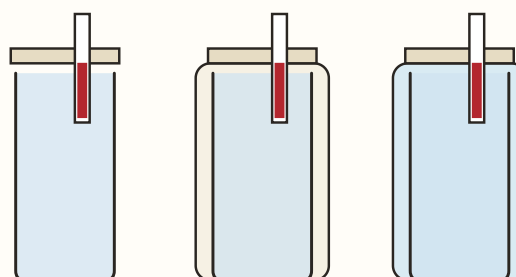
Heating: specific heat capacity and insulation

Use it

The two practicals: heating a block (required practical 1) and comparing insulators (required practical 2)



Energy supplied = $V \times I \times t$. $c = \Delta E \div (m \Delta \theta)$.



no insulation
80 °C at the start

cotton wool
80 °C at the start

bubble wrap
80 °C at the start

Same volume, start temperature and time. Compare the fall in temperature.

A 2.5 kg block of aluminium has a specific heat capacity of 900 J/kg °C. Its temperature rises from 18 °C to 46 °C. (a) Calculate the energy transferred to the block. (b) A 1.5 kW heater supplies all of it. How long does that take? [5 marks]

$$\Delta \theta = 46 - 18 = 28 \text{ °C} \checkmark$$

$$\Delta E = 2.5 \times 900 \times 28 \checkmark = 63\,000 \text{ J} \checkmark$$

$$(b) 1.5 \text{ kW} = 1500 \text{ W} \checkmark$$

$$63\,000 = 1500 \times t, \text{ so } t = 42 \text{ s} \checkmark$$

5/5

1 for the temperature change. 2, 3 for the substitution and the answer in joules. 4 for 1.5 kW as 1500 W. 5 for the answer from $63\,000 = 1500 \times t$. The substitution mark is for the equation as printed, with the numbers in. The kilowatt conversion is the slip AQA's reports keep naming.

Try it In a specific heat capacity experiment the thermometer reading keeps rising for a short time after the heater is switched off. Explain why, and say which reading to use. Then explain why the block is insulated. [3 marks]

It could be asked as: Calculate the energy to change the temperature of a mass of material, or the specific heat capacity from measurements. · Describe how to find the specific heat capacity of a metal block, and say why it is insulated. · Plan an investigation into the best thermal insulator, naming the variables. · Explain what a faster fall in temperature shows about the rate of energy transfer.

Cover both pages, write it from memory, then count the facts

facts: predict ___ / 10 got ___ / 10

Quick-fire. Answers are on page 53

3.1 How much energy raises 2.0 kg of water by 5.0 °C? ($c = 4200 \text{ J/kg °C}$)

3.2 State the unit of specific heat capacity.

3.3 A block is heated from 20 °C to 35 °C. What is $\Delta \theta$?

3.4 Beaker A cools by 12 °C in 10 minutes and beaker B by 7 °C in the same time. Which has the better insulation?

4 Energy resources

Part one · Energy

Learn it

In sixty seconds

Energy resources are renewable if they are replenished as they are used, and non-renewable if they are not. Fossil fuels (coal, oil and gas) and nuclear fuel are non-renewable. Bio-fuel, wind, hydroelectricity, geothermal, the tides, the Sun and water waves are renewable. They are used for transport, electricity and heating, and they differ in reliability and in their effect on the environment.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- The main resources are fossil fuels (coal, oil and gas), nuclear fuel, bio-fuel, wind, hydroelectricity, geothermal, the tides, the Sun and water waves.
- A **renewable** resource is being, or can be, replenished as it is used. **Non-renewable** resources, the fossil fuels and nuclear fuel, will run out.
- Resources are used for **transport**, **electricity generation** and **heating**. You don't need to describe how each one generates electricity.
- Burning fossil fuels releases carbon dioxide, which causes global warming. Also sulfur dioxide (acid rain), nitrogen oxides (breathing problems, acid rain) and particulates (global dimming). Gas gives less carbon dioxide than coal, and no sulfur dioxide or particulates.
- Nuclear power stations release no carbon dioxide when running, but leave radioactive waste that needs safe storage for a long time.
- A **reliable** resource can supply energy whenever it is needed. A wind turbine gives little in light winds and is shut down in very strong winds. Solar cells give little in the dark or in cloud.
- Hydroelectric output depends on rainfall, and a reservoir floods land. Solar farms need a large area for a low power output, and the materials for cells and batteries are limited.
- Bio-fuels can be grown again, so they are renewable, but growing them takes land. Geothermal energy is reliable but only available in some places.
- Describe a pattern or trend in a graph or table by quoting values: what has risen or fallen, from what to what, and over what time.
- Science can show what the environmental problem is. It can't always solve it, because political, social, ethical and economic factors decide what is done.

Key words

- Renewable** replenished as it is used. ☐
- Non-renewable** will run out because it is not replaced. ☐
- Fossil fuel** coal, oil or natural gas. ☐
- Bio-fuel** a fuel made from plants or waste, which can be regrown. ☐
- Reliable** able to supply energy whenever it is needed. ☐
- Global warming** a rise in the Earth's temperature caused by gases such as carbon dioxide. ☐
- Acid rain** rain made acidic by gases such as sulfur dioxide. ☐
- Geothermal** energy from hot rocks underground. ☐

Reading a graph for reliability. In 2023 the mark was for using the graph: in the summer one source fell while the other rose, so the total varied less. Name both sources, quote the months, then say what that does to the supply.

Name the gas and what it causes: carbon dioxide, global warming (2021). In 2022 "wind is unreliable" scored but "weather conditions" alone did not: say what the wind does. Repeating "more reliable" from the question earned nothing (2023). For a graph, quote values and a time period (2020).

Spot it Which pair?

Which pair are both renewable energy resources?

- (A) Bio-fuel and nuclear fuel. (B) Wind and natural gas.
- (C) Geothermal and the tides. (D) Coal and the Sun.

Cover this, choose, then read

C. Renewable resources are replenished as they are used. Geothermal, tides, wind, the Sun and bio-fuel are renewable. Coal, oil, natural gas and nuclear fuel are not.

4 Energy resources

Part one · Energy

Use it

The resources side by side

Resource	Renewable?	Reliable?	Used for	One point to know
Coal, oil, gas	No	Yes	electricity, heating, transport	Burning gives carbon dioxide, sulfur dioxide and particulates
Nuclear fuel	No	Yes	electricity	No carbon dioxide when running; radioactive waste
Wind	Yes	No	electricity	Little in light wind; shut down in very strong wind
Solar	Yes	No	electricity, heating water	Daylight only; large area for a low power output
Hydroelectric	Yes	Depends on rainfall	electricity	A reservoir floods land
Tides and waves	Yes	Tides vary but are predictable; waves depend on weather	electricity	No fuel needed
Bio-fuel	Yes	Yes	transport, heating, electricity	Needs land to grow the crop
Geothermal	Yes	Yes	heating, electricity	Only in some places

A town needs an average power of 36 MW. Each wind turbine has a maximum output of 3.0 MW but averages 30% of that. (a) Calculate how many turbines are needed to supply the town on average. (b) Name one other resource that could back them up, and say why a back-up is needed. [4 marks]

average per turbine = $0.30 \times 3.0 = 0.90$ MW ✓

turbines = $36 \div 0.90 = 40$ ✓

(b) A gas or hydroelectric station could back them up ✓, because on days with little wind the turbines produce less than the average

4/4

1 for the average output of one turbine. 2, 3 for the division and the answer. 4 for a back-up with the reason: turbines give little in light winds. "Weather" on its own earned nothing in 2022. The two megawatt figures cancel, so no conversion was needed here.

Try it The table shows the share of a country's electricity made from renewable resources (invented figures). Describe the trend, and say between which two years the share rose most and by how many percentage points. [3 marks]

Year	2005	2010	2015	2020
Renewable share of electricity (%)	4	7	17	25

It could be asked as: Compare two resources for generating electricity: reliability, environment, cost. · Explain why a resource is renewable or non-renewable. · Describe the environmental impact of burning fossil fuels, naming the gas and its effect. · Use a graph to explain why using several resources makes the supply more reliable.

Cover both pages, write it from memory, then count the facts

facts: predict ___ / 10 got ___ / 10

Quick-fire. Answers are on page 53

4.1 Name two fossil fuels.

4.2 Which gas released by burning fossil fuels causes global warming?

4.3 Why can't a wind farm supply electricity all the time?

4.4 Name one use of energy resources other than generating electricity.

5 Circuits: current, p.d. and resistance

Learn it

In sixty seconds

Charge flows round a closed circuit that includes a source of potential difference. The current is the rate of flow of charge, in amperes, and $V = IR$ links p.d., current and resistance. In a series circuit the current is the same everywhere and the p.d. is shared. In a parallel circuit each branch has the supply p.d. and the currents add.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- ☐ Circuit diagrams use standard symbols (page 36). You should be able to draw them, and read them.
- ☐ **Current** is the rate of flow of electrical charge: $Q = It$. Charge Q is in coulombs (C), current I in amperes (A) and time t in seconds (s). In a single closed loop the current is the same at every point.
- ☐ Charge only flows round a **closed circuit**, that includes a source of **potential difference**, such as a cell, a battery or a power supply.
- ☐ **$V = IR$** : potential difference (p.d., also called voltage) in volts, current in amperes, resistance in ohms (Ω). One volt is one joule for each coulomb. More resistance means less current for the same p.d.
- ☐ **Series**: the same current through each component, the supply p.d. is shared between them, and total resistance $= R_1 + R_2$.
- ☐ **Parallel**: the p.d. across each branch is the same, the total current is the sum of the branch currents, and the total resistance is less than the smallest single resistance.
- ☐ An **ammeter** goes in series and measures current. A **voltmeter** goes in parallel across a component and measures the p.d. across it.
- ☐ **Required practical 3**: the resistance of a wire at constant temperature is directly proportional to its length: a straight line through the origin on a graph of resistance against length. Resistors in series and parallel are also tested.
- ☐ Keep currents low, or switch off between readings, so the wire doesn't heat and change its resistance.
- ☐ Change milliamperes to amperes ($\div 1000$), minutes to seconds ($\times 60$), hours to seconds ($\times 3600$) and kilohms to ohms ($\times 1000$) before you substitute.

Key words

- Current** the rate of flow of electrical charge. ☐
- Charge** what flows round a circuit, measured in coulombs. ☐
- Potential difference** what pushes charge round a circuit, measured in volts. ☐
- Resistance** how much a component opposes current, in ohms. ☐
- Series** components in one loop, one after another. ☐
- Parallel** components on separate branches. ☐
- Ammeter** measures current, connected in series. ☐
- Voltmeter** measures p.d., connected across a component. ☐

Why parallel lowers resistance. Two $12\ \Omega$ resistors in parallel on $12\ \text{V}$ each take $1.0\ \text{A}$, so the supply gives $2.0\ \text{A}$ in total, and $12 \div 2.0 = 6.0\ \Omega$. More branches means more paths, so the supply gives more current in total (AQA 2020), and the total resistance is always less than the smallest branch.

AQA 2021: to show two quantities are inversely proportional, work out the product for three or more pairs of values and show it is constant. "As one goes up the other goes down" scored nothing. 2023: a voltmeter in series stops the circuit working, which capped a plan at Level 1.

Spot it Which is correct?

A $6.0\ \Omega$ resistor and a $12\ \Omega$ resistor are in series with a $9.0\ \text{V}$ battery. Which statement is correct?

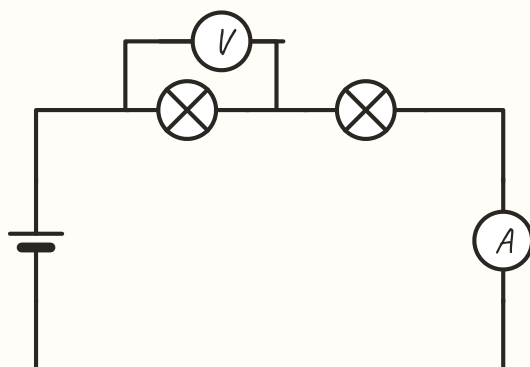
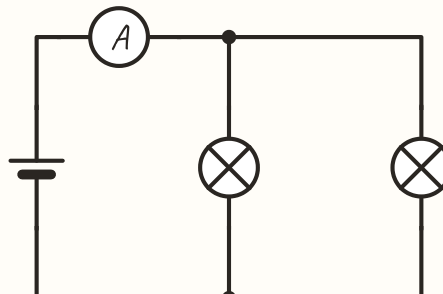
- ☐ (A) The p.d. across each resistor is $9.0\ \text{V}$.
- ☐ (B) More current flows through the $6.0\ \Omega$ resistor.
- ☐ (C) The total resistance is $4.0\ \Omega$.
- ☐ (D) The current is the same in both resistors.

Cover this, choose, then read

D. In series there is one loop, so the current is the same through both. The $9.0\ \text{V}$ is shared between them, not $9.0\ \text{V}$ each. The total resistance is $6.0 + 12 = 18\ \Omega$, so the current is $0.50\ \text{A}$. $4.0\ \Omega$ is the wrong answer for a parallel pair.

5 Part two · Electricity

Circuits: current, p.d. and resistance

*Use it***Series and parallel: the same two lamps, wired two ways***Series: one loop**Parallel: branches*

	Series	Parallel
Current	same everywhere in the loop	adds up: total = sum of the branches
Potential difference	shared out between the components	same across every branch
Total resistance	adds: $R_1 + R_2$	less than the smallest single resistor

A $4.0\ \Omega$ resistor and an $8.0\ \Omega$ resistor are connected in series to a $12\ \text{V}$ battery. Calculate the current and the potential difference across the $8.0\ \Omega$ resistor.

[5 marks]

total resistance = $4.0 + 8.0 = 12\ \Omega$ ✓

$12 = I \times 12$ ✓, so $I = 1.0\ \text{A}$ ✓

$V = 1.0 \times 8.0 = 8.0\ \text{V}$ ✓

5/5

1 for adding the resistances. 2, 3 for the substitution into $V = IR$ and the current. 4, 5 for the substitution and answer for the $8.0\ \Omega$ resistor. Check: the other resistor has $1.0 \times 4.0 = 4.0\ \text{V}$, and $4.0 + 8.0 = 12\ \text{V}$, the supply. Using $12\ \text{V}$ across the $8.0\ \Omega$ resistor would be the common slip.

Try it A $12\ \text{V}$ supply is connected across a $30\ \Omega$ resistor and a $60\ \Omega$ resistor in parallel. Calculate the current in each resistor and the total current.

[4 marks]

It could be asked as: Calculate current, p.d. or resistance using $V = IR$, converting units first. · Draw a circuit diagram with an ammeter and a voltmeter in the right places. · Find the total resistance of resistors in series, or say what happens in parallel. · Use $Q = It$ to find charge flow.

Cover both pages, write it from memory, then count the facts

facts: predict ___ / 10 got ___ / 10

Quick-fire. Answers are on page 53

5.1 A current of $0.50\ \text{A}$ flows for 2.0 minutes. How much charge flows?

5.2 A $6.0\ \text{V}$ battery drives $0.20\ \text{A}$ through a resistor. What is its resistance?

5.3 Two $10\ \Omega$ resistors are in series. What is the total resistance?

5.4 Does a second identical resistor in parallel raise or lower the total resistance?

6 Resistors and I–V graphs

Part two · Electricity

Learn it

In sixty seconds

A resistor at a constant temperature is ohmic: its current is directly proportional to the p.d., so its I–V graph is a straight line through the origin. Other components don't obey this. A filament lamp's resistance rises as it heats up, a diode lets current through in one direction only, a thermistor's resistance falls as it gets hotter and an LDR's falls as it gets brighter.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- An **ohmic conductor** at constant temperature has a current directly proportional to the p.d. across it, so its resistance stays constant. Its I–V graph is a straight line through the origin.
- Other components aren't ohmic. A lamp's resistance changes with the current, a thermistor's with temperature and an LDR's with light.
- A **filament lamp**: its resistance increases as the filament gets hotter. The I–V graph curves and gets shallower as the p.d. increases, and is the same shape for negative p.d.
- A **diode** lets current through in one direction only, with a very high resistance in the reverse direction. An LED is a diode that gives out light. In the forward direction almost no current flows until about 0.6 to 0.7 V.
- A **thermistor's** resistance decreases as the temperature increases. It is used in circuits such as a thermostat.
- An **LDR's** resistance decreases as light intensity increases. It is used in circuits such as one that switches a light on when it gets dark.
- **Required practical 4**: put an ammeter in series with the component and a voltmeter across it. Change the p.d. with a variable resistor, and record the current and p.d. in steps.
- To get negative values, reverse the connections to the power supply and repeat. Switch off between readings, and keep the current low, so the component doesn't heat up.
- Plot current on the y-axis and p.d. on the x-axis, and draw a smooth line through the points. The resistance at a point is $V \div I$ there. It isn't the gradient: on a straight I–V line the gradient is $1 \div R$.
- Repeat the readings and calculate a mean. Discard an anomaly if one reading is far from the pattern.

Key words

Ohmic conductor current is proportional to p.d. at constant temperature. ☐

I–V characteristic a graph of current against p.d. for a component. ☐

Filament lamp a lamp with a thin wire that glows when hot. ☐

Diode a component that lets current flow in one direction only. ☐

Thermistor a resistor whose resistance falls as it gets hotter. ☐

LDR a light-dependent resistor: resistance falls in brighter light. ☐

Variable resistor a resistor you can adjust to change the current. ☐

Anomaly a result that doesn't fit the pattern. ☐

Direct and inverse proportion. A straight line through the origin means directly proportional: double the p.d., double the current. For a fixed p.d., current and resistance are inversely proportional: $I \times R$ stays the same.

AQA 2023: a plan for the I–V practical reached Level 3 only with a way to get negative values, such as reversing the supply connections. Reversing the meters wasn't enough. 2021: for a digital meter, "less chance of misreading" and "no parallax error" scored, "more accurate" was allowed, "easier to read" was not.

Spot it What explains it?

A student plots current against p.d. for a lamp. The line goes through the origin and gets shallower as the p.d. rises. What explains this?

- (A) The resistance rises as the filament heats up.
- (B) The resistance falls as the p.d. rises, so the current rises faster.
- (C) It is a diode, so it only conducts one way.
- (D) Its resistance is constant, so it is ohmic.

Cover this, choose, then read

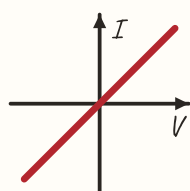
A. A shallower line means less extra current for each extra volt, so the resistance is increasing: the filament is getting hotter. An ohmic conductor's line is straight, and a diode's graph is flat for a reverse p.d.

6 Resistors and I–V graphs

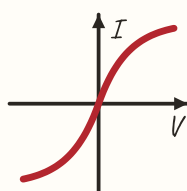
Part two · Electricity

Use it

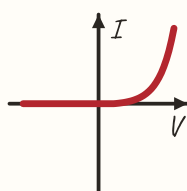
The I–V graphs to know



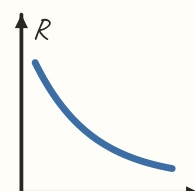
Resistor



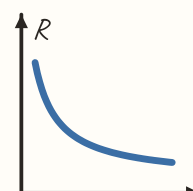
Filament lamp



Diode



Thermistor



LDR

Required practical 4 in short

Ammeter in series, voltmeter across the component, a variable resistor to change the p.d. in equal steps. Switch off between readings. Reverse the supply connections for negative values. Plot I against V and draw a smooth line. The circuit diagram and the full method, with results, are on page 43.

A filament lamp carries 0.25 A when the p.d. is 2.0 V and 0.50 A when the p.d. is 6.0 V. Calculate the resistance at each p.d. and explain why it changes.

[5 marks]

$$2.0 = 0.25 \times R \checkmark, \text{ so } R = \mathbf{8.0 \, \Omega} \checkmark$$

$$6.0 = 0.50 \times R, \text{ so } R = \mathbf{12 \, \Omega} \checkmark$$

The bigger current heats the filament $\checkmark$, so its resistance increases $\checkmark$

5/5

1, 2 for the substitution and 8.0 Ω . 3 for 12 Ω . 4, 5 for the cause and the effect: a hotter filament, so more resistance. Writing "the current is bigger so the resistance is bigger" gives the effect without the cause and scores one. The resistance is not the gradient: it is $V \div I$ at each point.

Try it Component X lets no current through when the p.d. is reversed, and only a small current in the forward direction until the p.d. reaches about 0.7 V. Name X and say what happens if it is connected the wrong round.

[3 marks]

It could be asked as: Draw and explain the I–V graph of a resistor, a filament lamp and a diode. · Describe how to investigate an I–V characteristic, including how to get negative values. · Say how the resistance of a thermistor or an LDR changes, and give a use. · Calculate resistance from a pair of readings on a graph.

Cover both pages, write it from memory, then count the facts

facts: predict ___ / 10 got ___ / 10

Quick-fire. Answers are on page 53

6.1 What does a straight I–V line through the origin show?

6.2 Why does a filament lamp's resistance rise as the current rises?

6.3 What happens to an LDR's resistance in brighter light?

6.4 A diode is connected backwards. What current flows?

7 Electrical power and energy

Part two · Electricity

Learn it**In sixty seconds**

The power of a circuit device is the p.d. across it times the current through it, $P = VI$, or $P = I^2 R$. The energy transferred depends on the power and how long it is on, $E = Pt$, or on the charge and the p.d., $E = QV$. A power rating says how many joules the device transfers each second when it is working normally.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- **Power:** $P = VI$, with power in watts, p.d. in volts and current in amperes. Also $P = I^2 R$, with resistance in ohms.
- In $P = I^2 R$ the current is **squared**: double it and the power is four times bigger. Double the p.d. across a fixed resistor and the current doubles too, so the power is four times bigger. In 2023 many forgot to square it.
- **Energy transferred:** $E = Pt$, with energy in joules, power in watts and time in seconds. The longer it is on, the more energy is transferred.
- **Energy and charge:** $E = QV$, with charge Q in coulombs and p.d. V in volts. One volt is one joule transferred for each coulomb of charge.
- These link up. $Q = It$, so $E = QV = VIt$, which is Pt again. Any route gives the same joules.
- A **power rating** is the energy transferred each second when the device is working normally. A 2.3 kW kettle transfers 2300 J every second.
- Everyday appliances transfer energy from a battery or the a.c. mains to the kinetic energy of electric motors or to the thermal energy of heating devices.
- The energy an appliance transfers depends on both its power and how long it is switched on, so a low-power device left on for hours can transfer a lot.
- Choose the equation from what you are given: V and I give P . I and R give P . P and t give E . Q and V give E .
- Convert before you calculate: kW to W ($\times 1000$), kJ to J ($\times 1000$), minutes to seconds ($\times 60$), a day to 86 400 s. A mis-converted value costs the conversion mark, but later marks can still be scored.

Key words

Power rating the energy transferred each second in normal use.	☐
Energy transferred how much energy moves from one store to another.	☐
Charge flow the amount of charge that passes, in coulombs.	☐
Kilowatt 1000 watts.	☐
Joule the unit of energy and work.	☐
Coulomb the unit of charge.	☐
Motor a device that transfers electrical energy to kinetic energy.	☐
Heating device a device that transfers electrical energy to thermal energy.	☐

Three routes to the same joules. A 12 V supply drives 2.0 A for 30 s. Charge $Q = 2.0 \times 30 = 60$ C, so $E = 60 \times 12 = 720$ J. Or $P = 12 \times 2.0 = 24$ W, so $E = 24 \times 30 = 720$ J. Use whichever the question's data suits.

A wrong or missing conversion is a common slip in every report: a day is 86 400 s, 30 minutes is 1800 s, a kilowatt is 1000 W. You lose the conversion mark, but later marks can still be scored with your unconverted value. In 2023 there was a separate mark for standard form.

Spot it Which gives the energy?

A 12 V motor carries a current of 2.0 A for 3.0 minutes. Which calculation gives the energy transferred?

- (A) $12 \times 2.0 \times 3.0 = 72$ J.
- (B) $12 \times 2.0 \times 180 = 4320$ J.
- (C) $12 \div 2.0 \times 180 = 1080$ J.
- (D) $12 \times 2.0 \times 30 = 720$ J.

Cover this, choose, then read

B. Convert 3.0 minutes to 180 s before you use it. $E = VIt = 12 \times 2.0 \times 180 = 4320$ J. 72 J leaves the time in minutes, 1080 J divides instead of multiplying, and 720 J takes 3 minutes as 30 s.

7

Part two · Electricity

Electrical power and energy

Use it**One kettle, six calculations: every route gives the same answer**

A 2.3 kW kettle on 230 V for 3.0 minutes	Working	Result
Current	$I = P \div V = 2300 \div 230$	10 A
Resistance of the element	$R = V \div I = 230 \div 10$	23 Ω
Power from I and R	$P = I^2 R = 10^2 \times 23$	2300 W
Energy from power and time	$E = P t = 2300 \times 180$	414 000 J
Charge	$Q = I t = 10 \times 180$	1800 C
Energy from charge and p.d.	$E = Q V = 1800 \times 230$	414 000 J

3.0 minutes is 180 s. The two energies agree, which is a check on the working.

A 12 V car battery drives a starter motor with a current of 150 A for 2.0 s. (a) Calculate the energy transferred by the battery. (b) Calculate the power of the starter motor. [5 marks]

$Q = 150 \times 2.0 \checkmark = 300 \text{ C } \checkmark$

$E = 300 \times 12 = \mathbf{3600 \text{ J}} \checkmark$

$(b) P = 12 \times 150 \checkmark = \mathbf{1800 \text{ W}} \checkmark$

5/5

1, 2 for $Q = I t$ and 300 C. 3 for $E = Q V$ and 3600 J. 4, 5 for $P = V I$ and the answer. Check by $E = P t$: $1800 \times 2.0 = 3600 \text{ J}$, which agrees. No unit, or the wrong unit (W for energy), loses the unit mark.

Try it The p.d. across a heater of fixed resistance is doubled. Show that its power is four times bigger. [3 marks]

It could be asked as: Calculate power from p.d. and current, or from current and resistance. · Calculate the energy an appliance transfers in a given time, in joules. · Use $Q = I t$ first, then $E = Q V$, when charge or current is given. · Describe the energy transfers in a kettle, a motor and a hairdryer.

Cover both pages, write it from memory, then count the facts

facts: predict ___ / 10 got ___ / 10

Quick-fire. Answers are on page 53

7.1 A heater has 230 V across it and a current of 8.0 A. What is its power?

7.2 A 40 Ω resistor carries 0.50 A. What is its power?

7.3 A 60 W lamp is on for 2.0 minutes. How much energy does it transfer?

7.4 How much energy is transferred when 15 C of charge crosses a p.d. of 9.0 V?

8 Mains electricity and the National Grid

Part two · Electricity

Learn it**In sixty seconds**

Mains electricity is an alternating supply, 50 Hz at about 230 V. Appliances connect through a three-core cable: live (brown), neutral (blue) and earth (green and yellow). The earth wire is a safety wire. The National Grid links power stations to consumers with cables and transformers. A step-up transformer raises the p.d. so the current is low. Less energy is then dissipated as thermal energy in the cables. A step-down transformer makes the p.d. safe to use.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- UK mains is an **alternating** (a.c.) supply, with a frequency of 50 Hz and a p.d. of about 230 V. 50 Hz means 50 complete cycles every second.
- A **direct** p.d. (d.c.) is always in one direction, from a cell or battery: its polarity doesn't change. An **alternating** p.d. keeps changing direction. Describe both in terms of the potential difference.
- Most appliances connect to the mains through a **three-core cable**. The insulation is colour coded: **live** brown, **neutral** blue, **earth** green and yellow stripes.
- The **live wire** carries the alternating p.d. from the supply: about 230 V between live and earth (0 V). The **neutral wire** completes the circuit and is at, or close to, 0 V.
- The **earth wire** is a safety wire that stops the appliance becoming live. It is at 0 V and only carries a current if there is a fault.
- A live wire may be dangerous even when a switch in the mains circuit is open. Any connection between the live wire and earth is dangerous: a large current can flow through whoever touches it.
- The **National Grid** is a system of cables and transformers linking power stations to consumers.
- A **step-up transformer** at the power station increases the p.d. and so decreases the current in the cables. A **step-down transformer** near homes decreases the p.d. to a safe value.
- A lower current means less energy is transferred as thermal energy to the surroundings from the cables, so power transmission is more efficient. The p.d. is raised, not lowered, for transmission.
- The power lost in the cables is $I^2 R$. Halving the current cuts the power lost to a quarter, which is why a very high p.d. and a low current are used.

Key words

- Alternating p.d.** a p.d. that keeps changing direction. ☐
- Direct p.d.** a p.d. that is always in one direction. ☐
- Frequency** the number of cycles each second, in hertz. ☐
- Live wire** carries the alternating p.d. from the supply. ☐
- Neutral wire** completes the circuit, at about 0 V. ☐
- Earth wire** a safety wire that only carries current if there is a fault. ☐
- Transformer** changes the size of an alternating p.d. ☐
- National Grid** the cables and transformers linking power stations to users. ☐

One cycle of the mains. At 50 Hz one complete cycle takes $1 \div 50 = 0.02$ s, which is why the a.c. graph on the next page is marked at 0.01 s and 0.02 s. For the same power, $P = VI$, so raising V lowers I, and the power lost in the cables falls with the square of the current.

2023: "the p.d. flows in one direction", or any answer about charge or current, scored nothing. "The p.d. is always in one direction" scored. 2022: step-up means p.d. up, current down, and "no energy is lost" earned nothing.

Spot it Which is correct?

Which statement about the wires in a mains cable is correct?

- (A) The neutral wire is at about 230 V, the same as the live wire.
- (B) The earth wire completes the circuit when the appliance is switched on.
- (C) The earth wire only carries a current if there is a fault.
- (D) The live wire has blue insulation and carries the supply p.d.

Cover this, choose, then read

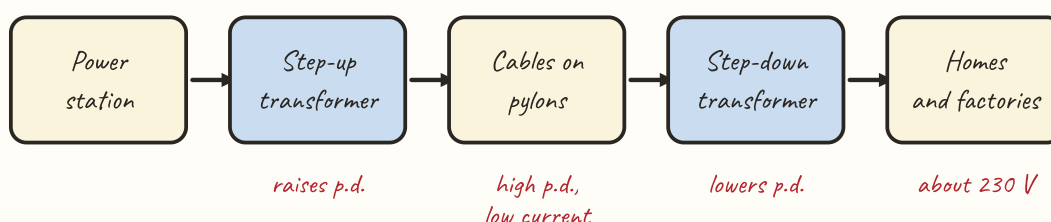
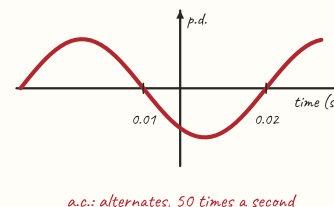
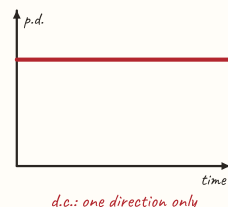
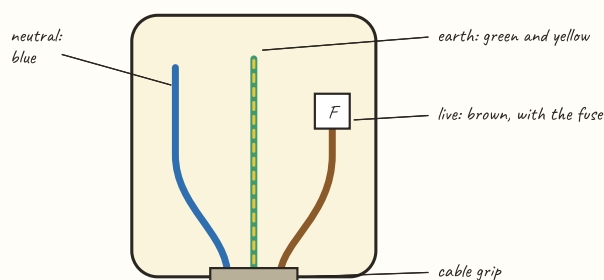
C. The neutral wire is at about 0 V and completes the circuit. The live wire is brown and carries the 230 V. The earth wire is a safety wire at 0 V, so it has no current unless something goes wrong.

8

Part two · Electricity

Mains electricity and the National Grid

Use it

The plug, the two kinds of p.d., and the path from the power station to your socket

A power station transmits 80 kW through cables of total resistance 5.0 Ω. At 4000 V, calculate the current and the power lost in the cables. Then say what the power lost would be at 40 000 V. [5 marks]

80 kW = 80 000 W, so $80\,000 = 4000 \times I$ ✓, $I = 20\text{ A}$ ✓

$P = I^2 R = 20^2 \times 5.0$ ✓ = **2000 W** ✓

At 40 000 V the current is 10 times smaller (2.0 A), so the loss is 100 times smaller: **20 W** ✓

5/5

1, 2 for the kW conversion and the current. 3, 4 for the substitution into $P = I^2 R$ (squared!) and the answer. 5 for the 20 W, from $2.0^2 \times 5.0$. This is the reason for the grid: ten times the p.d. gives a hundredth of the wasted power. In 2023 many forgot to square the current.

Try it Describe the difference between a direct p.d. and an alternating p.d., and give the frequency and the approximate p.d. of the UK mains supply. [4 marks]

It could be asked as: Describe the difference between direct and alternating p.d., in terms of p.d. · Name the three wires in a mains cable and give the colour and job of each. · Explain why a live wire is dangerous even when a switch is open. · Explain why electricity is transmitted at a high p.d., using the idea of current and thermal energy.

Cover both pages, write it from memory, then count the facts

facts: predict ___ / 10 got ___ / 10

Quick-fire. Answers are on page 53

8.1 What are the frequency and approximate p.d. of UK mains?

8.2 Give the colours of the live, neutral and earth wires.

8.3 What does a step-up transformer do to the p.d. and the current?

8.4 Why is a live wire still dangerous when a switch in the mains circuit is open?

9 Static electricity and electric fields

Part two · Electricity · **Physics only**Learn it**In sixty seconds**

Rubbing two insulating materials together rubs electrons off one and onto the other. The material that gains electrons becomes negatively charged and the one that loses them is left with an equal positive charge. Objects with the same type of charge repel and objects with different types attract, without touching. A charged object has an electric field around it, strongest close to it, and a strong field can make the air break down as a spark.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- **Physics only** When certain **insulating** materials are rubbed together they become electrically charged. Negatively charged **electrons** are rubbed off one material and onto the other.
- The material that **gains** electrons becomes **negatively** charged. The material that **loses** electrons is left with an equal **positive** charge. Only electrons move.
- Two objects that carry the **same** type of charge **repel**. Two objects that carry **different** types of charge **attract**.
- These are **non-contact forces**. Evidence: a charged rod hung from a thread swings away from, or towards, a second charged rod held near it without touching.
- A charged object creates an **electric field** around itself. The field is strongest close to the object and gets weaker further away.
- A second charged object placed in the field experiences a force. The force gets stronger as the distance between the objects decreases.
- For an isolated charged sphere draw field lines straight in or out from the sphere, with arrows **away** from a positive charge and **towards** a negative charge.
- **Sparkling**: a large p.d. between a charged object and a conductor gives a strong field, which makes the air break down so charge moves through it as a spark.

Key words

Static electricity charge that builds up on an insulator and stays there. ☐

Insulator a material that doesn't let charge flow through it easily. ☐

Electron a negatively charged particle that can be rubbed off an atom. ☐

Charged carrying more of one type of charge than the other. ☐

Non-contact force a force between objects that are not touching. ☐

Electric field the region around a charged object where it exerts a force. ☐

Spark charge moving through air when the air breaks down. ☐

Repel push apart. ☐

A force, not extra mass. Two rods with the same charge push apart without touching, because like charges repel. If one sits on a balance, a charged rod held above it adds a downward force, so the reading goes up. Describe the force and the electrons; don't say the rod got heavier.

2022 mark scheme: electrons move. "Positive electrons" and a transfer of positive charge scored 0, and many mixed up ions, protons and electrons. The cloth ends up positive because it has lost negative electrons, so it has more positive charges than negative ones. For a spark the large p.d. mattered: a strong field breaks down the air.

Spot it What happened?

A plastic comb is pulled through dry hair and becomes negatively charged. What happened?

- (A) Electrons moved from the hair to the comb, leaving the hair positive.
- (B) Protons moved from the hair to the comb, which left the hair positively charged.
- (C) Electrons were created on the comb by the rubbing, so the comb became negative.
- (D) Positive charge moved from the comb to the hair, leaving the comb negative.

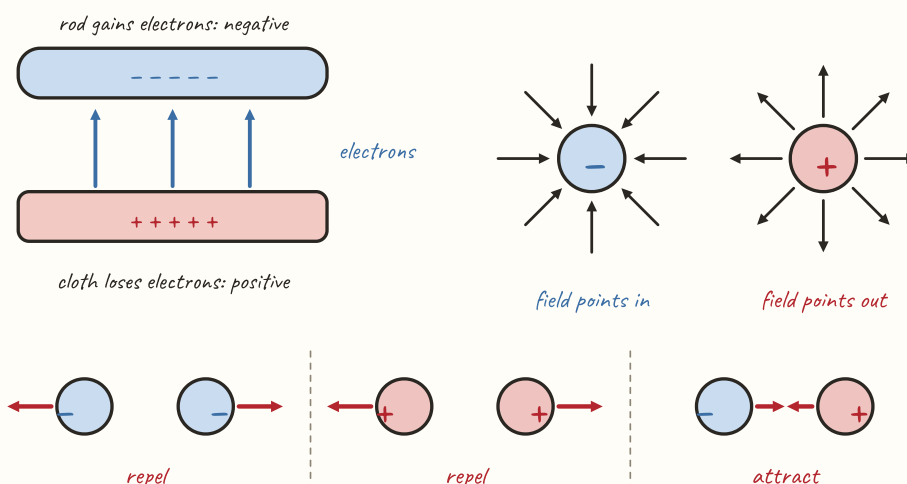
Cover this, choose, then read

A. Only electrons can be rubbed off. The comb gains them, so it is negative, and the hair that lost them has an equal positive charge. Charge is transferred, not made. Protons are fixed in the nuclei.

9 Static electricity and electric fields

Part two · Electricity · **Physics only**Use it

Charge by rubbing, and the field and force around charged objects



A student rubs a glass rod with a silk cloth and the rod becomes positively charged. (a) Explain, in terms of electrons, why the rod is positive and the cloth is negative. (b) The rod is held near a hanging positively charged ball. Describe what happens and why.

[5 marks]

- (a) Electrons are transferred from the rod to the cloth ✓. The rod has lost electrons, so it has more positive charge than negative ✓. The cloth has gained electrons, so it has more negative charge than positive ✓.
- (b) The ball is pushed away from the rod ✓, because they have the same type of charge and like charges repel ✓.

5/5

1 for the transfer in the right direction: here the rod is the one that loses electrons. 2 for the rod's charge from the missing electrons. 3 for the cloth, linked to the extra electrons. 4, 5 for the effect and its reason. Writing "the rod gains positive charge" on its own isn't an explanation: say it loses electrons.

Try it A small positive charge is placed near a charged metal sphere and then moved closer to it. Describe how the electric field and the force on the small charge change.

[3 marks]

It could be asked as: Explain, in terms of electrons, how rubbing charges an insulator. · Describe evidence that charged objects exert forces on each other without touching. · Draw the electric field around an isolated charged sphere, with arrows the right way. · Use the idea of an electric field to explain a spark.

Cover both pages, write it from memory, then count the facts

facts: predict ___ / 8 got ___ / 8

Quick-fire. Answers are on page 53

9.1 Which particles move when an insulator is charged by rubbing?

9.2 A rod gains electrons. Is it positive or negative?

9.3 Do a negative charge and a positive charge attract or repel?

9.4 Which way do the field lines point around an isolated negative sphere?

10

Density and states of matter

Part three · Particle model of matter

*Learn it***In sixty seconds**

Density is mass divided by volume: $\rho = m \div V$. In a solid the particles are in a regular pattern and vibrate about fixed positions, in a liquid they are close together but move past each other, and in a gas they are far apart and move randomly, so a gas is much less dense. Changes of state are physical changes and the mass is conserved. To find a density you need a mass from a balance and a volume from measuring, from displacement, or from a measuring cylinder for a liquid.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- **Density** $\rho = m \div V$, in kg/m^3 with mass in kg and volume in m^3 . $1 \text{ g/cm}^3 = 1000 \text{ kg/m}^3$, and $1 \text{ cm}^3 = 1 \times 10^{-6} \text{ m}^3$.
- **Solid:** particles in a regular pattern, close together, vibrating about fixed positions.
- **Liquid:** particles close together in a random arrangement, moving past each other, so a liquid flows.
- **Gas:** particles far apart, moving randomly. The same mass takes up a much bigger volume, so a gas has a much lower density.
- Melting, freezing, boiling, evaporating, condensing and sublimating are **changes of state**. The **mass is conserved**. The density changes.
- A change of state is a **physical** change: reverse it and the material gets its original properties back. A chemical change makes new substances.
- **Required practical 5, a regular solid:** mass on a balance. Length, width and height with a ruler, or a micrometer or Vernier callipers for a small object. $V = l \times w \times h$.
- **An irregular solid:** use displacement. The volume of water it pushes out of a displacement can, or the rise in the level of a measuring cylinder, is the volume of the solid.
- **A liquid:** weigh an empty measuring cylinder. Add liquid, read the volume at eye level at the bottom of the curve (the meniscus) and weigh again. The liquid's mass is the difference.
- Check the balance reads zero (a **zero error**). Repeat each measurement and take a mean. Give a range as a maximum and a minimum, the right way round.

Key words

- | | |
|---|--------------------------|
| Density mass divided by volume. | ☐ |
| Particle model matter as tiny particles with energy and forces between them. | ☐ |
| Mass conserved the mass is the same before and after. | ☐ |
| Physical change one that can be reversed, with the original properties back. | ☐ |
| Displacement water pushed aside by an object, used to find volume. | ☐ |
| Meniscus the curved surface of a liquid in a narrow tube. | ☐ |
| Zero error a reading that isn't zero when it should be. | ☐ |
| Sublimation a solid changing straight to a gas. | ☐ |

Work in g and cm^3 first. A cube of side 3.0 cm has a volume of $3.0^3 = 27 \text{ cm}^3$. With a mass of 70.2 g its density is $70.2 \div 27 = 2.6 \text{ g/cm}^3$. Multiply by 1000 at the end: 2600 kg/m^3 .

A number of students quoted the density equation wrongly in 2022 although it was printed, and in 2020 a wrong form beside a right one scored 0. "Scale" scored nothing for a balance: say balance or scales (2021). Copy numbers carefully: 988 for 998 lost marks (2020).

Spot it Which measurement?

A student drops a stone into a measuring cylinder of water. Which measurement gives the volume of the stone?

- | | |
|---|--|
| (A) The water level before the stone goes in. | (B) The water level after the stone goes in. |
| (C) The mass of the stone divided by the water level. | (D) The rise in the water level. |

Cover this, choose, then read

D. The stone pushes aside its own volume of water, so the level rises by that volume: the level after minus the level before. Neither reading on its own is the volume.

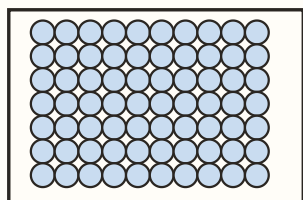
10

Part three · Particle model of matter

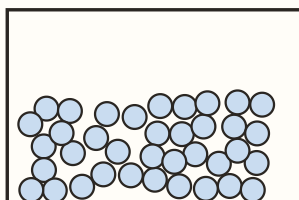
Density and states of matter

Use it

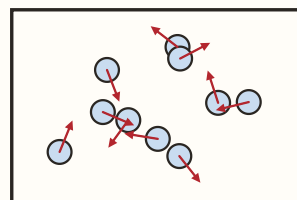
States of matter, and the three ways to find a volume



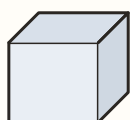
solid



liquid

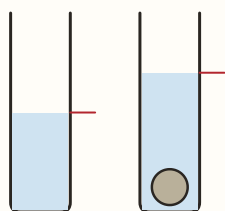


gas



regular block:

$$V = l \times w \times h$$



before

after

rise in level = volume of stone

Measuring	Use	Reads to (typical)
Mass	balance (scales)	0.01 g
Length of a block	ruler	1 mm
Small length	micrometer, Vernier callipers	0.01 mm, 0.1 mm
Liquid volume	measuring cylinder	1 cm ³
Stone volume	displacement can or cylinder	1 cm ³

A stone has a mass of 62.4 g. It is lowered into a measuring cylinder holding 60 cm³ of water, and the level rises to 84 cm³. Calculate the density of the stone in kg/m³. [5 marks]

volume = 84 – 60 = 24 cm³ ✓
 = 0.000024 m³ ✓ and 62.4 g = 0.0624 kg ✓
 $\rho = 0.0624 \div 0.000024 = 2600 \text{ kg/m}^3$ ✓

5/5

1 for the volume from the rise in the water level. 2, 3 for the two conversions: with a value that wasn't converted you lose that mark, but later marks can still be scored with your unconverted value. 4, 5 for the substitution and answer. Check in g/cm³: 62.4 ÷ 24 = 2.6 g/cm³, and × 1000 gives 2600 kg/m³.

Try it Describe how you would find the density of a liquid, using a measuring cylinder and a balance. [4 marks]

It could be asked as: Describe how to measure the density of a regular solid, an irregular solid and a liquid. · Calculate density, or mass or volume, converting units first. · Use the particle model to explain the differences between solids, liquids and gases. · Say why mass is conserved in a change of state.

Cover both pages, write it from memory, then count the facts

facts: predict ___ / 10 got ___ / 10

Quick-fire. Answers are on page 53

10.1 A block has a mass of 0.90 kg and a volume of 0.00030 m³. Calculate its density.

10.2 Convert 2.7 g/cm³ to kg/m³.

10.3 Why does a gas have a much lower density than a solid?

10.4 Is boiling a physical or a chemical change? What happens to the mass?

11

Gas pressure

Part three · Particle model of matter

Learn it

In sixty seconds

The molecules of a gas are in constant random motion, and the temperature of the gas is related to their average kinetic energy. The pressure of a gas is caused by its particles hitting the walls of the container: each collision gives a force at right angles to the wall, and pressure is the force on each unit of area. Heating a gas at constant volume raises its pressure. For a fixed mass of gas at constant temperature, pressure $\times$ volume is constant.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- The molecules of a gas are in constant **random** motion. The temperature of the gas is related to the average kinetic energy of its molecules.
- **Pressure** comes from the particles hitting the container wall. Each collision gives a small force at right angles to the wall. Pressure is the force on each unit of area.
- The collisions that matter are with the **walls**. Pressure isn't caused by particles colliding with each other (AQA 2020).
- **Constant volume, higher temperature:** the particles move faster, so they hit the walls more often each second and with a bigger force each time. More force on each square metre means a higher pressure.
- **More particles in the same space**, such as gas added to a sealed container: more hits on the walls each second, so a higher pressure. The speed hasn't changed.
- **Physics only** At constant temperature, a fixed mass of gas obeys **$pV = \text{constant}$** (on the equations sheet). Double the volume and the pressure halves: they are inversely proportional.
- **Physics only** **Squeezing a gas** into a smaller volume puts the same particles in less space. They hit the walls more often, so the pressure rises. Expanding it does the reverse.
- Write $pV = \text{constant}$, not $p \div V = \text{constant}$ (AQA 2020). Use any units for p and V , as long as you use the same ones on both sides.
- **Physics only** **HT Work** is the transfer of energy by a force. Doing work on a gas, such as pushing in a bicycle pump, raises its internal energy and so its temperature.
- In a calculation, write $p_1 V_1 = p_2 V_2$. Then check: a smaller volume must give a bigger pressure. Copy the numbers carefully: a missing zero cost marks in 2020.

Key words

- Pressure** force on each unit of area. ☐
- Random motion** movement in all directions with no pattern. ☐
- Collision** a particle hitting the wall (or another particle). ☐
- Average kinetic energy** linked to the temperature of the gas. ☐
- Fixed mass** no gas added or taken away. ☐
- Inversely proportional** one doubles when the other halves. ☐
- Work done** energy transferred by a force. ☐
- Internal energy** the total kinetic and potential energy of the particles. ☐

Four points for a pressure explanation. (1)

The particles move faster, or there are more of them, or less space. (2) So they hit the walls more often each second. (3) With a bigger force in each collision, if they're faster. (4) So there is more force on each square metre, and the pressure is higher. AQA 2023 marked each of these separately.

*2020: many said pressure comes from particles hitting each other, not the walls.
2021: "more collisions" scored nothing: say more often each second, and say the force on the wall. 2023: pumping in more air is more particles, not faster ones, and linking it to temperature lost the mark.*

Spot it Why does it rise? **Physics only**

A fixed mass of gas in a sealed syringe is slowly compressed at constant temperature. Why does the pressure rise?

- (A) The particles move faster, so they hit the walls harder and more often.
- (B) The particles hit the walls more often, as there is less space.
- (C) The particles get bigger, so they fill more of the space.
- (D) More particles are squeezed in from outside the syringe.

Cover this, choose, then read

B. The temperature is constant, so the average speed is the same, and no particles were added. In a smaller volume the particles collide with the walls more often each second, so the total force on the walls, and the pressure, rises.

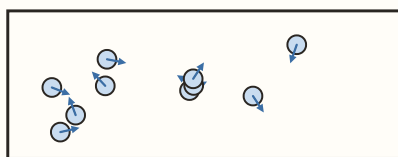
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Part three · Particle model of matter

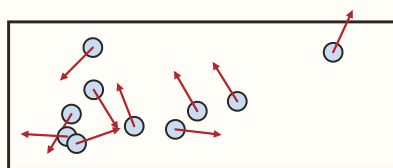
Gas pressure

Use it

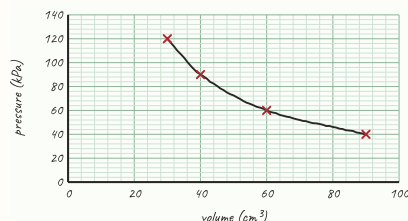
Heating a gas, and the numbers behind $pV = \text{constant}$



cool: slower, fewer hits each second



hot: faster, more hits, and harder



$V \text{ (cm}^3\text{)}$	$p \text{ (kPa)}$	$p \times V \text{ (kPa cm}^3\text{)}$
30	120	3600
40	90	3600
60	60	3600
90	40	3600

The product is the same each time: $pV = \text{constant}$.

Physics only A fixed mass of gas has a pressure of 150 kPa and a volume of 40 cm³. It expands at constant temperature to 100 cm³. (a) Calculate the new pressure. (b) Explain, using particles, why the pressure falls. [5 marks]

(a) $p_1 V_1 = 150 \times 40 = 6000$ ✓

$6000 = p \times 100$ ✓, so $p = 60 \text{ kPa}$ ✓

(b) The same particles are in a bigger volume, so they hit the walls less often each second ✓, so there is less force on each unit of area ✓

5/5

1 for the product. 2, 3 for the substitution and answer (no need to convert to Pa: both pressures are in kPa). 4 for particles hitting the walls less often. 5 for the link to force on each unit of area. Check: volume up, pressure down.

Try it A sealed syringe of air is held at a constant volume in a water bath. The table shows the pressure at four temperatures. Describe the pattern, and explain it using the particle model. The table is invented. [4 marks]

Temperature (°C)	20	40	60	80
Pressure (kPa)	101	108	115	122

It could be asked as: Explain why the pressure of a gas rises when it is heated at constant volume, or when it is compressed.
 · Calculate a new pressure or volume using $pV = \text{constant}$.
 · Explain why adding more gas to a fixed container raises its pressure.
 · Explain why a bicycle pump gets warm when used (HT).

Cover both pages, write it from memory, then count the facts

facts: predict ___ / 10 got ___ / 10

Quick-fire. Answers are on page 53

11.1 **Physics only** A gas at 70 kPa and 30 cm³ is compressed at constant temperature to 20 cm³. What is the new pressure?

11.2 Why does a gas's pressure rise as its temperature rises at constant volume?

11.3 What causes the pressure of a gas on the wall of its container?

11.4 **Physics only** **HT** Why does the air in a bicycle pump get hotter as it is squeezed?

12 Internal energy and latent heat

Part three · Particle model of matter

Learn it**In sixty seconds**

Internal energy is the total kinetic and potential energy of all the particles in a system. Heating raises it, either raising the temperature, so the kinetic energy of the particles increases, or changing the state, so the potential energy of the particles increases while the temperature stays constant. The specific latent heat is the energy needed to change the state of 1 kg of a substance with no change in temperature: $E = m L$.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- Energy is stored inside a system by the particles (atoms and molecules) that make it up. This is **internal energy**: the total kinetic energy and potential energy of all the particles.
- **Heating** increases the energy of the particles. It either raises the temperature of the system or produces a change of state.
- When the temperature rises, the particles' **kinetic energy** increases: they move or vibrate faster.
- During a change of state the energy supplied changes the **potential energy** of the particles, which are moved further apart, but not their kinetic energy. The **temperature stays constant**.
- The energy needed for a substance to change state is **latent heat**. The **specific latent heat** is the amount of energy required to change the state of one kilogram of the substance with no change in temperature.
- **$E = m L$** : energy in joules, mass in kilograms, specific latent heat in J/kg. The specific latent heat of **fusion** is for solid to liquid, and of **vaporisation** for liquid to vapour.
- Use the mass that changed state. If water boils away, that is the change in mass, not the mass at the start. Using one of the masses given scored zero in 2022.
- On a heating curve the **sloping** sections are the temperature changing (specific heat capacity, $\Delta E = m c \Delta \theta$) and the **flat** sections are changes of state (latent heat, $E = m L$).
- For the same mass and power, a steeper slope means a smaller specific heat capacity. A longer flat section means more energy is needed for that change of state.
- Cooling is the reverse: freezing and condensing give out the same energy for each kilogram, at constant temperature.

Key words

- Internal energy** the total kinetic and potential energy of all the particles. ☐
- Latent heat** the energy needed for a change of state. ☐
- Specific latent heat** the energy to change the state of 1 kg with no change in temperature. ☐
- Latent heat of fusion** for melting or freezing (not nuclear fusion). ☐
- Latent heat of vaporisation** for boiling or condensing. ☐
- Change of state** melting, freezing, boiling, evaporating, condensing or sublimating. ☐
- Particle potential energy** stored in the forces and distances between particles. ☐
- Particle kinetic energy** the energy of the particles' movement. ☐

Why the temperature stays constant.

During melting the energy goes into moving the particles apart against the forces between them, which raises their potential energy. None is left to raise the average kinetic energy, so the temperature can't change until the change of state is finished.

2023 (6 marks): Level 2 compared the arrangement and movement of the particles in ice and water (density and spacing were ignored). Level 3 added potential energy rising while it melts at constant temperature, or kinetic energy rising as the liquid warms. 6 marks needed both. 2022: use the change in mass. 2021: the two ideas were mixed up.

Spot it Where does the energy go?

A pan of water is heated at a steady rate. It boils and the temperature stays at 100 °C. Where is the extra energy going?

- (A) Into the kinetic energy of the particles, which are moving faster.
- (B) Nowhere: all the energy supplied is dissipated to the surroundings.
- (C) Into the particles' potential energy as the water becomes steam.
- (D) Into raising the temperature of the steam.

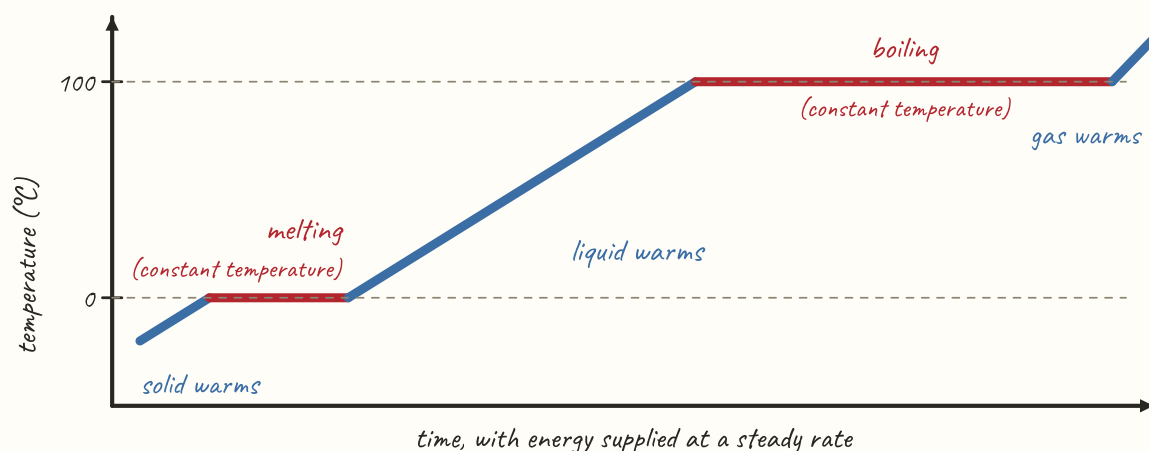
Cover this, choose, then read

C. During a change of state the temperature is constant, so the average kinetic energy isn't changing. The energy goes into the potential energy of the particles as they move apart. Some is dissipated to the surroundings, but that isn't why the temperature is flat.

12

Internal energy and latent heat

Part three · Particle model of matter

Use it**Heating a solid at a steady rate (drawn not to scale): slopes and flat sections**

Section of the curve	What is happening	Which equation
Slope	temperature rises, kinetic energy of the particles rises	$\Delta E = m c \Delta \theta$
Flat	state changes, potential energy of the particles rises	$E = m L$

A 0.40 kg block of ice at 0 °C is melted using 134 kJ. (a) Calculate the specific latent heat of fusion of ice. (b) The 0.40 kg of water is then warmed from 0 °C to 12 °C. The specific heat capacity of water is 4200 J/kg °C. Calculate the energy needed. [5 marks]

$$134 \text{ kJ} = 134\,000 \text{ J} \checkmark$$

$$134\,000 = 0.40 \times L \checkmark, L = 335\,000 = 3.35 \times 10^5 \text{ J/kg} \checkmark$$

$$(b) \Delta E = 0.40 \times 4200 \times 12 \checkmark = 20\,160 \text{ J} \checkmark$$

5/5

1 for kJ to J. 2, 3 for $E = m L$ and the answer with its unit. 4, 5 for $\Delta E = m c \Delta \theta$ and the answer. Part (a) uses latent heat, because the temperature doesn't change. Part (b) uses specific heat capacity, because it does.

Try it Explain why steam at 100 °C causes a more severe burn than the same mass of water at 100 °C.

[3 marks]

It could be asked as: Explain, using internal energy, why the temperature doesn't change while a substance melts or boils. · Calculate the energy to change the state of a mass, or a specific latent heat. · Describe and explain each section of a heating or cooling curve. · Say what a steeper slope on a heating curve shows.

Cover both pages, write it from memory, then count the facts

facts: predict ___ / 10 got ___ / 10

Quick-fire. Answers are on page 53

12.1 What is internal energy?

12.2 0.50 kg of a liquid has a specific latent heat of vaporisation of $2.0 \times 10^6 \text{ J/kg}$. How much energy turns it all to vapour?

12.3 Which particle energy rises while ice melts at 0 °C?

12.4 On a heating curve, what does a flat section show?

13 Part four · Atomic structure Atoms, isotopes and models of the atom

Learn it

In sixty seconds

An atom has a small positively charged nucleus of protons and neutrons, with electrons around it in energy levels. The atomic number is the number of protons and the mass number is protons plus neutrons. Isotopes are atoms of the same element with different numbers of neutrons. The model of the atom changed as evidence arrived: plum pudding, then the nuclear model after the alpha scattering experiment, then Bohr's electron orbits.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- An atom's radius is about 1×10^{-10} m. The nucleus is less than 1/10 000 of that, and has most of the atom's mass.
- A positively charged **nucleus** of **protons** and **neutrons** has negatively charged **electrons** around it. Equal numbers of electrons and protons mean no overall charge.
- Electrons are in different **energy levels**. An electron moves up a level by absorbing electromagnetic radiation, and down by emitting it.
- **Atomic number** = number of protons. **Mass number** = protons + neutrons. So neutrons = mass number – atomic number. In the symbol, the mass number is above the atomic number.
- **Isotopes** are atoms of the same element, so with the same number of protons, but with different numbers of neutrons. Losing an outer electron makes a positive ion, gaining one a negative ion.
- Atoms were once thought to be indivisible spheres. Finding the electron led to the **plum pudding model**: a ball of positive charge with electrons embedded in it.
- In the **alpha scattering experiment** most alpha particles went straight through, a few were deflected and a very few bounced back: the mass is at the centre, in a positive nucleus, and the atom is mostly empty space.
- Alpha particles are positive and so is the nucleus, so they **repel**. One that passes closer feels a stronger force. It is not a collision, and electrons don't deflect it.
- The **nuclear model** replaced the plum pudding, then **Bohr** suggested electrons orbit at specific distances. **Neutrons** (Chadwick) came about 20 years after the nucleus was accepted.
- The order of discovery: electron, then the nucleus, then the proton, then the neutron. Other scientists check new findings: **peer review**.

Key words

Nucleus the positive centre of an atom, made of protons and neutrons. ☐

Atomic number the number of protons in an atom. ☐

Mass number the number of protons plus neutrons. ☐

Isotope atoms of one element with different numbers of neutrons. ☐

Ion an atom that has gained or lost electrons. ☐

Plum pudding model a ball of positive charge with electrons embedded in it. ☐

Nuclear model a small positive nucleus with electrons far outside it. ☐

Energy level the distance from the nucleus at which an electron orbits. ☐

Reading the symbol. $^{14}_6\text{C}$ has mass number 14 and atomic number 6, so 6 protons, 6 electrons and $14 - 6 = 8$ neutrons. Any numbers you quote must be right: in 2023 “carbon-12 has 12 neutrons” scored nothing.

2023: for isotopes say the same protons and electrons, a different number of neutrons, with correct numbers. A collision, or electrons deflecting the alpha particle, scored 0. Bohr's model still has a nucleus.

Spot it Which is correct?

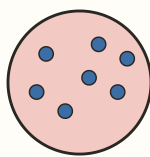
Which statement about the alpha particle scattering experiment is correct?

- (A) A few alpha particles were deflected a lot because the positive nucleus repels them.
- (B) A few alpha particles were deflected because they collided with electrons in the atom.
- (C) Most alpha particles were deflected, which showed the atom is a solid ball of charge.
- (D) Some alpha particles bounced back off the nucleus because they are negatively charged.

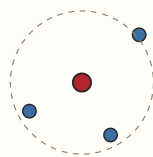
Cover this, choose, then read

A. Alpha particles are positive, and so is the nucleus, so they repel. Most went straight through, which showed the atom is mostly empty space. The electrons are too light to turn an alpha particle.

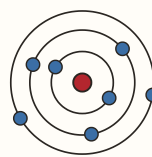
13 Part four · Atomic structure Atoms, isotopes and models of the atom

*Use it***Three models of the atom, and the experiment that overturned the first**

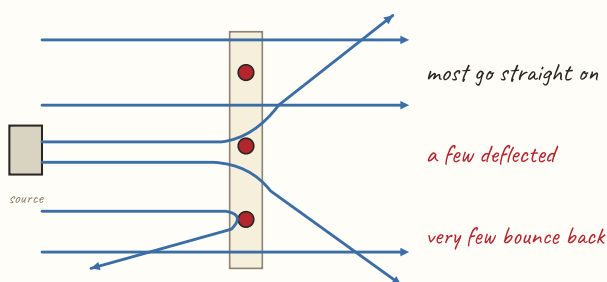
Plum pudding:
after the electron
was found



Nuclear: after
alpha scattering



Bohr: electrons at
set distances



Particle	Charge	Mass
Proton	+1	1
Neutron	0	1
Electron	-1	tiny

Relative charge and relative mass.

Atom	Protons	Neutrons
A	12	12
B	12	14
C	13	14
D	14	14

The table shows four atoms. (a) Which two are isotopes of the same element? Give two reasons. (b) Give the mass number of atom C. (c) How many electrons does a neutral atom of D have?

[5 marks]

(a) A and B ✓: both have 12 protons ✓, but A has 12 neutrons and B has 14, so they differ in neutrons ✓

(b) $13 + 14 = 27$ ✓

(c) a neutral atom has as many electrons as protons: **14** ✓

5/5

1 for A and B. 2 for the same number of protons. 3 for different numbers of neutrons, with the numbers. 4 for the mass number as protons plus neutrons. 5 for electrons equal to protons. Isotopes are of the same element, so the proton number decides. C has 13 protons, so it is a different element from A and B.

Try it Explain why the plum pudding model could not explain alpha particles that bounced straight back.

[2 marks]

It could be asked as: Define an isotope, or state the particles in an atom or ion from its symbol. · Describe the alpha scattering experiment and what it showed. · Explain how the plum pudding model was replaced, and how Bohr changed the nuclear model. · Explain what happens when an electron moves between energy levels.

Cover both pages, write it from memory, then count the facts

facts: predict ___ / 10 got ___ / 10

Quick-fire. Answers are on page 53

13.1 How many neutrons does an atom of oxygen-18 have? (atomic number 8)

13.2 Why do atoms have no overall charge?

13.3 What did the discovery of the electron lead to?

13.4 What happens when an electron absorbs electromagnetic radiation?

14

Radioactive decay and half-life

Part four · Atomic structure

*Learn it***In sixty seconds**

Some nuclei are unstable and give out radiation as they become more stable. This is radioactive decay, and it is random. Alpha particles are two protons and two neutrons, beta particles are fast electrons from the nucleus and gamma rays are electromagnetic radiation. They differ in penetration, range in air and ionising power. A nuclear equation balances the mass numbers and the atomic numbers. The half-life is the time for the number of nuclei, or the activity, to halve.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- Some nuclei are unstable. They give out radiation as they change to become more stable. This is **radioactive decay**, a **random** process: you can't tell when a particular nucleus will decay.
- **Activity** is the rate at which a source of unstable nuclei decays, in becquerel (Bq). **Count rate** is the number of decays a detector, such as a Geiger-Müller tube, records each second.
- **Alpha (α):** two protons and two neutrons, the same as a helium nucleus. Strongly ionising. A few centimetres' range in air. Stopped by paper or skin.
- **Beta (β):** a high-speed electron ejected from the nucleus as a neutron turns into a proton. Moderately ionising. A range of about a metre in air. Stopped by thin aluminium.
- **Gamma (γ):** electromagnetic radiation from the nucleus. Weakly ionising. Travels a long way in air. Reduced by thick lead or concrete.
- A **neutron** can also be emitted. All these radiations **ionise**: they knock electrons off atoms (not cells). The more strongly ionising, the more damage to living tissue.
- In a **nuclear equation** the mass numbers (top) and atomic numbers (bottom) balance. Alpha: mass number -4, atomic number -2. Beta: mass number the same, atomic number +1. Gamma changes neither.
- **Half-life:** the time it takes for the number of nuclei of the isotope in a sample to halve, or the time it takes for the count rate (or activity) from a sample containing the isotope to fall to half its initial level.
- After 1 half-life $\frac{1}{2}$ is left, after 2 half-lives $\frac{1}{4}$, after 3 half-lives $\frac{1}{8}$. If $\frac{1}{4}$ remains, write "2 half-lives", not just "2". **HT** The net decline as a ratio: after 3 half-lives, final : initial = 1 : 8.

Key words

Radioactive decay an unstable nucleus giving out radiation at random. ☐

Activity the number of decays each second, in becquerel. ☐

Count rate the decays a detector records each second. ☐

Alpha particle two protons and two neutrons. ☐

Beta particle a high-speed electron from the nucleus. ☐

Gamma ray electromagnetic radiation from the nucleus. ☐

Half-life the time for the number of nuclei, or the activity, to halve. ☐

Ionisation knocking electrons off atoms to make ions. ☐

Half-life from a graph. Read the starting activity, halve it, go across to the curve and down to the time axis: that time is one half-life. Check by halving again. The second half-life should take the same time, and every half-life is the same length.

2023: "the time for the radioactivity to halve" scored nothing. Say what halves: the number of nuclei, the activity or the count rate. 2022: an alpha particle is two protons and two neutrons, and adding "a helium atom" cancelled the mark. In a nuclear equation both numbers must balance.

Spot it What is left?

A sample has an activity of 640 Bq. Its half-life is 3.0 hours. What is its activity after 9.0 hours?

- (A) 213 Bq (B) 160 Bq
(C) 320 Bq (D) 80 Bq

Cover this, choose, then read

D. 9.0 hours is $9.0 \div 3.0 = 3$ half-lives: $640 \rightarrow 320 \rightarrow 160 \rightarrow 80$ Bq. 160 Bq is only two half-lives, 320 Bq is one, and 213 Bq divides by 3 instead of halving three times.

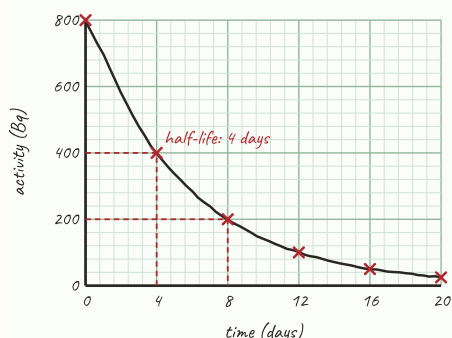
14

Radioactive decay and half-life

Part four · Atomic structure

Use it

The three radiations and what stops them, and a decay curve with its half-life



	alpha	beta	gamma	
	paper	thin aluminium	thick lead	
	α	β	γ	
Ionising	strong	moderate	weak	
Range in air	few cm	about 1 m	long way	
Stopped by	paper	thin Al	thick lead	

A radioactive isotope has a half-life of 12 minutes. A sample has an initial activity of 960 Bq. (a) [5 marks]
 Calculate its activity after 48 minutes. (b) Radon-222 (atomic number 86) decays by emitting an alpha particle to form polonium-218 (atomic number 84). Write the nuclear equation.

(a) $48 \div 12 = 4$ half-lives ✓ $960 \rightarrow 480 \rightarrow 240 \rightarrow 120 \rightarrow 60 \text{ Bq}$ ✓(b) ${}_{86}^{222}\text{Rn} \rightarrow {}_{84}^{218}\text{Po} + {}_2^4\text{He}$ ✓✓

5/5

1 for 4 half-lives, written out. 2 for the halving worked through. 3 for 60 Bq. 4, 5 for the mass number 218 and the alpha particle with 4 and 2. Both columns balance: $222 = 218 + 4$ and $86 = 84 + 2$.
 Writing only the number 4 isn't enough for part (a): say 4 half-lives.

Try it Carbon-14 (atomic number 6) decays by beta emission to nitrogen-14 (atomic number 7). Write the [3 marks]
 nuclear equation. HT What is the ratio of the final to the initial activity after 3 half-lives?

It could be asked as: State what alpha, beta and gamma radiation are, and compare how they are stopped and how ionising they are. · Complete a nuclear equation for alpha or beta decay. · Define half-life, and use a decay curve or a table to find one or to find what is left. · Explain why radioactive decay is random.

Cover both pages, write it from memory, then count the facts

facts: predict ___ / ? got ___ / ?

Quick-fire. Answers are on page 53

14.1 What is an alpha particle made of?

14.2 A sample has 800 undecayed nuclei and a half-life of 5 days. How many remain after 10 days?

14.3 What happens to the mass number and atomic number in beta decay?

14.4 Which of alpha, beta and gamma is stopped by paper?

15 Part four · Atomic structure Radiation: hazards and uses

Learn it

In sixty seconds

Radioactive contamination is the unwanted presence of radioactive atoms on other materials. Irradiation is exposing an object to radiation, and the object doesn't become radioactive. Suitable precautions protect against a source. Background radiation is always around us. The hazard depends on the type of radiation and the half-life, and radiation is used in medicine to explore organs and to destroy unwanted tissue. Background radiation and the medical uses are Physics only.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- **Contamination** is the unwanted presence of materials containing radioactive atoms on other materials. The hazard is from the decay of the contaminating atoms, and depends on the type of radiation they emit.
- **Irradiation** is the process of exposing an object to nuclear radiation. The irradiated object does **not** become radioactive.
- Contamination goes on irradiating until the atoms decay or are removed. Alpha is most dangerous inside the body, as it is highly ionising and absorbed by tissue, but outside it is stopped by skin.
- **Precautions** for a source: hold it with tongs, keep it as far away as possible, shield it (lead), spend as little time near it as possible, wear protective clothing, and keep it sealed in a lead-lined box.
- **Physics only** **Background radiation** is around us all the time. Natural: rocks and cosmic rays. Man-made (a source that is artificial): fallout from weapons tests and accidents, medical X-rays and radiotherapy. Not sunlight, microwaves or phones.
- **Physics only** **Dose** is measured in sieverts (Sv): $1000 \text{ mSv} = 1 \text{ Sv}$. It can depend on occupation or location.
- **Physics only** A **short half-life** means a high activity that falls quickly, so waste is safe sooner. A **long half-life** gives a lower activity that stays hazardous for much longer. Compare the radiation emitted each second.
- **Physics only** Medical uses: **exploring internal organs** (a tracer whose radiation is detected outside the body) and **controlling or destroying unwanted tissue**, such as a tumour.
- Choose a radiation from its properties: alpha is stopped by paper, beta by thin aluminium, gamma passes through. A short half-life suits a tracer, a long half-life a source that must last.
- Studies of the effects of radiation on humans must be published and shared so that other scientists can check them: **peer review**.

Key words

- Contamination** unwanted radioactive atoms on or in a material. ☐
- Irradiation** exposure to radiation; the object doesn't become radioactive. ☐
- Background radiation** radiation that is always around us. ☐
- Physics only** **Dose** a measure of radiation absorbed, in sieverts. ☐
- Physics only** **Tracer** a radioactive substance followed through the body. ☐
- Precaution** a step taken to reduce a risk. ☐
- Peer review** other scientists checking a study. ☐
- Activity** decays each second, in becquerel. ☐

Physics only **Evaluating a use.** Give a benefit and a risk, then judge. A gamma tracer shows an organ without surgery, and its short half-life means the activity soon falls, but the patient still gets a dose that carries a small risk to cells. Say which matters more, and why.

2023: "radiation is around you but contamination is in you" scored nothing: use the definitions. Don't mix up radioactive (the material) with radiation (what it emits). A long half-life isn't automatically the biggest risk: compare the radiation emitted each second. 2020: "man-made" means an artificial source, not something made by people.

Spot it Which is correct?

A scientist stands 1 m from a sealed gamma source for ten minutes, and then the source is put away. Which statement is correct?

- (A) She was contaminated, because the radiation reached her.
- (B) She was irradiated, and she isn't radioactive.
- (C) She became radioactive because she absorbed gamma rays.
- (D) She was irradiated, and she will keep irradiating other people.

Cover this, choose, then read

B. Irradiation is exposure to radiation, and the irradiated object doesn't become radioactive. Contamination would need radioactive atoms on or in her. The gamma rays came from the source, which is now away.

15 Part four · Atomic structure Radiation: hazards and uses

Use it

Contamination and irradiation, and which radiation for which job

	Contamination	Irradiation
What it is	radioactive atoms on or in a material	exposure to radiation from a source
Does the object become radioactive?	yes, it has radioactive atoms on it	no
When does it stop?	when the atoms decay or are removed	when the source is removed or shielded
Job	Radiation	Why
Smoke alarm	alpha	ionises air; stopped by paper so low risk outside; long half-life
Checking thickness of paper or foil	beta	passes through thin sheets but is reduced by thicker ones
Tracer in the body	gamma, short half-life	passes out of the body to be detected; activity falls fast
Radiotherapy, sterilising	gamma	penetrates tissue or packaging; damages cells or bacteria

Physics only A hospital tracer gives out gamma rays and has a half-life of 6.0 hours. A patient is given a dose with an activity of 400 MBq. (a) Calculate the activity after 24 hours. (b) Explain why gamma rays and a short half-life suit a tracer. [5 marks]

(a) $24 \div 6.0 = 4$ half-lives ✓

$400 \rightarrow 200 \rightarrow 100 \rightarrow 50 \rightarrow 25$ MBq ✓

(b) Gamma rays pass out of the body, so they can be detected outside ✓. Alpha would be absorbed in the body, where it is highly ionising ✓. A short half-life means the activity soon falls, so the patient gets a lower dose ✓

5/5

1 for 4 half-lives. 2 for 25 MBq. 3 for gamma being detectable outside the body, with the comparison. 4 for the alpha danger inside the body. 5 for the short half-life giving a lower dose. Each reason is linked to its effect, which is what makes it a mark.

Try it **Physics only** Scan A gives a patient a dose of 0.05 mSv. Scan B gives 6 mSv. The average dose from background radiation in a year is 2.5 mSv. (All invented for this question.) A doctor suggests scan B. Evaluate the risk. [3 marks]

It could be asked as: Compare contamination and irradiation, and say which is more dangerous for alpha. · Explain why the hazard from a source depends on its half-life and the type of radiation. · Evaluate a medical use of radiation: one benefit, one risk, a judgement. · Choose a radiation for a job, and give the reason.

Cover both pages, write it from memory, then count the facts

facts: predict ___ / 10 got ___ / 10

Quick-fire. Answers are on page 53

15.1 **Physics only** State one man-made source of background radiation.

15.2 Does irradiation make an object radioactive?

15.3 Name two precautions when using a radioactive source.

15.4 **Physics only** Why is a short half-life good for a medical tracer?

16

Part four · Atomic structure · Physics only

Nuclear fission and fusion

Learn it

In sixty seconds

Nuclear fission is the splitting of a large unstable nucleus such as uranium or plutonium. The nucleus absorbs a neutron, splits into two smaller nuclei, emits two or three neutrons and gamma rays, and releases energy. The neutrons can cause more fissions in a chain reaction, controlled in a reactor and uncontrolled in a weapon. Nuclear fusion is the joining of two light nuclei to form a heavier nucleus, with some of the mass converted into the energy of radiation.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- ☐ **Nuclear fission** is the splitting of a large and unstable nucleus, such as uranium or plutonium.
- ☐ Spontaneous fission is rare. Usually the nucleus must first **absorb a neutron**: the neutron becomes part of the nucleus. Saying it “collides” isn’t enough.
- ☐ The nucleus splits into **two smaller nuclei**, roughly equal in size, and emits **two or three neutrons** plus **gamma rays**.
- ☐ **Energy is released**. All of the fission products have kinetic energy, which heats a reactor.
- ☐ The neutrons may be absorbed by other nuclei, which split and release more neutrons: a **chain reaction**.
- ☐ In a nuclear **reactor** the chain reaction is controlled, to control the energy released. In a nuclear **weapon** it is uncontrolled, which causes an explosion.
- ☐ **Nuclear fusion** is the joining of two light nuclei to form a heavier nucleus. Some of the mass may be converted into the energy of radiation.
- ☐ Say **nuclei**, not atoms or elements: “two light nuclei join to form a heavier nucleus” (AQA 2020).
- ☐ Both nuclei are positive and repel each other, so fusion needs very high temperatures and pressures to bring them close enough.
- ☐ Small-scale fusion experiments help scientists make fusion possible, understand it, and assess its efficiency, safety and environmental impact, and cost less than a full-scale plant.

Key words

- Nuclear fission** the splitting of a large unstable nucleus. ☐
- Nuclear fusion** the joining of two light nuclei to form a heavier one. ☐
- Chain reaction** neutrons from one fission causing more fissions. ☐
- Nuclear reactor** where a controlled chain reaction releases energy. ☐
- Uranium** a large nucleus used in fission (plutonium is another). ☐
- Fission products** the smaller nuclei, neutrons and gamma rays made. ☐
- Gamma ray** electromagnetic radiation from the nucleus. ☐
- Absorb** take in: a neutron absorbed becomes part of the nucleus. ☐

Nuclei, not atoms. A neutron is absorbed by a uranium **nucleus**, which splits into two daughter **nuclei**. Say what is absorbed, and by what, and how many parts it splits into. Don’t go on to describe how electricity is generated when the question doesn’t ask.

2020: only 6% scored all 4 marks for describing fission and only 8% both marks for fusion. Fusion needs “nuclei join to form a heavier nucleus” and “some mass is converted into energy”. “Elements fuse” or “atoms fuse” was insufficient, and some wrongly described breaking bonds.

Spot it Which is correct?

Which statement about nuclear fission is correct?

- ☐ (A) A uranium atom splits into three equal parts, giving out three neutrons.
- ☐ (B) A uranium nucleus splits on its own most of the time, so it needs no neutron.
- ☐ (C) A uranium nucleus absorbs a neutron, then splits into two smaller nuclei.
- ☐ (D) Two uranium nuclei join to make a heavier nucleus, which releases energy.

Cover this, choose, then read

C. Fission usually starts when a nucleus absorbs a neutron. It splits into two smaller nuclei, roughly equal in size, and releases two or three neutrons. Spontaneous fission is rare, and joining nuclei is fusion.

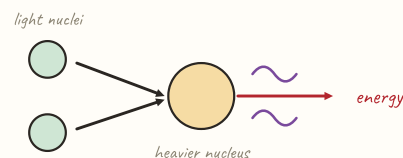
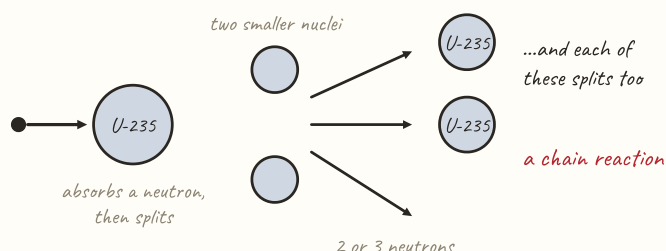
16

Part four · Atomic structure · **Physics only**

Nuclear fission and fusion

Use it

A chain reaction, fusion, and the two compared



	Fission	Fusion
What happens	a large nucleus splits into two smaller ones	two light nuclei join to make a heavier one
What starts it	a nucleus absorbs a neutron	very high temperature and pressure
What comes out	2 or 3 neutrons, gamma rays, kinetic energy	energy of radiation (some mass converted)
Where	nuclear reactors and weapons	stars; experiments

A uranium-235 nucleus absorbs one neutron, giving a nucleus with mass number 236. This splits into a barium nucleus (mass number 141) and a krypton nucleus (mass number 92), and some neutrons. (a) How many neutrons are released? (b) Each released neutron causes one more fission. How many fissions are there in the third generation, counting the first fission as generation 1? (c) Why must a nuclear reactor control this? [5 marks]

- (a) $236 = 141 + 92 + \text{neutrons}$ ✓; $141 + 92 = 233$ ✓, so **3 neutrons** ✓
- (b) generation 1: 1 fission; 2: 3 fissions; 3: $3 \times 3 = 9$ fissions ✓
- (c) Without control the number of fissions rises faster and faster, an uncontrolled chain reaction ✓, so the energy would be released all at once, as in a weapon

5/5

1, 2, 3 for balancing the mass numbers: they must add up on both sides, as in a nuclear equation. 4 for 9. 5 for the uncontrolled chain reaction. A reactor controls the chain so the energy is released steadily. Say nuclei absorb the neutron, not "atoms".

Try it State two differences between nuclear fission and nuclear fusion, and one thing they have in common.

[3 marks]

It could be asked as: Describe nuclear fission, including what starts it and what is released. · Explain what a chain reaction is, and how a reactor differs from a weapon. · State what nuclear fusion is, and why it is difficult to achieve. · Compare fission and fusion.

Cover both pages, write it from memory, then count the facts

facts: predict ___ / 10 got ___ / 10

Quick-fire. Answers are on page 53

16.1 State one nucleus that can undergo fission.

16.2 What happens to a uranium nucleus before it undergoes fission?

16.3 What is nuclear fusion?

16.4 In a fusion reaction, what happens to some of the mass?

Skills

Equations, units and circuit symbols

AQA's specification lists equations to **recall** and equations to **select and apply from a sheet**. In June 2022 and June 2023 every equation was printed on the sheet. Learn the first group anyway: a calculation you can start without the sheet is quicker, and a recalled equation is accepted in any correct rearrangement, in words or symbols. Writing a right and a wrong form together scores 0.

Name	Equation	Units	AQA
Kinetic energy	$E_k = \frac{1}{2} m v^2$	J, kg, m/s	learn it
Gravitational potential energy	$E_p = m g h$	J, kg, N/kg, m	learn it
Elastic potential energy	$E_e = \frac{1}{2} k e^2$	J, N/m, m	on the sheet
Power	$P = E \div t, P = W \div t$	W, J, s	learn it
Efficiency	useful output energy $\div$ total input energy	no unit	learn it
Efficiency, from power	useful power out $\div$ total power in	no unit	learn it
Change in thermal energy	$\Delta E = m c \Delta \theta$	J, kg, J/kg °C, °C	on the sheet
Charge flow	$Q = I t$	C, A, s	learn it
Potential difference	$V = I R$	V, A, Ω	learn it
Electrical power	$P = V I, P = I^2 R$	W, V, A, Ω	learn it
Energy transferred	$E = P t, E = Q V$	J, W, s, C, V	learn it
Resistors in series	$R_{\text{total}} = R_1 + R_2$	Ω	in the spec
Density	$\rho = m \div V$	kg/m ³ , kg, m ³	learn it
Energy for a change of state	$E = m L$	J, kg, J/kg	on the sheet
Gas pressure and volume	$p V = \text{constant}$	any matching units	on the sheet

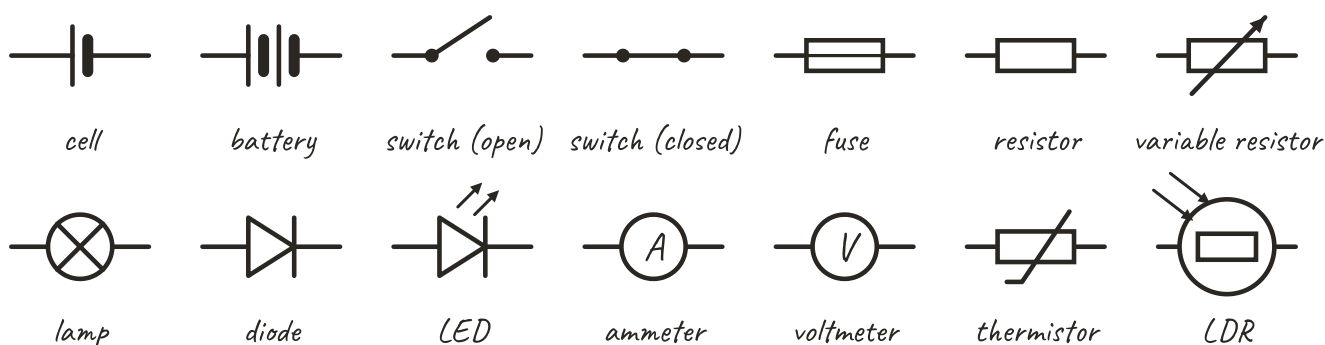
Change units first

To change	Do this
kJ, MJ to J	$\times 1000, \times 1\,000\,000$
kW, MW to W	$\times 1000, \times 1\,000\,000$
minute, hour, day to s	$\times 60, \times 3600, \times 86\,400$
g to kg	$\div 1000$
cm, mm to m	$\div 100, \div 1000$
cm ³ to m ³	$\div 1\,000\,000$
g/cm ³ to kg/m ³	$\times 1000$
mA to A	$\div 1000$
k Ω to Ω	$\times 1000$

A power of ten slip, from a unit not converted or converted the wrong way, shows up in every AQA report. Write the converted value on its own line, then substitute.

Give an answer to the same number of significant figures as the least precise data, and include the unit. In 2023 a correct answer rounded to two or three significant figures still scored, but a wrongly rounded one did not.

Circuit symbols AQA uses



Skills

Which equation?

With the equations printed on the sheet, choosing the right one is the skill. Read what you are **given** and what you **want**, pick the row, write the equation with the numbers in, then rearrange if you need to.

You are given	You want	Use	Watch out	See page
mass, speed	kinetic energy	$E_k = \frac{1}{2} m v^2$	square the speed; kg	4–5
mass, height, g	gravitational potential energy	$E_p = m g h$	height in m	4–5
spring constant, extension	elastic potential energy	$E_e = \frac{1}{2} k e^2$	extension in m, squared	4–5
energy or work, time	power	$P = E \div t$	time in s	6–7
useful and total, energy or power	efficiency	useful $\div$ total	same units; no $\times 100$ in the equation	6–7
mass, c, temperature change	energy to heat a material	$\Delta E = m c \Delta \theta$	$\Delta \theta$ = final – start	8–9
current, time	charge	$Q = I t$	s; mA $\div 1000$	12–13
two of V, I, R	the third	$V = I R$	substitute first, then rearrange	12–13
resistors in series	total resistance	$R_1 + R_2$	parallel gives less than the smallest	12–13
V and I, or I and R	power	$P = V I$, $P = I^2 R$	square the current	16–17
power and time, or charge and p.d.	energy transferred	$E = P t$, $E = Q V$	s; kW to W	16–17
power, p.d., cable resistance	power lost in cables	$I = P \div V$, then $P = I^2 R$	two steps	18–19
mass, volume	density	$\rho = m \div V$	kg and m ³ , or g and cm ³	22–23
p and V of a fixed mass of gas (Physics only)	the new p or V	$p_1 V_1 = p_2 V_2$	same units each side	24–25
mass, energy	energy to change state, or L	$E = m L$	the mass that changed state	26–27
half-life, time	what is left	halve once for each half-life	write “n half-lives”	30–31

Two equations in one question

Heating water with a heater: $E = P t$ for the energy, then $\Delta E = m c \Delta \theta$ for the temperature rise.

A fall or a drop: $E_p = m g h$, then $\frac{1}{2} m v^2$ gives the speed at the bottom.

A lift: $E_p = m g h$, then $P = E \div t$, then efficiency.

Cables: $P = V I$ gives the current, then $P = I^2 R$ gives the power lost.

Before you write the answer

Is the unit right, and is the size sensible? A car of 1200 kg does not have 240 J of kinetic energy at 20 m/s.

Did you use the quantity the equation asks for? Latent heat uses the **change** in mass. Specific heat capacity uses the **change** in temperature.

Did you give one equation, not a right one beside a wrong one?

Quantities, symbols and units

Quantity	Symbol	Unit
energy, work	E, W	J
power	P	W
charge	Q	C
current	I	A
potential difference	V	V
resistance	R	Ω
mass	m	kg
speed	v	m/s
density	ρ	kg/m ³

Quantity	Symbol	Unit
pressure	p	Pa
time	t	s
height	h	m
volume	V	m ³
specific heat capacity	c	J/kg °C
specific latent heat	L	J/kg
field strength	g	N/kg
spring constant	k	N/m
extension	e	m
temperature change	$\Delta \theta$	°C
activity		Bq
radiation dose		Sv

Skills

The maths you need

Set every calculation out the same way: write the equation, put the numbers in with their units, calculate, then write the unit. Check it is sensible. Examiners give marks for each step, so show them all. At least 30% of the marks on a Physics paper test maths, and handwriting that can't be read costs marks too.

Rearranging an equation

A 1.5 kW kettle transfers 270 kJ. How long does it take?
Substitute into $E = P t$ first: $270\,000 = 1500 \times t$
 $t = 270\,000 \div 1500$

$$= 180\text{ s}$$

In 2022's straightforward calculations the first mark was the substitution as printed. Rearranging wrongly first scored nothing.

Changing units

A 75 g mass is lifted 40 cm. $g = 9.8\text{ N/kg}$.
 $75\text{ g} = 0.075\text{ kg}$ and $40\text{ cm} = 0.40\text{ m}$
 $E_p = 0.075 \times 9.8 \times 0.40$

$$= 0.294\text{ J}$$

Forgetting a conversion is a power of ten error, the commonest way to lose marks. Do it before you substitute.

Standard form

$4.5 \times 10^9\text{ J}$ is supplied at 2.5 MW.
 $2.5\text{ MW} = 2.5 \times 10^6\text{ W}$
 $t = (4.5 \times 10^9) \div (2.5 \times 10^6)$

$$= 1.8 \times 10^3\text{ s}$$

Use the $\times 10^x$ or EXP key. In 2023 there was a separate mark for writing the answer in standard form.

Significant figures

$12.0 \div 0.35 = 34.2857\dots$ on the calculator.
The least precise number, 0.35, has 2 significant figures.

$$= 34$$

Keep every digit until the last step, then round once. A correctly rounded answer still earns the mark; rounding in the middle can lose it.

Efficiency

A device takes in 250 J and wastes 60 J.
useful = $250 - 60 = 190\text{ J}$
efficiency = $190 \div 250$

$$= 0.76 = 76\%$$

No unit. Never more than 1. Choose the energy version when energies are given.

Mean and spread

Currents of 0.31 A, 0.33 A and 0.35 A.
mean = $(0.31 + 0.33 + 0.35) \div 3$
The readings spread 0.02 A either side of the mean.

$$= 0.33\text{ A} \pm 0.02\text{ A}$$

The specification uses the range of the measurements about the mean as the uncertainty.

Maximum and minimum

A density is $7.85 \pm 0.15\text{ g/cm}^3$.
maximum = $7.85 + 0.15$
minimum = $7.85 - 0.15$

$$= 8.00\text{ and }7.70\text{ g/cm}^3$$

Give both, the right way round. In 2022 some wrote a maximum of the value and a minimum of the uncertainty.

Squared quantities

A car's speed doubles. $E_k = \frac{1}{2} m v^2$, so the kinetic energy is 2^2 times bigger.
A cable's current is halved. $P = I^2 R$, so the power lost is $(\frac{1}{2})^2$ of what it was.

$$= 4\text{ times bigger} \cdot \frac{1}{4}\text{ of the power}$$

Squaring is why a speed limit matters for stopping, and why the grid uses a low current.

Estimating first

A 2.1 kW kettle runs for 3 minutes. Estimate the energy.
about $2000\text{ W} \times 200\text{ s} = 4 \times 10^5\text{ J}$
exactly 2100×180

$$= 378\,000\text{ J}$$

A rough answer first catches a slip of ten or a thousand. If the exact answer is far from it, look for the unit.

Skills

Drill: units, rearranging, standard form

Unit and power of ten slips cost marks in every AQA report. Do this page with a calculator and no notes, then check it on page 54. Repeat the ones you got wrong two days later.

A. Change the units

- | | | |
|----------------------------------|--|----------------------------------|
| 1 450 mA to A = _____ | 2 2.4 kV to V = _____ | 3 3.6 MJ to kJ = _____ |
| 4 15 minutes to s = _____ | 5 2.5 hours to s = _____ | 6 80 g to kg = _____ |
| 7 6.5 cm to m = _____ | 8 250 cm ³ to m ³ = _____ | 9 120 kPa to Pa = _____ |
| 10 0.6 kW to W = _____ | 11 7200 s to hours = _____ | 12 36 000 J to kJ = _____ |

B. Rearrange (write one line, with the new subject on the left)

- | | |
|--|--|
| a make v the subject of $E_k = \frac{1}{2} m v^2$: _____ | b make I the subject of $P = I^2 R$: _____ |
| c make e the subject of $E_e = \frac{1}{2} k e^2$: _____ | d make c the subject of $\Delta E = m c \Delta \theta$: _____ |
| e make h the subject of $E_p = m g h$: _____ | f make V_2 the subject of $p_1 V_1 = p_2 V_2$ (Physics only): _____ |

C. Standard form

- | | | |
|---|---|--|
| 1 Write 0.000 36 in standard form. = _____ | 2 Write 4.2×10^4 in full. = _____ | 3 $(6.0 \times 10^{-3}) \times (2.0 \times 10^2) =$ _____ |
| 4 $(9.0 \times 10^6) \div (3.0 \times 10^2) =$ _____ | | |

D. Numbers in context

- | | |
|---|--|
| 1 A 2.2 kW kettle runs for 4.0 minutes. Calculate the energy transferred, in J. _____ | 2 What p.d. drives 0.30 A through a 12 Ω resistor? _____ |
| 3 A speed rises from 5.0 to 10 m/s. How many times bigger is the kinetic energy? _____ | |

E. Two steps

- | | |
|---|--|
| 1 A 60 W lamp is on for 2.0 hours. Calculate the energy transferred, in kJ. _____ | 2 0.25 kg of water is heated from 20 °C to 60 °C ($c = 4200$ J/kg °C). Calculate the energy needed, in kJ. _____ |
| 3 A 12 V battery drives 150 mA through a lamp for 10 minutes. Calculate the charge and the energy transferred. _____ | 4 Physics only: a gas at 160 kPa and 0.30 m ³ is compressed at constant temperature to 0.20 m ³ . Calculate the new pressure. _____ |

Three habits that stop the slips

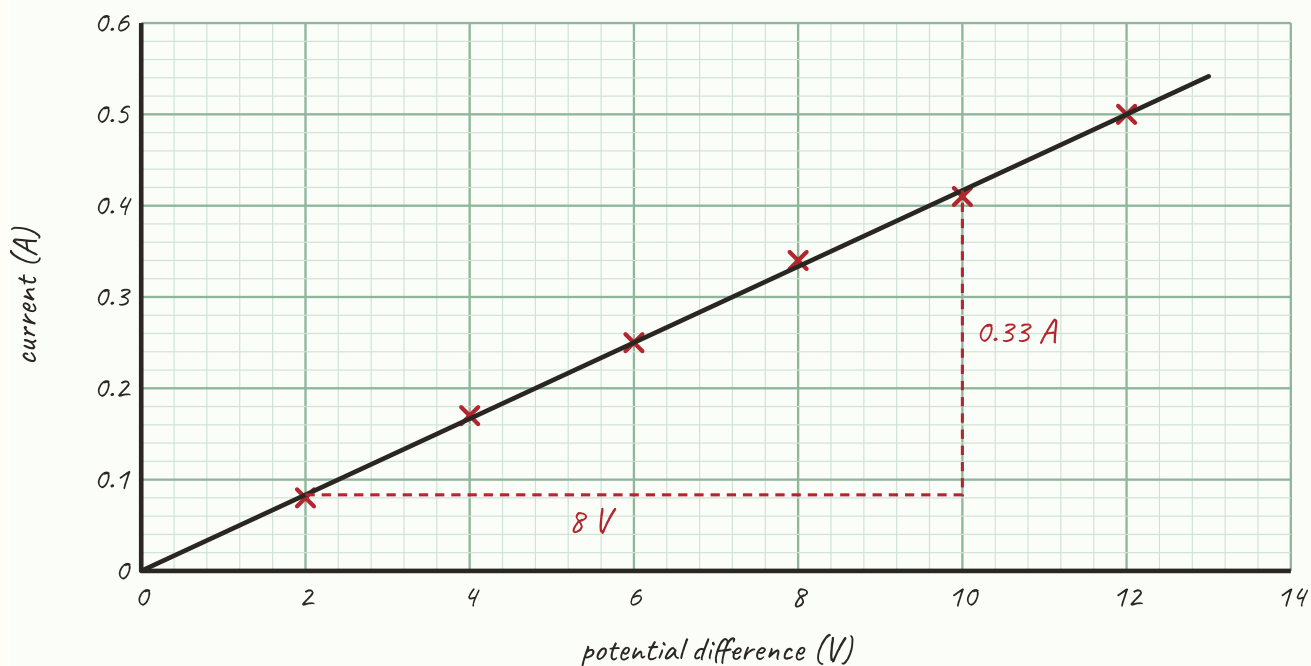
Write the converted value on its own line. Write the unit after every number. Ask whether the answer is sensible: a boy with a mass of over a tonne, or a moving car with 240 J of kinetic energy, should make you check.

Skills

Graphs and data

Plotted the way an examiner wants it. The results are made up for practice, for a resistor. The red triangle gives the gradient: $0.333 \div 8 = 0.042 \text{ A per V}$, and $1 \div 0.042 = 24 \Omega$.

P.d. (V)	2	4	6	8	10	12
Current (A)	0.08	0.17	0.25	0.34	0.41	0.50

**Plotting**

- Independent variable on the x-axis. Label both axes with the quantity and the unit.
- A scale that fills more than half the grid, in even steps. Not 3s, not 7s.
- Plot with a small cross, **in pencil**. An ink point can't be changed, and the examiner can't give the benefit of the doubt.
- Draw one line of best fit with a ruler or a smooth curve, with points either side of it. Not dot to dot. In 2021 many **continued the existing line** instead of drawing their own.
- Read values off the line with a ruler and mark the reading on the graph. In 2020 a current of 0.08 A was misread as 0.8 A, and in 2021 AQA noted that many students can't read values accurately.

The gradient

Pick two points far apart on the **line**, not on the data. Divide the change in y by the change in x, and give the unit as y per x. On a graph of current against p.d. for an ohmic resistor the gradient is $1 \div R$, not R . For a curve, find the resistance at a point as $V \div I$ at that point.

Proportional

A straight line **through the origin** means directly proportional: double one and the other doubles. For inverse proportion, show the product of the two quantities is constant for three or more pairs, as AQA asked in 2021. "One goes up, the other goes down" scored nothing.

Accuracy, precision, resolution

Accurate: close to the true value. **Precise:** repeat readings close together. **Resolution:** the smallest change the instrument shows, such as 0.1°C . AQA found many writing "precision" when they meant "resolution".

Errors

A scatter of points either side of the line is **random error**: repeat and take a mean. A **systematic error** moves every result the same way, such as a balance that does not read zero (a **zero error**). **Parallax** is reading a scale from the wrong angle.

Describing a trend

Say what happens to one variable as the other changes and quote numbers from both ends: "as the p.d. rises from 2 V to 12 V, the current rises from 0.08 A to 0.50 A."

Skills

The five required practicals

Practical skills are marked on every paper. Questions on these five have come as calculations, as planning questions and as “what would improve this?”. The aims are adapted from the specification, and the next three pages show each practical step by step. The rest is what AQA's papers have asked about each one.

Practical	The aim	What gets asked
1 Specific heat capacity	Investigate the specific heat capacity of one or more materials, linking the decrease of one energy store to the increase in temperature and the thermal energy stored.	Measure the mass, heat with an electric heater, and use $E = V I t$ or $P t$. Insulate the block, so the energy leaks out more slowly and c is more accurate. Leave the thermometer in the block before switching on, until it shows the block's temperature (not “room temperature”). Use the temperature change from the right part of the graph. Then $c = \Delta E \div (m \Delta \theta)$. AQA 2023.
2 Thermal insulators Physics only	Investigate the effectiveness of different materials as thermal insulators, and the factors that may affect it.	Independent variable: the type of insulation (in 2022 the thickness was kept the same, so thickness is the variable only if you test it). Dependent variable: what you measure, here the time for a set fall in temperature. Control the start temperature, volume of water and container. A shorter time for the same fall means a higher rate of energy transfer and higher thermal conductivity. “Good insulator” alone was not enough. The reading error to name is parallax. AQA 2022.
3 Resistance	Use circuit diagrams to set up circuits to investigate the factors affecting resistance: the length of a wire at constant temperature, and resistors in series and parallel.	Ammeter in series, voltmeter across the wire. $R = V \div I$ for each length. Plot resistance against length: a straight line through the origin means resistance is proportional to length. Keep the current low, or switch off between readings, so the wire stays at the same temperature.
4 I–V characteristics	Use circuit diagrams to construct circuits to investigate the I–V characteristics of a resistor, a filament lamp, a diode and other components.	Variable resistor to change the p.d., ammeter in series, voltmeter in parallel (a voltmeter in series stops the circuit working). A range of p.d. in equal steps, such as 0 to 4 V in 0.5 V steps. Reverse the supply connections for negative values. Repeat and take a mean. Plot I against V and draw a smooth line. A digital meter lowers the chance of misreading. AQA 2021 and 2023.
5 Density	Use apparatus to make the measurements needed to find the densities of regular and irregular solid objects, and of liquids.	Mass on a balance (“scales”, not “scale”: every instrument has a scale). A regular solid: ruler for length, width and height. An irregular one: the water it displaces. Calculate $\rho = m \div V$. Repeat and take a mean. Check the zero first. Give a result as a maximum and a minimum. AQA 2021 and 2022.

Words for a fair test

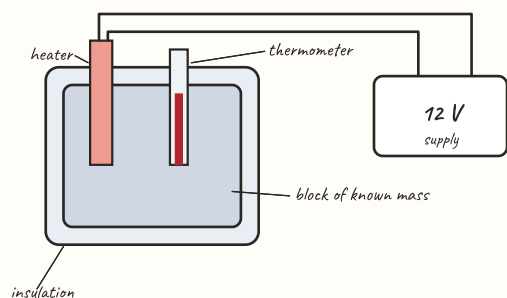
Word	Meaning	Example
Independent variable	The one thing you change.	type of insulation, length of wire
Dependent variable	What you measure.	time for a set fall in temperature, current
Control variable	Everything you keep the same.	volume and start temperature of the water, the wire's material
Resolution	The smallest change an instrument can show.	a thermometer that reads to 0.1 °C
Repeatable · reproducible	Same person gets similar results again · different people with different kit do.	Repeat three times and find a mean

The list principle. If you give more than one answer, an examiner marks them as a list and a wrong one can cancel a right one. Give one answer, or the number asked for. **Hazards.** Name the hazard and one precaution: a hot block or heater (let it cool, use a heatproof mat); hot or boiling water (carry it carefully, keep it away from the edge); a wire that gets hot (low current, switch off between readings).

Skills

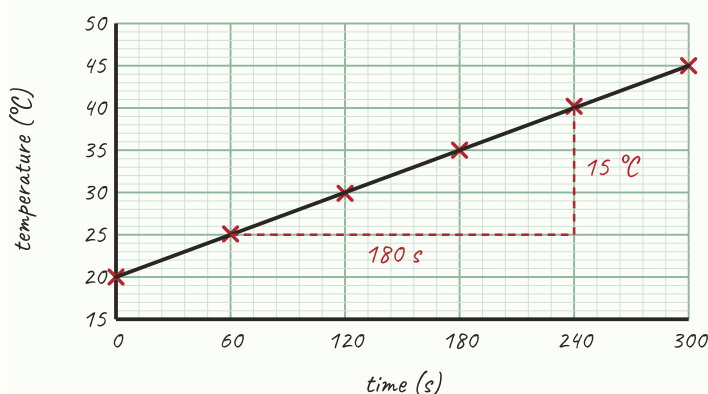
Practicals 1 and 2: heating

Required practical 1: the specific heat capacity of a block



1. Measure the mass of the block. Fit the heater and the thermometer and wrap the block in insulation.
2. Leave the thermometer in the block until it shows the block's temperature. Record it as the starting temperature.
3. Switch the heater on and start a stopwatch. Record the temperature every 60 s.
4. Switch off. Read the highest temperature the thermometer shows.
5. Energy supplied = $P \times t$ (or $V \times I \times t$, or a joulemeter).
6. $c = \Delta E \div (m \Delta \theta)$.

A 0.80 kg aluminium block, a 60 W heater. Made-up results for practice.



Analysis. $\Delta E = 60 \times 300 = 18\,000 \text{ J}$. $\Delta \theta = 45.0 - 20.0 = 25.0 \text{ °C}$. $c = 18\,000 \div (0.80 \times 25.0) = \mathbf{900 \text{ J/kg °C}}$.

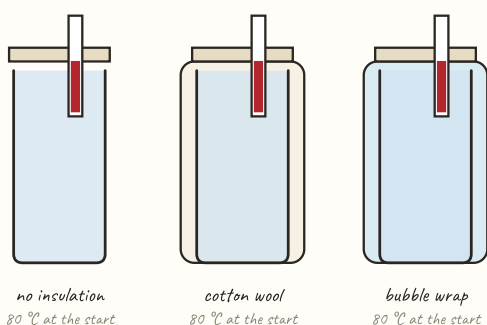
A second method. From the gradient: $15 \div 180 = 0.083 \text{ °C/s}$. Since $P t = m c \Delta \theta$, $c = P \div (m \times \text{gradient}) = 60 \div (0.80 \times 0.083) = 900$.

Improve it. Insulate the block so less energy escapes. Put a little oil in the thermometer hole for better contact. Repeat and take a mean.

Hazard. A hot block and heater can burn: let them cool before touching.

Why leave the thermometer in the block before switching on? So it shows the block's temperature, not room temperature.

Why is the block insulated? To lower the rate of energy loss, so more of the energy supplied warms the block and c is more accurate.

Required practical 2 **Physics only** : which material is the best thermal insulator?

1. Wrap identical beakers in different materials. Keep one with nothing as a control.
2. Fill each with the same volume of water at 80 °C and put on identical lids.
3. Record the temperature at the start and again after 10 minutes. Repeat the whole test.
4. Work out the fall in temperature for each. The smallest fall means the lowest rate of energy transfer.

Material	Start (°C)	After 10 min (°C)	Fall (°C)
none	80	58	22
cotton wool	80	66	14
bubble wrap	80	68	12

Conclusion. Bubble wrap, with a fall of 12 °C, is the best insulator of the three: it has the lowest rate of energy transfer.

Variables. Independent: the material (or the number of layers or the thickness, if one material is tested). Dependent: the fall in temperature. Control: starting temperature, volume of water, beaker, lid, time. **Improve it.** A thermometer that reads to 0.1 °C, and more repeats.

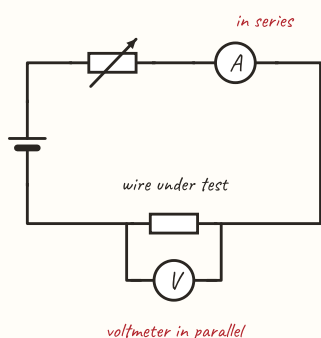
Why have a beaker with no insulation? To compare: it shows how fast the water cools without any.

Why is "bubble wrap is a good insulator" not enough? Say it has a lower rate of energy transfer.

Skills

Practicals 3 and 4: circuits

Required practical 3: the resistance of a wire, and of resistors in series and parallel

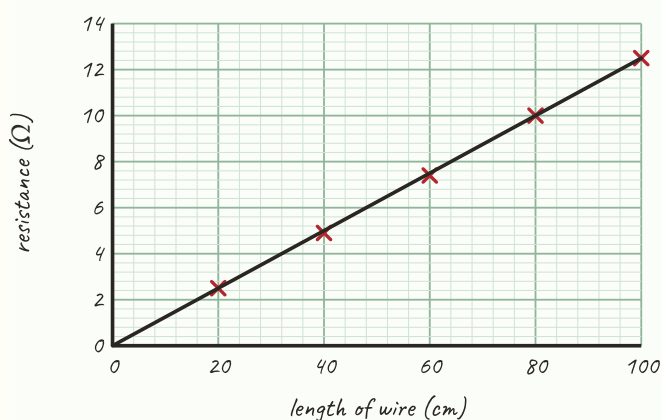


1. Build the circuit with the wire between two clips: an ammeter in series, a voltmeter across the wire.
2. Set the clips 20 cm apart. Switch on and record the p.d. and the current. Switch off at once.
3. Repeat for 40, 60, 80 and 100 cm. Calculate $R = V \div I$ each time.
4. Plot resistance against length. A straight line through the origin means resistance is directly proportional to length.

Series and parallel. Two $10\ \Omega$ resistors measure $20\ \Omega$ in series and $5\ \Omega$ in parallel: the total is less than either one.

Length (cm)	I (A) at 2.0 V	R (Ω)
20	0.80	2.5
40	0.41	4.9
60	0.27	7.4
80	0.20	10.0
100	0.16	12.5

Made-up results. The gradient is $12.5 \div 100 = 0.125\ \Omega$ per cm. Keep the current low, or switch off between readings, so the wire stays at the same temperature.



Why must the wire stay at a constant temperature? A hotter wire has a higher resistance, which would spoil the pattern.

Why repeat and take a mean? To reduce the effect of random errors and to spot an anomaly.

Try it Describe how you would show that the resistance of a wire is directly proportional to its length. [3 marks]

Required practical 4: the I–V characteristic of a component

1. Connect a power supply, a variable resistor, an ammeter and the component in series. Put a voltmeter across the component only.
2. Use the variable resistor to change the p.d. in steps, such as 0 to 4 V in 0.5 V steps. Record the current at each step.
3. Switch off between readings so the component doesn't heat up.
4. Reverse the connections to the supply and repeat, to get negative values. Repeat and take a mean.
5. Plot current on the y-axis and p.d. on the x-axis, and draw a smooth line.

Why is the voltmeter in parallel? It measures the p.d. across the component. In series the circuit would not work.

What does reversing the supply show? How the component behaves in the other direction: a diode passes almost no current.

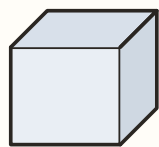
Why take more readings where the graph bends? To draw the curve accurately.

The graphs to expect are on pages 14–15.

Skills

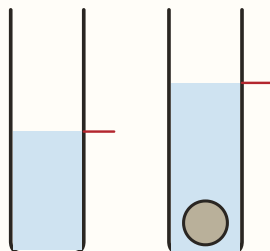
Practical 5, and the latent heat experiment

Required practical 5: density of a regular solid, an irregular solid and a liquid



regular block:

$$V = l \times w \times h$$



before

after

rise in level = volume of stone

1. **Regular solid:** mass on a balance. Length, width and height with a ruler (or a micrometer or Vernier callipers for a small one). $V = l \times w \times h$.
2. **Irregular solid:** mass on a balance. Lower it into water. The volume of water displaced, or the rise in a measuring cylinder, is its volume.
3. **Liquid:** weigh an empty measuring cylinder. Add the liquid, read the volume at eye level at the bottom of the meniscus, weigh again.
4. $\rho = m \div V$ each time. Repeat and take a mean.

Made-up results	Working	Density
Block $4.00 \times 2.50 \times 2.00$ cm, 54.0 g	$V = 20.0 \text{ cm}^3$; $54.0 \div 20.0$	$2.7 \text{ g/cm}^3 = 2700 \text{ kg/m}^3$
Oil: cylinder 85.2 g, with 50.0 cm^3 of oil 131.2 g	oil = 46.0 g; $46.0 \div 50.0$	$0.92 \text{ g/cm}^3 = 920 \text{ kg/m}^3$

Errors and uncertainty. Check the balance reads zero first. Repeat and take a mean to reduce random error. Give a result as a maximum and a minimum, such as $2.7 \pm 0.1 \text{ g/cm}^3$, so 2.8 and 2.6. **Improve it.** A micrometer instead of a ruler for a small block reduces the uncertainty in the volume. “Scales” or “balance”, not “scale”.

Why is “precise” not the same as “has a fine scale”? Precise means repeat readings are close together. A fine scale is a small resolution.

Why read the meniscus at eye level? To avoid a parallax error.

The latent heat of fusion of water (an experiment in the specification)

1. Put crushed ice in two funnels over two beakers. In one funnel, put an electric heater of known power. Leave the other with no heater as a control.
2. Switch on and collect the water from both for the same time, 300 s. Measure the mass of water in each beaker.
3. The heater funnel gives 62 g and the control 17 g. The control shows what the room melts anyway.
4. Mass melted by the heater = $62 - 17 = 45 \text{ g} = 0.045 \text{ kg}$. Energy = $P \times t = 50 \times 300 = 15\,000 \text{ J}$.
5. $L = E \div m = 15\,000 \div 0.045 = 3.3 \times 10^5 \text{ J/kg}$ (to 2 significant figures).

Why use the control funnel? Some ice melts without the heater, so that mass must be subtracted.

Which mass goes into $E = m L$? The change: the extra mass melted by the heater, not the total.

Try it Explain how you would find the density of a pebble that is too big to fit into a measuring cylinder. [3 marks]

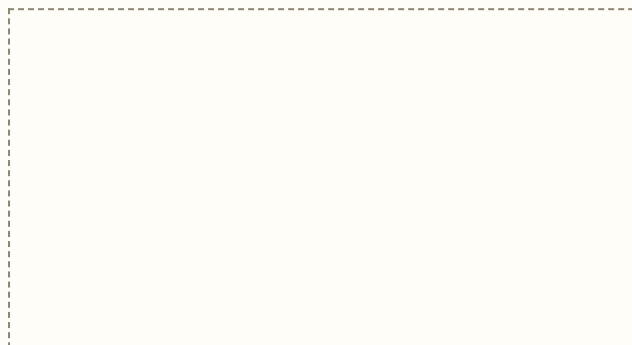
Skills

Draw it

The specification asks for drawing, and so do the papers. Draw each one in pencil, then tick your own checklist. Rub out and redraw the ones you missed.

1 A circuit for the I-V of a filament lamp

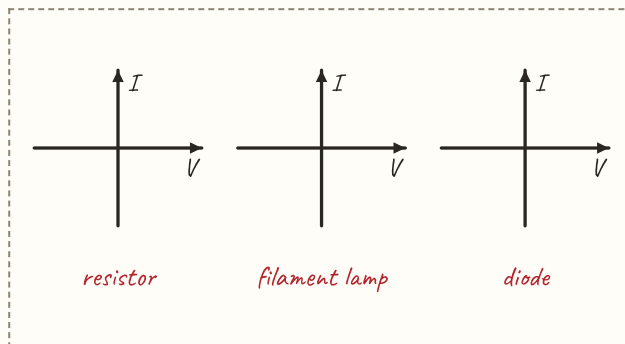
Cell, variable resistor, ammeter, lamp and voltmeter.



Check: one loop; ammeter in series; voltmeter across the lamp only; correct symbols.

2 Sketch three I-V graphs

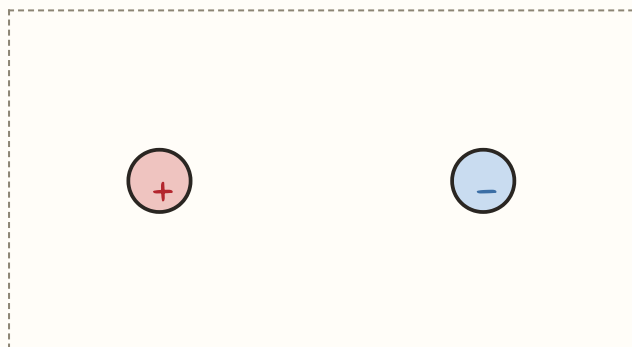
A resistor, a filament lamp and a diode, with both directions.



Check: a straight line through the origin; a curve that gets shallower; flat, then rising, for the diode.

3 Electric field lines (Physics only)

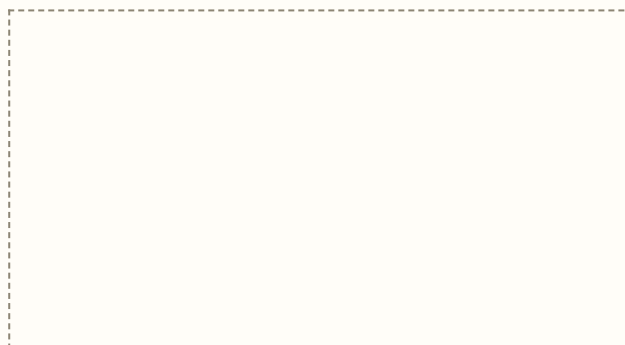
Draw four lines with arrows on each sphere.



Check: lines straight out of +, straight into -; arrows the right way; none crossing.

4 A Sankey diagram

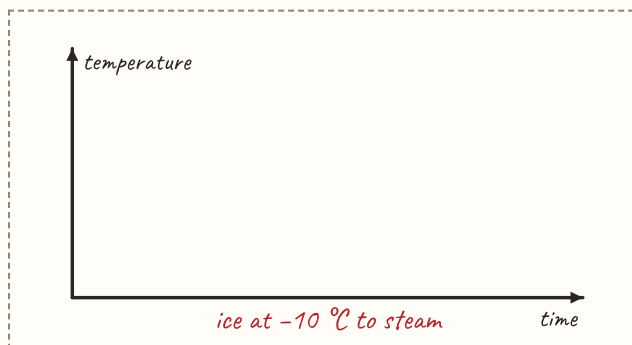
100 J of electrical energy in, 65 J useful, the rest wasted. Draw the widths in proportion.



Check: input 100 wide; useful arrow 65; wasted arrow 35 leaving it; labelled in J.

5 A heating curve

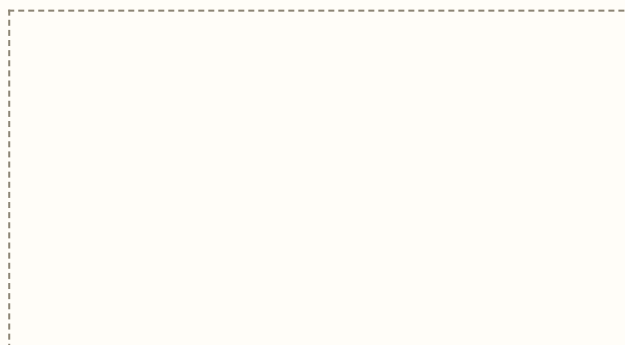
Ice at -10°C heated to steam at a steady rate. Add the flat sections.



Check: two flat sections; the longer one is boiling; labelled with melting and boiling points.

6 A fission chain reaction (Physics only)

A neutron, a uranium nucleus, two smaller nuclei and the neutrons released, then one more fission.



Check: neutron absorbed; two smaller nuclei; two or three neutrons; a second nucleus splitting.

Skills

What AQA's examiners saw students get wrong

These come from AQA's Reports on the Examination and mark schemes for the Higher paper (November 2020, November 2021, June 2022, June 2023) and the Foundation report (June 2019), paraphrased. "Mark scheme" marks the ones the reports don't mention. The struck-through words are what students wrote. The green words are what earned the mark.

Units. A calculation with a ~~kilowatt, megawatt, kilojoule, gram, centimetre or minute~~ not converted, or converted the wrong way. Convert first and write the new value. You lose the conversion mark, but later marks can still be scored.

Rearranging. ~~Rearranging first~~, then substituting into the new equation. Substitute into the equation as printed on the sheet, then rearrange (2022).

Efficiency. The ~~power version~~ when energies were given (2023). Match the version to the data: energies or powers.

Energy stores. ~~Gravitational energy or elastic energy~~, with "potential" left out. Gravitational potential, elastic potential. KE, GPE and EPE are fine.

Conservation. ~~No energy is lost or no energy was wasted~~. The total energy is conserved. Some is dissipated, so less is useful.

Specific heat capacity. Leaving the block to reach ~~room temperature~~. Using ~~the total temperature change~~. Leave the thermometer in the block until it shows the block's temperature, before switching on. Use the change from the right part of the graph (2023).

Thermal insulation. ~~Good insulator, bad insulator, difficult to read~~. A higher rate of energy transfer. Parallax, or the viewing angle.

Resolution and precision. ~~Precision~~ when it was the resolution; ~~scale~~ for a balance. Precision is the spread of repeats; resolution is the smallest reading; the instrument is "scales".

Inverse proportion. ~~As one goes up the other goes down~~. The product $I \times R$ is the same for three or more pairs of values.

I-V practical. ~~Reversing the meters~~ to get negative values. Reverse the connections to the power supply.

Direct and alternating. ~~The p.d. flows in one direction~~, or answers in terms of ~~charge or current~~. The p.d. is always in one direction. It never goes negative.

Transformers. ~~Step-up lowers the p.d.~~ (mark scheme), ~~no energy is lost~~, the p.d. and the current mixed up for the step-down one (2022). Step-up: p.d. up, current down, less thermal energy to the surroundings. Step-down: p.d. down.

Static. ~~Positive electrons, transfer of positive charge~~ (mark scheme). Electrons move. The cloth has more positive than negative charge.

Gas pressure. ~~More collisions. Particles vibrate more~~ for a gas. More collisions per second, with more force on the wall. A gas's particles move faster.

Alpha scattering. The alpha particle ~~collided with the nucleus or with electrons~~. The positive nucleus repels the positive alpha particle. Closer means a stronger force.

Isotopes. ~~Carbon 12 has 12 neutrons~~, a wrong number in a right statement. Same protons and electrons, different neutrons: 6 and 8. Every number must be right.

Half-life. ~~The time for the radioactivity to halve~~; the number ~~2~~ for 2 half-lives. The time for the number of nuclei or the activity to halve. Write "2 half-lives".

Uncertainty. A ~~maximum of the value~~ and a ~~minimum of the uncertainty~~ (2022). Value plus the uncertainty, and value minus the uncertainty.

Reading a graph. A current of ~~0.8 A read for 0.08 A~~, or values ~~read roughly~~ (2020, 2021). Check what each square is worth, and read to the resolution of the grid.

Equations. A ~~right and a wrong form~~ written together, such as $Q = I t$ and $I = t \div Q$ (2020). Write one equation. Any correct rearrangement of a recalled equation is accepted.

Diode. ~~The circuit is not complete~~ when a diode is reversed (2020). A diode has a very high resistance in the reverse direction, so almost no current flows.

Man-made background. ~~Sunlight, microwaves or phones~~ (2020). Medical X-rays, radiotherapy, fallout from weapons tests and accidents: an artificial source.

Fission. A neutron only ~~collides with~~ the nucleus, or an ~~atom~~ absorbs it (2020). A neutron is absorbed by a uranium nucleus, which splits into two smaller nuclei, 2 or 3 neutrons and gamma rays.

Fusion. ~~Elements fuse or atoms fuse~~ (insufficient), and ~~breaking bonds~~ (2020). Light nuclei join to form a heavier nucleus, and some mass is converted into energy.

Risk and precaution. A ~~precaution~~ given when a risk was asked for (Foundation 2019). Name the risk, then the precaution. Use comparative words, "lower" not "low".

Skills

Two six-mark answers, marked

Plan for twenty seconds, then write in order. The red ticks show where the points are. Both answers were written for this guide to meet the top-level description.

Describe an investigation to find out which of three materials is the best thermal insulator.

[6 marks]

Wrap three identical beakers in the three materials, and leave a fourth with nothing as a control ✓. Fill each with the same volume of hot water at the same starting temperature, such as 80 °C, and put on identical lids ✓. Put a thermometer through each lid and record the temperature at the start ✓. Start a stopwatch, and after 10 minutes record the temperature again ✓. Work out the fall in temperature for each, and repeat the whole thing three times and take a mean ✓. The material with the smallest fall in temperature has the lowest rate of energy transfer, so it is the best insulator ✓.

Level 3

Name the variable you change (the material), the one you measure (the fall in temperature in a fixed time) and what you keep the same. Finish with how the result answers the question, in terms of the rate of energy transfer. AQA's top level is a method that would give a valid outcome, with the key steps in a logical order.

A school can put a wind turbine or solar panels on its roof. Evaluate the two, using the data and your own knowledge.

[6 marks]

Invented data	Wind turbine	Solar panels
Maximum power output	6.0 kW	4.0 kW
Average output, as a share of the maximum	25%	12%
Cost	£22 000	£9 000
Gives power when	the wind blows	it is daylight
Emissions when running	none	none

The turbine averages $6.0 \times 0.25 = 1.5$ kW, which is over three times the 0.48 kW of the panels ✓. It costs £22 000 against £9 000 ✓, but that is about £14 700 for each kilowatt of average output against about £18 800 for the panels ✓. Neither is reliable: a turbine gives little in light winds and is shut down in very strong winds, and panels give nothing at night ✓. Both release no carbon dioxide while running ✓. **Overall** the turbine is better value if the school is in a windy place, and the panels are cheaper to start with if money is limited ✓.

Level 3

Use the data, then use what you know. Work out one new figure from the table, such as the average output. Give both sides, then a judgement that says what it depends on. Repeating the table back isn't evaluating.

The insulation question at three levels

Level 1 (1 to 2 marks). "Put hot water in some beakers with different materials round them and see which stays hot." Some steps, but nothing about measuring or keeping the test fair.

Level 2 (3 to 4 marks). "Wrap beakers in the materials, fill them with the same amount of hot water and measure the temperature after ten minutes." Most steps, but no repeats, or the explanation is missing.

Level 3 (5 to 6 marks). The answer above: every key step in a logical order, giving a valid outcome.

Your turn

Cover the answers. Write one in six minutes, then mark yourself: did every sentence do something, and did the last one reach a judgement? Do the other one two days later.

Skills

Two more six-mark answers, marked

Both answers meet the top-level description, and both were written for this guide. Cover them, write your own in six minutes, then mark yourself against the ticks.

Describe how you would investigate the I-V characteristic of a diode.

[6 marks]

Connect a power supply, a variable resistor, an ammeter and the diode in series ✓, and put a voltmeter across the diode only ✓. Use the variable resistor to change the p.d. in small steps, such as 0 to 1.0 V in 0.1 V steps, and record the current and p.d. at each step ✓. Switch off between readings so the diode does not heat up ✓. Reverse the connections to the supply and repeat, to get the readings in the reverse direction ✓. Repeat the readings and take a mean, then plot current against p.d. and draw a smooth curve through the points ✓.

Level 3

A circuit that would work, a range and steps, and a way to get negative values are what the top level needs. A voltmeter in series would stop the circuit working and cap the answer at Level 1. Reversing the meters, rather than the supply, doesn't get the negative values. Take smaller steps where the curve bends.

Explain what happens to the pressure of a gas in a sealed flask when it is heated, and what happens to the pressure of a gas in a syringe when it is squeezed slowly (the squeezing is Physics only).

[6 marks]

Heated flask. Heating gives the particles more kinetic energy, so they move faster ✓. They hit the walls more often each second ✓, and with a bigger force in each collision ✓. So there is more force on each square metre of the wall, and the pressure rises ✓.

Squeezed syringe. The same particles are in a smaller volume ✓, so they hit the walls more often. More hits each second mean more force on each unit of area, so the pressure rises ✓.

Level 3

Particles first, then the whole gas. Say how often they hit the wall, say the force on the wall, and finish with pressure as force on each unit of area. "More collisions" alone and "greater force per m²" alone scored nothing. At constant temperature the speed doesn't change, so don't say the particles are faster in the syringe.

The gas question at three levels

Level 1 (1 to 2 marks). "The particles move faster and hit the sides, so the pressure goes up." One idea, with no link to how often or how hard, and nothing on the syringe.

Level 2 (3 to 4 marks). "Faster particles hit the walls more often, so there is a greater pressure. In the syringe there is less room so more collisions." Both situations, but the force and the pressure link are missing.

Level 3 (5 to 6 marks). The answer above: both situations, explained through the particles and the walls, ending in force on each unit of area.

Which six-markers come up?

Plans for a required practical (the I-V curve, density, heating, resistance), explanations from the particle model (gas pressure, change of state, internal energy) and evaluations of energy resources or radiation. Practise one of each type a week.

Practice

Practice paper, part one

90 marks over four pages, about 94 minutes. Written for this guide, with invented data. Mark it on page 55. Use the equations on page 36. HT marks Higher tier questions, and Physics only marks the ones that aren't in Combined Science.

1 Tick one box for each question. [1 mark each] *[4]*

1.1 Which is a renewable energy resource?

- ☐ A coal ☐ B the tides
☐ C natural gas ☐ D nuclear fuel

1.3 Which type of nuclear radiation is an electromagnetic wave?

- ☐ A alpha ☐ B beta
☐ C neutron ☐ D gamma

1.2 Which component's resistance decreases as its temperature rises?

- ☐ A a thermistor ☐ B a diode
☐ C a filament lamp ☐ D a fixed resistor

1.4 The mass number of an atom is the number of:

- ☐ A protons ☐ B neutrons
☐ C protons plus neutrons ☐ D electrons

2.1 A 0.20 kg ball is thrown upwards at 12 m/s. Calculate its kinetic energy as it leaves the hand. *[2]*

2.2 Ignoring air resistance, calculate the greatest height the ball reaches. ($g = 9.8 \text{ N/kg}$) *[3]*

2.3 In practice the ball does not reach this height. Explain why. *[2]*

3.1 A kettle takes in 480 kJ of electrical energy and transfers 396 kJ to the water. Calculate its efficiency. *[2]*

3.2 The water has a mass of 2.0 kg. Calculate its temperature rise. ($c = 4200 \text{ J/kg } ^\circ\text{C}$) *[3]*

4.1 Draw a circuit diagram with a cell, a lamp and a variable resistor in series, and a voltmeter that measures the p.d. across the lamp. *[3]*

4.2 A 9.0 V battery drives a current of 0.30 A through resistor X. Calculate the resistance of X. *[2]*

Practice

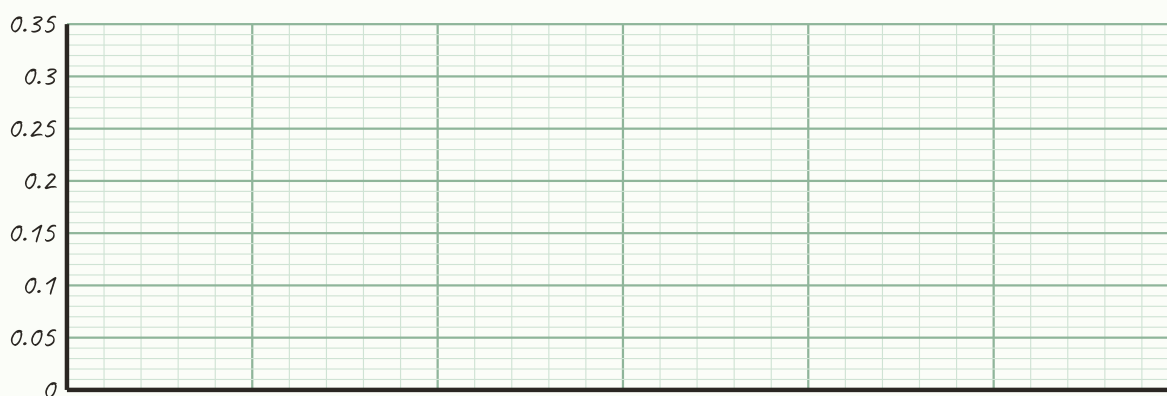
Practice paper, part two

- 4.3** A $20\ \Omega$ resistor Y is added in series with X. Calculate the new current. [3]

- 4.4** Calculate the power of resistor Y in the new circuit. [2]

- 5.1** A student measured the current through a filament lamp at different potential differences. Plot the results and draw a curve of best fit. [3]

P.d. (V)	0.0	1.0	2.0	3.0	4.0	5.0	6.0
Current (A)	0.00	0.10	0.17	0.22	0.26	0.29	0.31



- 5.2** Use your graph to find the resistance of the lamp when the p.d. is 3.5 V. [2]

- 5.3** Explain why the lamp's resistance is greater at 6.0 V than at 2.0 V. [2]

- 6.1** Name the wire in a mains cable with green and yellow insulation, and state its job. [2]

- 6.2** State the frequency of the UK mains supply. [1]

- 6.3** A power station sends 50 kW along a cable of resistance $4.0\ \Omega$ at 2000 V. Calculate the power lost as thermal energy in the cable. [4]

Practice

Practice paper, part three

- 6.4** Describe the difference between a direct p.d. and an alternating p.d. [2]

- 7.1** **Physics only** A balloon rubbed on a woollen jumper becomes negatively charged. Explain why, and why it then pushes away a second negatively charged balloon. [4]

- 7.2** **Physics only** The diagram shows a positively charged sphere. Draw four electric field lines with arrows. [2]



- 8.1** A metal cube has sides of 2.0 cm and a mass of 62.4 g. Calculate its density in g/cm^3 and in kg/m^3 . [4]

- 8.2** **Physics only** A fixed mass of gas has a pressure of 120 kPa and a volume of 60 cm^3 . It is compressed at constant temperature to 40 cm^3 . Calculate the new pressure. [2]

- 8.3** **Physics only** Explain, using the particle model, why the pressure of the gas rises. [3]

- 9.1** A 0.35 kg sample of a metal melts at a constant temperature when 8.4 kJ of energy is transferred to it. Calculate the specific latent heat of fusion of the metal. [3]

- 9.2** Explain why the temperature doesn't rise while the metal is melting. [2]

- 10.1** Describe what the alpha particle scattering experiment showed about the structure of the atom. [3]

Practice

Practice paper, part four

10.2 Americium-241 (in some smoke alarms) decays by emitting an alpha particle to form neptunium-237. Complete the nuclear equation: ${}_{95}^{241}\text{Am} \rightarrow {}_{93}^{237}\text{Np} + ___$ [2]

10.3 A radioactive sample has an activity of 2400 Bq. Eighteen hours later it is 300 Bq. Calculate the half-life. [3]

10.4 **HT** What is the ratio of the final activity to the initial activity after 3 half-lives? [1]

10.5 A technician has two sealed sources with the same activity, one giving out alpha and one giving out gamma. Which gives the greater dose to a person standing 1 m away? Explain your answer. [2]

10.6 A worker spills a radioactive liquid on her gloves. A visitor stands 2 m from a sealed gamma source for an hour. Say whether each person is contaminated or irradiated, and why. [2]

10.7 **Physics only** Each fission of a uranium nucleus releases two or three neutrons. Explain what would happen to the number of fissions each second if every one of those neutrons caused another fission. [3]

11.1 A student investigates how the length of a wire affects its resistance. She uses an ammeter and a voltmeter. Name the independent variable and the dependent variable. [2]

11.2 Give one control variable. [1]

11.3 Her ammeter reads to the nearest 0.1 A. Explain why one that reads to 0.01 A would improve the investigation. [1]

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12 Describe how you could find the specific heat capacity of a block of aluminium using an electric heater. [6]

13 Give one advantage and one disadvantage of using wind turbines to generate electricity. [2]

Answers

Quick-fire answers

1 Energy stores and transfers

- 1.1** $\frac{1}{2} \times 2.0 \times 3.0^2 = 9.0 \text{ J}$.
- 1.2** $4.0 \times 9.8 \times 1.5 = 58.8 \text{ J}$ (about 59 J).
- 1.3** It is transferred to thermal energy in the brakes and the surroundings.
- 1.4** $\frac{1}{2} \times 200 \times 0.10^2 = 1.0 \text{ J}$.

4 Energy resources

- 4.1** Any two of coal, oil and natural gas.
- 4.2** Carbon dioxide.
- 4.3** Turbines give little in light winds and are shut down in very strong winds.
- 4.4** Transport or heating.

7 Electrical power and energy

- 7.1** $230 \times 8.0 = 1840 \text{ W}$.
- 7.2** $0.50^2 \times 40 = 10 \text{ W}$.
- 7.3** $60 \times 120 = 7200 \text{ J}$.
- 7.4** $15 \times 9.0 = 135 \text{ J}$.

10 Density and states of matter

- 10.1** $0.90 \div 0.00030 = 3000 \text{ kg/m}^3$.
- 10.2** 2700 kg/m^3 .
- 10.3** Its particles are much further apart, so the same mass takes up a much bigger volume.
- 10.4** A physical change. The mass is conserved.

13 Atoms and models of the atom

- 13.1** $18 - 8 = 10$.
- 13.2** They have equal numbers of protons (+) and electrons (-).
- 13.3** The plum pudding model.
- 13.4** It moves to a higher energy level, further from the nucleus.

16 Fission and fusion

- 16.1** Uranium (or plutonium).
- 16.2** It absorbs a neutron.
- 16.3** The joining of two light nuclei to form a heavier nucleus.
- 16.4** It is converted into energy of radiation.

2 Power and efficiency

- 2.1** $3600 \div 60 = 60 \text{ W}$.
- 2.2** 2500 W and 7200 s.
- 2.3** Useful = 15 J, so $15 \div 60 = 0.25$ (25%).
- 2.4** It would give out more useful energy than it takes in, and energy can't be created.

5 Circuits and resistance

- 5.1** $0.50 \times 120 = 60 \text{ C}$.
- 5.2** $6.0 \div 0.20 = 30 \text{ }\Omega$.
- 5.3** 20 Ω .
- 5.4** Lower: there are more paths, and the total is less than either resistor.

8 Mains and the National Grid

- 8.1** 50 Hz and about 230 V.
- 8.2** Brown, blue, and green and yellow stripes.
- 8.3** It increases the p.d. and decreases the current.
- 8.4** It is still connected to the supply at about 230 V, so touching it can send a current through you to earth.

11 Gas pressure

- 11.1** $70 \times 30 \div 20 = 105 \text{ kPa}$.
- 11.2** The particles move faster, so they hit the walls more often and with more force.
- 11.3** The particles hitting the wall.
- 11.4** Work is done on the gas, which increases its internal energy and so its temperature.

14 Radioactive decay and half-life

- 14.1** Two protons and two neutrons.
- 14.2** Two half-lives, so $800 \div 4 = 200$.
- 14.3** The mass number stays the same and the atomic number goes up by 1.
- 14.4** Alpha.

3 Heating and insulation

- 3.1** $2.0 \times 4200 \times 5.0 = 42\,000 \text{ J}$.
- 3.2** J/kg °C.
- 3.3** 15 °C.
- 3.4** B: a smaller fall means a lower rate of energy transfer.

6 Resistors and I–V graphs

- 6.1** The current is directly proportional to the p.d.: an ohmic conductor at constant temperature.
- 6.2** The filament gets hotter.
- 6.3** It decreases.
- 6.4** Almost none: its resistance is very high in the reverse direction.

9 Static electricity

- 9.1** Electrons.
- 9.2** Negative.
- 9.3** Attract.
- 9.4** Towards the sphere.

12 Internal energy, latent heat

- 12.1** The total kinetic energy and potential energy of all the particles in a system.
- 12.2** $0.50 \times 2.0 \times 10^6 = 1.0 \times 10^6 \text{ J}$.
- 12.3** Potential energy. The kinetic energy stays the same.
- 12.4** A change of state, at constant temperature.

15 Radiation: hazards and uses

- 15.1** Fallout from weapons tests or accidents, or medical X-rays or radiotherapy.
- 15.2** No.
- 15.3** Any two of: tongs, keep it far away, shield it, limit the time, protective clothing.
- 15.4** The activity falls quickly, so the patient gets a lower dose.

Answers

Try it answers, and the drill

1 Energy stores and transfers [3] Going down, gravitational potential energy decreases as kinetic energy increases [1]. When braking, the kinetic energy is transferred to thermal energy in the brakes and surroundings [1]. Some energy is dissipated to the air all the way down, so the kinetic energy at the bottom is less than the gravitational potential energy lost, though the total is conserved [1].

2 Power and efficiency [2] Some energy is always dissipated, usually as thermal energy, so no machine is 100% efficient [1]. A true claim: “it wastes less energy than the old motor” (or “less of the input energy is wasted”) [1].

3 Heating and insulation [3] The thermometer takes time to reach the temperature of the block [1], so use the highest reading, which is the block's temperature [1]. Insulation reduces the rate of energy transfer to the surroundings, so more of the energy supplied warms the block and c is more accurate [1].

4 Energy resources [3] The share rises in every period, from 4% in 2005 to 25% in 2020 [1]. The biggest rise is between 2010 and 2015 [1], by 10 percentage points (7% to 17%) [1].

5 Circuits and resistance [4] The p.d. across each is 12 V [1]. $12 = I \times 30$, so $I = 0.40$ A [1]. $12 = I \times 60$, so $I = 0.20$ A [1]. Total current = $0.40 + 0.20 = 0.60$ A [1].

6 Resistors and I–V graphs [3] X is a diode [1]. It has a very high resistance in the reverse direction [1], so almost no current flows when it is connected the wrong way round [1].

7 Electrical power and energy [3] $V = IR$, so doubling V doubles the current [1]. $P = VI$, and both V and I are now twice as big [1], so the power is $2 \times 2 = 4$ times bigger [1].

8 Mains and the National Grid [4] A direct p.d. is always in one direction, so it never goes negative [1]. An alternating p.d. keeps changing direction [1]. UK mains has a frequency of 50 Hz [1] and a p.d. of about 230 V [1].

9 Static electricity [3] The sphere has an electric field around it [1]. The field is strongest close to the sphere and gets weaker further away [1]. So the force on the small charge gets stronger as it moves closer [1].

10 Density and states of matter [4] Measure the mass of the empty measuring cylinder on the balance [1]. Pour in some liquid and read the volume at eye level, at the bottom of the meniscus [1]. Measure the mass of the cylinder and liquid, and subtract to get the mass of the liquid [1]. Density = mass $\div$ volume. Repeat and take a mean [1].

11 Gas pressure [4] As the temperature rises from 20 °C to 80 °C the pressure rises from 101 kPa to 122 kPa [1]. The particles gain kinetic energy and move faster [1], so they hit the walls more often each second [1] and with a bigger force, so there is more force on each unit of area [1].

12 Internal energy, latent heat [3] The steam condenses on the skin before it cools [1]. Condensing gives out latent heat ($E = mL$), which the water at 100 °C does not [1]. So more energy is transferred to the skin, which causes the more severe burn [1].

13 Atoms and models of the atom [2] In the plum pudding model the positive charge is spread through the whole atom [1], so there is no small, concentrated charge to push an alpha particle back. They would pass through with only small deflections [1].

14 Radioactive decay and half-life [3] ${}^{14}_6\text{C} \rightarrow {}^{14}_7\text{N} + {}^0_{-1}\text{e}$. Mass number 14 on both sides, and atomic number $7 + (-1) = 6$ [2]. HT: after 3 half-lives the activity is $\frac{1}{8}$ of the start, a ratio of 1 : 8 [1].

15 Radiation: hazards and uses [3] Scan B gives 120 times the dose of scan A ($6 \div 0.05$) [1], and about 2.4 times a year of background radiation ($6 \div 2.5$) [1]. A larger dose carries a greater risk of damaging cells, so B is only worth it if it shows something A can't: a judgement with that reason [1].

16 Fission and fusion [3] Fission splits a large nucleus; fusion joins two light nuclei [1]. Fission is started by a nucleus absorbing a neutron; fusion needs very high temperature and pressure [1]. Both release energy [1].

Practicals 3 and 4 [3] Measure the p.d. and the current for several lengths of the wire, and calculate $R = V \div I$ each time [1]. Plot resistance against length [1]. A straight line through the origin shows the resistance is directly proportional to the length [1].

Practical 5 [3] Fill a displacement can to the level of its spout and put a measuring cylinder under the spout [1]. Lower the pebble in, and measure the volume of water collected: that is the volume of the pebble [1]. Measure the mass with a balance and calculate density = mass $\div$ volume [1].

The drill on page 39

A. Units. 1 0.45 A; 2 2400 V; 3 3600 kJ; 4 900 s; 5 9000 s; 6 0.080 kg; 7 0.065 m; 8 $2.5 \times 10^{-4} \text{ m}^3$; 9 120 000 Pa; 10 600 W; 11 2 hours; 12 36 kJ.

B. Rearranging. $a v = \sqrt{(2 E_k \div m)}$; $b I = \sqrt{(P \div R)}$; $c e = \sqrt{(2 E_e \div k)}$; $d c = \Delta E \div (m \Delta \theta)$; $e h = E_p \div (m g)$; $f V_2 = p_1 V_1 \div p_2$.

C. Standard form. 1 3.6×10^{-4} ; 2 42 000; 3 1.2; 4 3.0×10^4 .

D. In context. 1 $2200 \times 240 = 528\,000 \text{ J}$ ($5.28 \times 10^5 \text{ J}$); 2 $V = 0.30 \times 12 = 3.6 \text{ V}$; 3 $2^2 = 4$ times bigger.

E. Two steps. 1 $60 \times 7200 = 432\,000 \text{ J} = 432 \text{ kJ}$; 2 $0.25 \times 4200 \times 40 = 42\,000 \text{ J} = 42 \text{ kJ}$; 3 $I = 0.15 \text{ A}$, $t = 600 \text{ s}$; $Q = 90 \text{ C}$, $E = 90 \times 12 = 1080 \text{ J}$; 4 $160 \times 0.30 \div 0.20 = 240 \text{ kPa}$.

Answers

Practice paper: marks and answers

1.1 B, the tides; 1.2 A, a thermistor; 1.3 D, gamma; 1.4 C, protons plus neutrons. [4]

2.1 $\frac{1}{2} \times 0.20 \times 12^2$ [1] = 14 J (14.4 J) [1].

2.2 All the kinetic energy becomes gravitational potential energy [1]; $14.4 = 0.20 \times 9.8 \times h$ [1]; $h = 7.3$ m [1].

2.3 Some energy is dissipated as thermal energy because of air resistance [1], so less kinetic energy becomes gravitational potential energy [1].

3.1 $396 \div 480$ [1] = 0.83, or 82.5% [1].

3.2 $396 \text{ kJ} = 396\,000 \text{ J}$ [1]; $396\,000 = 2.0 \times 4200 \times \Delta\theta$ [1]; $\Delta\theta = 47^\circ\text{C}$ [1].

4.1 A cell, a lamp and a variable resistor in one loop [1]; correct symbols [1]; a voltmeter in parallel with the lamp only [1].

4.2 $9.0 = 0.30 \times R$ [1]; $R = 30 \Omega$ [1].

4.3 Total resistance = $30 + 20 = 50 \Omega$ [1]; $9.0 = I \times 50$ [1]; $I = 0.18 \text{ A}$ [1].

4.4 $P = I^2 R = 0.18^2 \times 20$ [1] = 0.65 W (0.648 W) [1].

5.1 Axes labelled with the quantity and unit, and a scale written on the p.d. axis that fills most of the grid [1]; points plotted as crosses, allowing one slip [1]; a smooth curve of best fit through the origin and the points, not a straight line or dot to dot [1].

5.2 Current read from the graph at 3.5 V as about 0.24 A (accept 0.23 to 0.25 A) [1]; $R = 3.5 \div 0.24 = 15 \Omega$ (accept 14 to 16 Ω) [1].

5.3 At 6.0 V the current is bigger, so the filament is hotter [1], and a filament lamp's resistance increases as its temperature rises [1].

6.1 The earth wire [1]. A safety wire that stops the appliance becoming live, and only carries a current if there is a fault [1].

6.2 50 Hz [1].

6.3 $50 \text{ kW} = 50\,000 \text{ W}$ [1]; $I = P \div V = 50\,000 \div 2000 = 25 \text{ A}$ [1]; $P = I^2 R = 25^2 \times 4.0$ [1] = 2500 W [1].

6.4 A direct p.d. is always in one direction, so it never goes negative [1]. An alternating p.d. keeps changing direction [1].

7.1 Electrons are rubbed off the wool onto the balloon [1]; the balloon has gained electrons, so it has more negative than positive charge [1]; two objects with the same type of charge repel [1]; this is a non-contact force, acting through the electric field [1].

7.2 Lines drawn straight out from the sphere, evenly spaced [1]; arrows pointing away from the sphere, because it is positive [1].

8.1 Volume = $2.0^3 = 8.0 \text{ cm}^3$ [1]; $62.4 \div 8.0$ [1] = 7.8 g/cm³ [1]; $\times 1000 = 7800 \text{ kg/m}^3$ [1].

8.2 $pV = \text{constant}$: $120 \times 60 = 7200$ [1]; $7200 \div 40 = 180 \text{ kPa}$ [1].

8.3 There are the same number of particles in a smaller volume, so they hit the walls more often [1]; collisions per second rise, so the total force on the walls rises [1]; pressure is force per unit area, so it rises [1].

9.1 $8.4 \text{ kJ} = 8400 \text{ J}$ [1]; $8400 = 0.35 \times L$ [1]; $L = 24\,000 \text{ J/kg}$ [1].

9.2 The energy supplied increases the potential energy of the particles as they move apart [1]; their kinetic energy doesn't change, so the temperature stays the same [1].

10.1 Most alpha particles went straight through, so the atom is mostly empty space [1]; a few were deflected through large angles, or came back, so there is a positive centre that repels them [1]; the nucleus is tiny and holds most of the mass [1].

10.2 ${}_{95}^{241}\text{Am} \rightarrow {}_{93}^{237}\text{Np} + {}_2^4\text{He}$. Mass number 4 [1] and atomic number 2, an alpha particle [1].

10.3 $2400 \rightarrow 1200 \rightarrow 600 \rightarrow 300$, so 3 half-lives [1]; $18 \div 3$ [1] = 6.0 hours [1].

10.4 1 : 8 [1].

10.5 Gamma [1]. Alpha has a range of only a few centimetres in air, so it does not reach a person 1 m away, but gamma travels a long way [1].

10.6 The worker is contaminated: radioactive atoms are on her gloves [1]. The visitor is irradiated: exposed to radiation from the source, and not made radioactive [1].

10.7 Each neutron could be absorbed by another nucleus, which would split [1]; so the number of fissions would grow each generation [1]; an uncontrolled chain reaction, with energy released faster and faster, as in a weapon [1].

11.1 Independent: the length of the wire [1]. Dependent: the resistance (or the current and p.d. she measures to find it) [1].

11.2 Any one of: the material or thickness of the wire, its temperature, the p.d. of the supply [1].

11.3 A smaller resolution shows small changes in current that steps of 0.1 A would hide [1].

12 Level 3 (5 to 6): the key steps in a logical order. (1) Measure the mass of the block on a balance. (2) Insulate it and put the heater and the thermometer in the holes. (3) Leave the thermometer in the block until it shows the block's temperature, then record the starting temperature. (4) Connect the heater to a joulemeter, or an ammeter and a voltmeter, and switch on for a measured time. (5) Switch off and read the highest temperature. (6) Work out the energy supplied ($V \times I \times t$) and the temperature change, then $c = \text{energy} \div (\text{mass} \times \text{temperature change})$. Repeat and take a mean. Level 2 (3 to 4): most steps, with a missing measurement or no energy calculation. Level 1 (1 to 2): some relevant steps, not linked.

13 Advantage, one of: no carbon dioxide while running, renewable, no fuel to buy [1]. Disadvantage, one of: gives little in light winds, shut down in very strong winds, spoils the view, noise [1].

Mark with a different colour and add up. Your teacher may accept other correct wording.

Answers

Lost marks, and your tracker

Lost marks on the practice paper? Go here

Question	Go to	Pages
1.1, 13	Topic 4	10–11
1.2, 5.1 to 5.3	Topic 6, graphs and data	14–15, 40
1.3, 10.2 to 10.4	Topic 14	30–31
1.4, 10.1	Topic 13	28–29
2.1 to 2.3	Topic 1	4–5
3.1	Topic 2	6–7
3.2, 12	Topic 3, practicals 1 and 2	8–9, 42
4.1 to 4.3, 11.1 to 11.3	Topic 5, practicals 3 and 4	12–13, 43
4.4	Topic 7	16–17
6.1 to 6.4	Topic 8	18–19
7.1, 7.2	Topic 9	20–21
8.1	Topic 10, practical 5	22–23, 44
8.2, 8.3	Topic 11	24–25
9.1, 9.2	Topic 12	26–27
10.5, 10.6	Topic 15	32–33
10.7	Topic 16	34–35

Your tracker

Colour a circle when it's done. Return two days later, and a week later. Write the part to repair in the last column.

Topic	Learn it	Use it	Try it	Recall box	Quick-fire	2 days	1 week	To repair
1 Energy stores and transfers	☐	☐	☐	☐	☐	☐	☐	
2 Power and efficiency	☐	☐	☐	☐	☐	☐	☐	
3 Heating and insulation	☐	☐	☐	☐	☐	☐	☐	
4 Energy resources	☐	☐	☐	☐	☐	☐	☐	
5 Circuits and resistance	☐	☐	☐	☐	☐	☐	☐	
6 Resistors and I–V graphs	☐	☐	☐	☐	☐	☐	☐	
7 Electrical power and energy	☐	☐	☐	☐	☐	☐	☐	
8 Mains and the National Grid	☐	☐	☐	☐	☐	☐	☐	
9 Static electricity	☐	☐	☐	☐	☐	☐	☐	
10 Density and states of matter	☐	☐	☐	☐	☐	☐	☐	
11 Gas pressure	☐	☐	☐	☐	☐	☐	☐	
12 Internal energy, latent heat	☐	☐	☐	☐	☐	☐	☐	
13 Atoms and models of the atom	☐	☐	☐	☐	☐	☐	☐	
14 Radioactive decay and half-life	☐	☐	☐	☐	☐	☐	☐	
15 Radiation: hazards and uses	☐	☐	☐	☐	☐	☐	☐	
16 Fission and fusion	☐	☐	☐	☐	☐	☐	☐	

Practice paper: my marks

Part	One	Two	Three	Four	Total
Out of	21	19	25	25	90
I scored					
Redo on					

More from Empower Educators

The Physics range

If this guide was useful, here is the rest of the Physics shelf. Everything shown is on the site now.



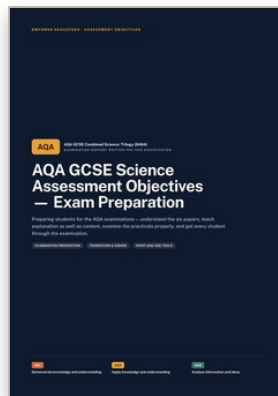
The Science playbook

The science department's playbook, with Physics inside it.



Schemes of work

Year 10 to Year 11. One sequence table a year, unit by unit and in teaching order.



Science exam board playbooks

The science department's books, one for each board, with Physics inside them.



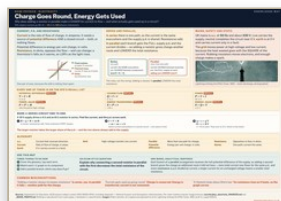
GCSE questions and answers

Exam-style questions, each answered three times: weak, middling and strong.



Knowledge organisers

Year 10 to Year 11. A4, printable, one per unit.



GCSE knowledge mats: electricity

One landscape sheet a topic, with the equations and the corrections.



GCSE knowledge mats: radioactivity

Atomic structure and radiation on one landscape sheet.

See the whole Physics range

empowereducators.co.uk/physics/

Details and previews for every resource.