Course Companion

OxfordAQA · International GCSE · Physics

Every topic handout in one volume

全部专题讲义合集

exercises.lol

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Forces and their effects

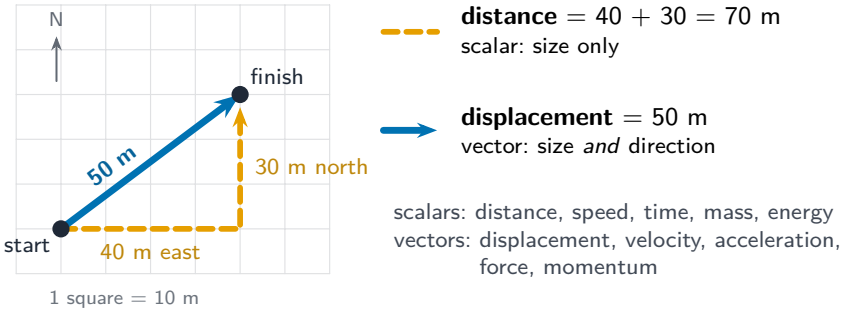
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Every push, pull and hold in the world is a force – and OxfordAQA's first topic organises them: contact and non-contact interactions, scalars against vectors, Newton's three laws, vehicle safety, and the P-extension ideas of momentum, terminal velocity, centre of mass and moments.

OxfordAQA International GCSE Physics 9203, topic 3.1 (Version 5.1, exams 2018 onwards). Statements marked (P) are Paper-2-only; paper details are in the specification's scheme of assessment. The specimen components on file are 9203-92031 and 9203-92032 – specimen practice in this package is always labelled as such.

Forces and their interactions

Objects interact by **non-contact field forces** (gravity, electrostatics, magnetism) and **contact forces** (friction, air resistance, tension, normal contact force). **Friction** 摩擦 acts between two surfaces, impedes motion and may heat them; air resistance is friction with a fluid.



Distance 70 m (a scalar, size only) against displacement 50 m (a vector, size and direction) on one walk.

Scalars 标量 have magnitude only (distance, speed, time); **vectors** 矢量 add direction (displacement, velocity, acceleration, force, momentum) and can be drawn as arrows. **Weight** is the force of gravity: $W = m \times g$.

Forces can **change shape** – stretching, bending, compressing. Elastic distortions recover; inelastic ones do not (P). A stretched spring stores **elastic potential energy**, and below the **limit of proportionality**:

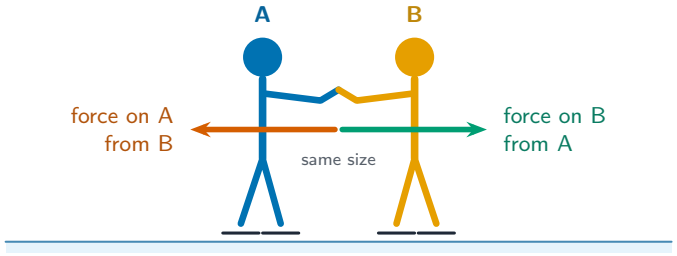
$$F = k \times e$$

Required practical: investigate force against extension for a spring (hang masses, plot the line, gradient = k).

Worked example (spring constant). A spring is 12.0 cm long with no load and 15.0 cm long with a 3.0 N load. The extension is $15.0 - 12.0 = 3.0$ cm $= 0.030$ m, so $k = F/e = 3.0 \div 0.030 = 100$ N/m. With a 5.0 N load (still below the limit of proportionality) $e = 5.0 \div 100 = 0.050$ m, so the spring is $12.0 + 5.0 = 17.0$ cm long.

Motion and Newton's laws

Speed is the gradient of a distance–time graph; velocity adds direction: $v = s/t$ (usable for average speeds too). Acceleration is the rate of change of velocity: $a = \Delta v/t$ – from the gradient of a velocity–time graph, whose **area gives distance travelled**. Changing direction at constant speed is still acceleration.



equal size, opposite directions, on *different* objects: they never cancel

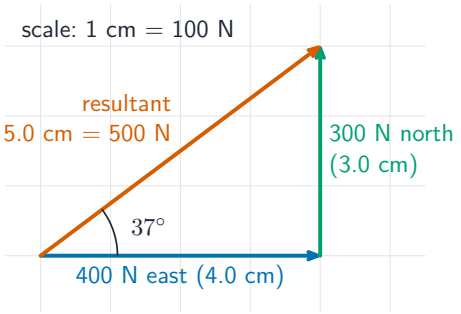
Two skaters push: equal and opposite forces on different objects (Newton's third law).

- **Newton's First Law**: zero resultant force → rest stays rest, motion keeps its velocity.
- **Newton's Second Law**: $F = m \times a$ in the direction of the resultant.
- **Newton's Third Law**: interacting objects exert equal, opposite forces on each other.

Resultants: opposite or parallel forces add along a line; two coplanar forces combine by **scale drawing** (drawn to scale, head to tail).

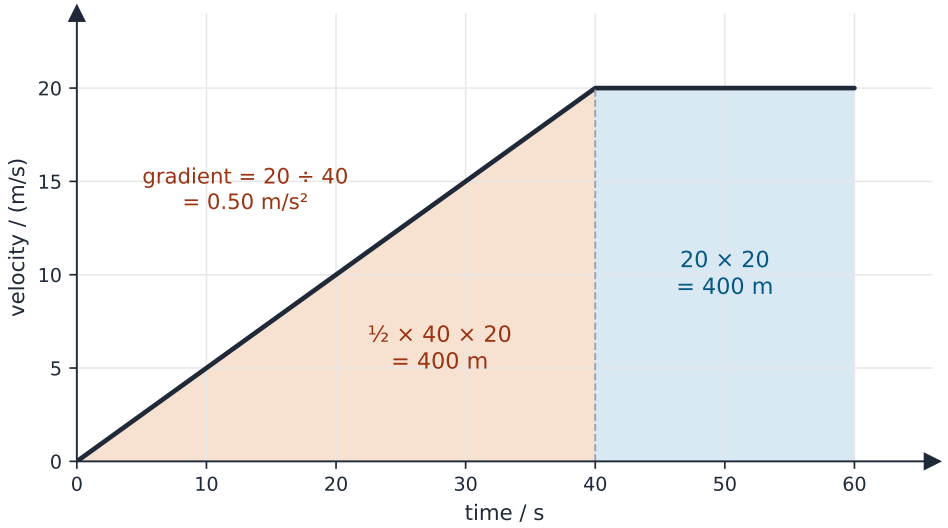
Worked example (resultant force and $F = ma$). A 1200 kg car has a driving force of 3000 N forwards and resistive forces of 600 N backwards. Draw the two arrows on the car first. The resultant is $3000 - 600 = 2400$ N forwards, so $a = F/m = 2400 \div 1200 = 2.0$ m/s^2. Later the car moves at a steady speed with the same driving force: the resistive forces must now be 3000 N, because the resultant is zero.

Worked example (scale drawing). A boat's engine pushes it east with 400 N while the wind pushes it north with 300 N. With a scale of 1 cm = 100 N, draw 4.0 cm east, then 3.0 cm north from the head of the first arrow. The resultant arrow measures 5.0 cm, so it is 500 N; a protractor gives 37° north of east.



Draw the forces head to tail to scale; the resultant runs from the start of the first arrow to the end of the last

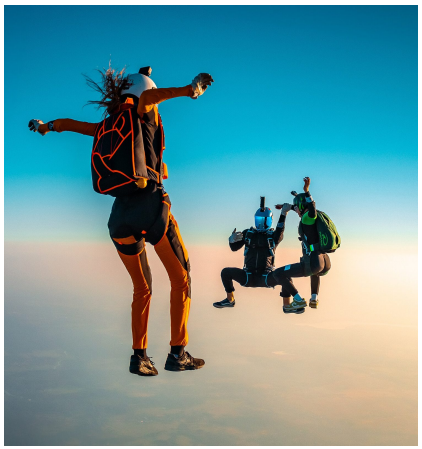
Worked example (reading a velocity–time graph). A train speeds up steadily from rest to 20 m/s in 40 s, then runs at 20 m/s for 20 s. Acceleration = gradient = $20 \div 40 = 0.50$ m/s^2. Distance = area: the triangle gives $\frac{1}{2} \times 40 \times 20 = 400$ m and the rectangle $20 \times 20 = 400$ m, so 800 m in 60 s, an average speed of $800 \div 60 = 13$ m/s.



Gradient gives the acceleration; the area under the line gives the distance

(P) Momentum, safety and terminal velocity

$$p = m \times v \qquad F = \frac{\Delta p}{t}$$



Skydivers in free fall: once air resistance balances weight, the resultant force is zero and they fall at terminal velocity

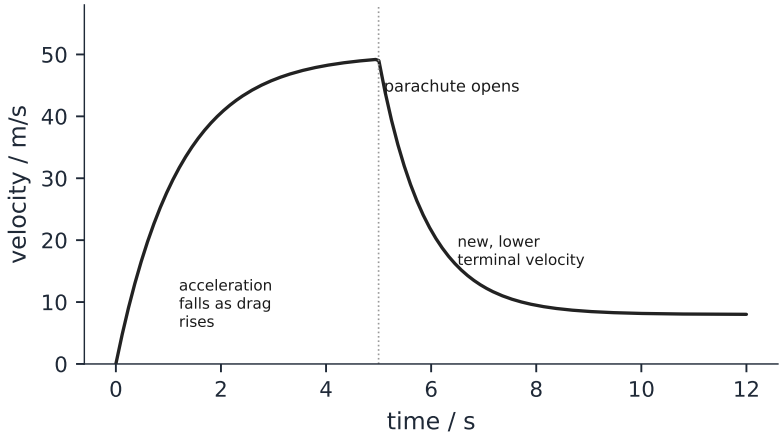
Momentum 动量 is conserved when the chosen system has zero resultant external force; negligible external impulse during a short collision or explosion gives an approximately fixed total. Car safety: airbags, seat belts, side-impact bars, crumple zones, crash mats, cushioned playground surfaces and cycle helmets all **lengthen the time** of impact, so for the same momentum change the force is smaller.

> **Worked example (P) (an explosion).** Two skaters, 60 kg and 40 kg, stand still and push apart. The total momentum is zero before, so it is zero after. If the 40 kg skater moves off at 3.0 m/s, the 60 kg skater must have momentum $40 \times 3.0 = 120$ kg m/s the other way: $v = 120 \div 60 = 2.0$ m/s, in the opposite direction.

> **Worked example (P) (force from momentum change).** A 0.40 kg football at rest is kicked to 25 m/s; the boot touches it for 0.010 s. $\Delta p = 0.40 \times 25 - 0 = 10$ kg m/s, so $F = \Delta p / t = 10 \div 0.010 = 1000$ N.

At a steady speed the driving force balances resistive forces. Stopping distance = **thinking** + **braking** distance; reaction time grows with tiredness, distraction, drugs and alcohol; braking force must grow with speed, and large decelerations overheat brakes. Braking converts the vehicle's kinetic energy into heating the brakes (friction work); braking distance lengthens on wet or icy roads and with worn brakes or tyres.

An object falling through a fluid reaches **terminal velocity** 终末速度 when drag plus upthrust balances weight; ignoring upthrust gives drag = weight; parachutes raise drag to cut the terminal velocity, and streamlining (a shark's shape, a car's design) reduces drag to raise the maximum speed.



Velocity against time for a parachutist: a first terminal velocity, then a lower one after opening.

(P) Centre of mass and moments

The **centre of mass** 质心 is where an object's mass may be thought concentrated; a freely suspended object rests with it below the suspension point, and a symmetrical object's centre of mass lies on the axis of symmetry. Find it for an irregular lamina by suspending it from two points and drawing plumb lines.

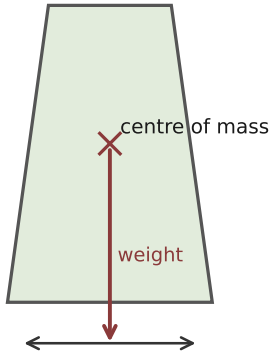


A tower crane balances the moment of its load with a counterweight on the other side of the mast

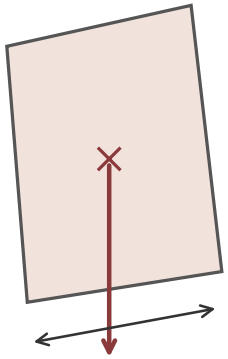
$$M = F \times d$$

A balanced object has equal total clockwise and anticlockwise **moments** 力矩; levers are force multipliers. If the weight's line of action falls outside the base, the resultant moment topples the object (vehicles, balancing toys).

Worked example (P) (balancing a seesaw). A child weighing 300 N sits 2.0 m to the left of the pivot: anticlockwise moment $= 300 \times 2.0 = 600$ N m. A 400 N child balances it at a distance $d = 600 \div 400 = 1.5$ m to the right. The heavier child sits closer to the pivot.



weight line inside the base: stable



weight line outside the base: topples

A stable block keeps its weight line inside the base; a tilted block with the line outside topples.

Common mistakes

- Using the length of the spring instead of the extension in $F = ke$. Subtract the original length, and change cm to m.
- Using one force in $F = ma$ when several act. Find the resultant force first.
- Saying a moving object must have a resultant force on it. At a steady velocity the forces are balanced (Newton's First Law).
- Thinking the two forces in Newton's Third Law cancel. They act on *different* objects, so they never cancel each other.
- Adding two perpendicular forces as numbers (400 N + 300 N = 700 N). Use a scale drawing; the resultant is 500 N.
- (P) Forgetting that momentum has direction. Objects moving the opposite way have negative momentum.
- (P) Measuring a moment's distance from the end of the beam. Measure from the pivot, perpendicular to the force.

Check yourself

1. Give one example each of a contact and a non-contact force.
2. Which of these are vectors: speed, displacement, time, force?
3. State the spring equation and the name of its constant.
4. State Newton's three laws in one sentence each.
5. A 900 kg car accelerates at 2 m/s^2. Calculate the resultant force.
6. Name two factors that lengthen thinking distance and two that lengthen braking distance.
7. (P) Explain how a crumple zone protects passengers, using F = Δp/t.
8. (P) Why does a parachutist reach a lower terminal velocity after opening the parachute?
9. (P) Where is the centre of mass of a symmetrical object?
10. (P) A 250 N force acts 0.4 m from a pivot. Calculate its moment.

Answers: 1 contact – friction/tension/air resistance/normal; non-contact – gravity/electrostatic/magnetic; 2 displacement and force; 3 $F = ke$, the spring constant (N/m); 4 first – no resultant force, no change in velocity; second – $F = ma$ along the resultant; third – interaction forces are equal and opposite; 5 $F = 900 \times 2 = 1800$ N; 6 thinking – tiredness, distractions, drugs/alcohol; braking – wet/icy roads, worn brakes or tyres (any two each); 7 (P) a longer collision time, so for the same Δp the force $F = \Delta p/t$ is smaller; 8 (P) much more drag, so drag balances weight at a lower speed; 9 (P) on its axis of symmetry; 10 (P) $M = 250 \times 0.4 = 100$ N m.

Energy

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Energy: the accountant of physics

Nothing destroys energy – it is only moved between stores and partly dissipated into less useful forms. OxfordAQA's second topic builds the accounting: work and power, the three energy-store equations, conservation with Sankey diagrams, and the choices behind national energy resources.

OxfordAQA International GCSE Physics 9203, topic 3.2 (Version 5.1). Statements marked (P) are Paper-2-only.

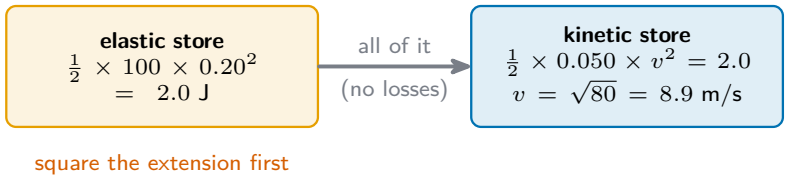
Forces and energy

$$W = F \times d \qquad E_e = \tfrac{1}{2}ke^2 \qquad E_p = mgh \qquad E_k = \tfrac{1}{2}mv^2 \qquad P = \frac{E}{t}$$

Work 功 is done when a force moves its point of application through a distance; work against friction transfers energy by heating (shuttle re-entry, meteorites, brakes). A stretched spring stores **elastic potential energy** $\tfrac{1}{2}ke^2$; a raised mass stores **gravitational potential energy** mgh; a moving mass carries **kinetic energy** ½mv^2 – doubling mass doubles it, doubling speed **quadruples** it (the road-safety link). **Power** 功率 is the rate of energy transfer.

Worked check. A 1500 kg car at 20 m/s brakes to rest: KE removed $= \tfrac{1}{2} \times 1500 \times 400 = 300\,000$ J – all transferred to heating the brakes. Lifting it 2 m at g = 10 N/kg stores $1500 \times 10 \times 2 = 30\,000$ J.

Worked example (elastic store to kinetic store). A catapult's elastic has $k = 100$ N/m and is stretched by 0.20 m. Stored energy $E_e = \tfrac{1}{2} \times 100 \times 0.20^2 = \tfrac{1}{2} \times 100 \times 0.040 = 2.0$ J (square the extension first). If all of it goes to a 0.050 kg stone: $\tfrac{1}{2} \times 0.050 \times v^2 = 2.0$, so $v^2 = 80$ and $v = 8.9$ m/s.

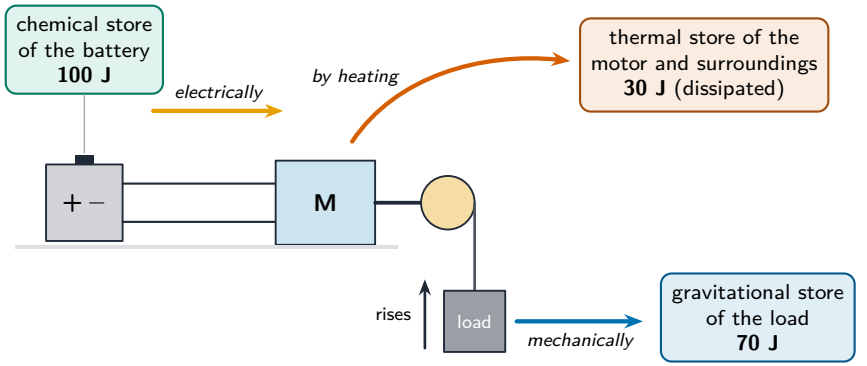


All 2.0 J moves from the elastic store to the kinetic store.

Worked example (falling). A ball is dropped from 5.0 m. Its GPE becomes KE: $mgh = \tfrac{1}{2}mv^2$, so $v = \sqrt{2gh} = \sqrt{2 \times 10 \times 5.0} = 10$ m/s, whatever its mass (ignoring air resistance).

Worked example (power). A crane lifts a 500 kg load through 12 m in 20 s. Energy transferred $= mgh = 500 \times 10 \times 12 = 60\,000$ J, so $P = 60\,000 \div 20 = 3000$ W = 3.0 kW.

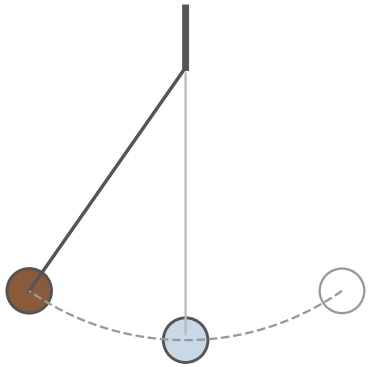
Energy transfers and dissipation



stores: kinetic, gravitational potential, elastic potential, thermal, chemical, magnetic, electrostatic, nuclear
pathways: mechanically (a force does work), electrically (a current), by heating, by radiation (light, sound waves)

One system, three stores: 100 J from the battery's chemical store ends as 70 J in the load's gravitational store and 30 J dissipated by heating.

When a system changes, energy is transferred – usefully, stored, or **dissipated** 耗散 ("wasted") into less useful stores; it is never created or destroyed. Friction and air resistance dissipate energy by heating. (P) A **pendulum** swaps kinetic and gravitational potential energy each swing.



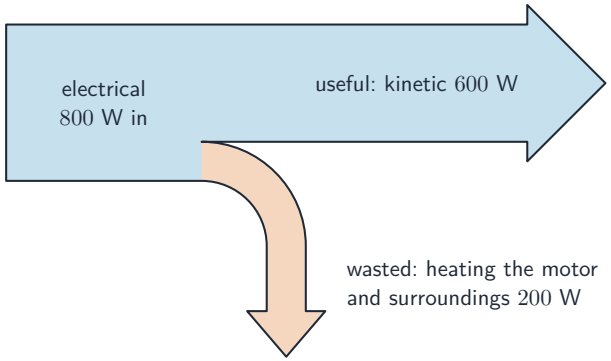
A pendulum: all gravitational potential energy at the top of each swing, all kinetic energy at the bottom.

$$\text{efficiency} = \frac{\text{useful energy out}}{\text{total energy in}} \times 100\% \; (= \frac{\text{useful power out}}{\text{total power in}})$$

Sankey diagrams show the redistribution: arrows split in proportion to the energy flows (draw them to scale – width $\propto$ energy).

Worked check. A 60 W lamp gives 6 W of light: **efficiency** 效率 $= 6/60 \times 100 = 10\%$.

> **Worked example (wasted energy).** A motor takes 800 W and gives out 600 W of useful power. Efficiency $= 600/800 \times 100 = 75\%$. The other 200 W is dissipated, so in one minute $200 \times 60 = 12\,000$ J heats the motor and its surroundings. On a Sankey diagram the input arrow splits into a useful arrow three times as wide as the wasted one.



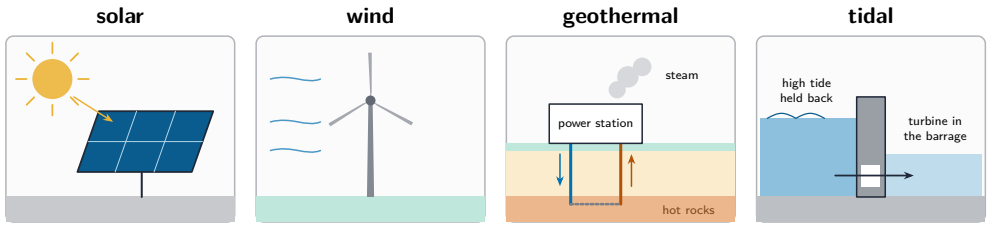
Drawn to scale: the useful arrow is three times as wide as the wasted one, and the two add up to the input

Energy resources

Fuels are chosen for ease of storage, energy content and safety; some transfer more of their energy usefully than others. National generation trades **renewability** against cost, reliability and the environmental cost of extraction, use and disposal.



Wind turbines: a renewable resource that transfers the kinetic energy of moving air to electricity, but only when the wind blows



+ renewable; no fuel cost

− none at night, less in cloud

+ renewable; no emissions while running

− output varies with the wind; visual impact

+ steady output, day and night

− few suitable sites

+ tides are predictable

− harsh marine environment

Four renewable resources, each with one advantage (+) and one drawback (−).

■ Common mistakes

- Forgetting the square in $E_e = \frac{1}{2}ke^2$ or $E_k = \frac{1}{2}mv^2$. Square e or v first, then multiply.
- Using a spring's length instead of its extension, or centimetres instead of metres.
- Using mass instead of weight in $W = F \times d$ for a lift. The force needed is the weight, mg.
- Getting an efficiency above 100%. Useful output can never be more than the total input.
- Saying dissipated energy is destroyed. It still exists, spread out in the surroundings as thermal energy.
- Drawing a Sankey diagram whose output arrows do not add up to the input arrow.

Check yourself

1. Calculate the work done by a 50 N force moving 4 m.
2. Calculate the elastic energy in a spring (k = 200 N/m) stretched 0.15 m.
3. A 2 kg book is lifted 3 m at g = 10 N/kg. Calculate the GPE gained.
4. What happens to the kinetic energy of a car when it brakes?
5. A motor transfers 800 J in 20 s. Calculate its power.
6. State the efficiency equation in energy and power forms.
7. A lamp gives out 12 J of light for every 100 J in. Calculate the efficiency.
8. What does a Sankey diagram's arrow width show?
9. Give one advantage and one drawback of wind power.
10. What does "dissipated" mean?

Answers: 1 $W = 50 \times 4 = 200$ J; 2 $E_e = \frac{1}{2} \times 200 \times 0.0225 = 2.25$ J; 3 $E_p = 2 \times 10 \times 3 = 60$ J; 4 it is transferred to thermal energy of the brakes and surroundings by the friction force (the brakes heat up); 5 $P = 800/20 = 40$ W; 6 useful energy out ÷ total energy in (×100 %); equally useful power out ÷ total power in; 7 $12/100 \times 100 = 12\%$; 8 the energy flowing in that direction – width is proportional to energy; 9 renewable with no fuel or emissions; unreliable output with visual impact; 10 transferred to less useful stores (often waste heat), so it cannot readily do what we want.

Waves

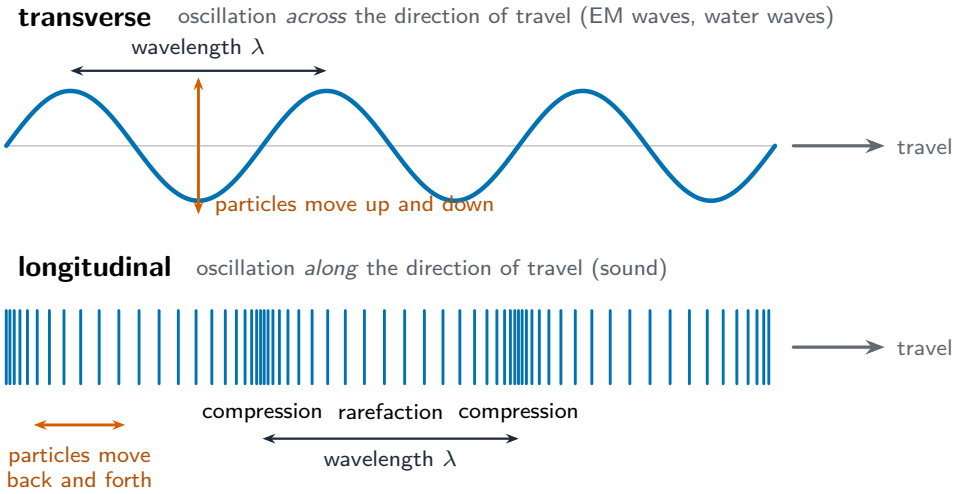
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Waves: carrying energy and information

Waves move energy from a source to a receiver without moving matter – light to an eye, sound to an ear, radio to a phone. This topic builds the wave model (frequency, wavelength, speed), then applies it across the electromagnetic spectrum, to sound and (P) ultrasound, reflection, refraction with total internal reflection, and (P) lenses and the eye.

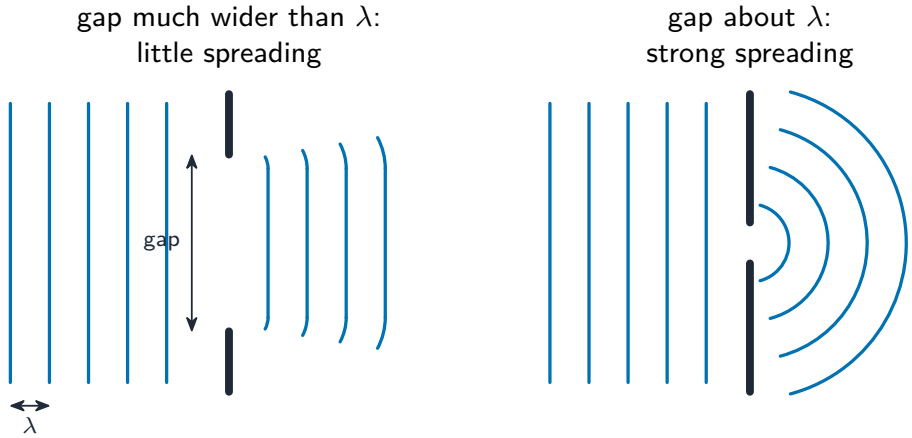
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General properties of waves



Transverse waves oscillate across their travel; longitudinal waves compress along it.

Transverse 横波: oscillations perpendicular to travel – electromagnetic and water waves. **Longitudinal** 纵波: oscillations parallel, as compressions and rarefactions – sound; mechanical waves may be either. At a boundary, waves are **reflected, transmitted or absorbed**; refraction 折射 comes from a **change of velocity** between media, and **diffraction** 衍射 spreads waves through a gap – strongly when the gap is comparable to the wavelength.



lines are wave crests one wavelength apart; the wavelength is the same after the gap

A wide gap gives little spreading; a gap near the wavelength spreads strongly.

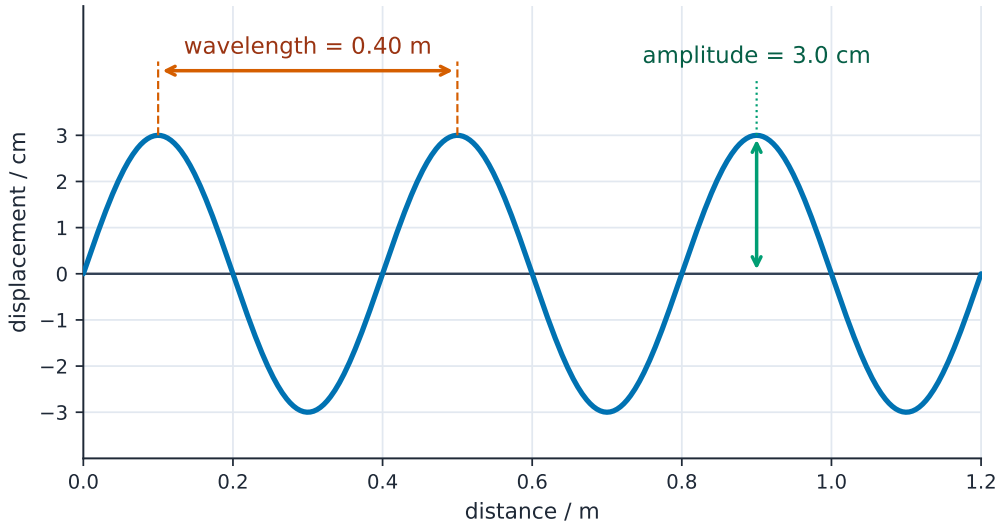
Amplitude, wavelength, frequency, period and wavefront define any wave, and:

$$v = f \times \lambda$$

Worked check. A water wave of frequency 2 Hz and wavelength 1.5 m travels at $2 \times 1.5 = 3$ m/s.

> **Worked example (an electromagnetic wave).** A radio station broadcasts at 100 MHz. All electromagnetic waves travel at 3.0×10^8 m/s in air, so $\lambda = v/f = 3.0 \times 10^8 \div 1.0 \times 10^8 = 3.0$ m. Change MHz to Hz first: 1 MHz $= 10^6$ Hz.

> **Worked example (reading a wave graph).** The graph shows the displacement of a water wave along a tank at one instant. Five waves pass a fixed point every 2.0 s.

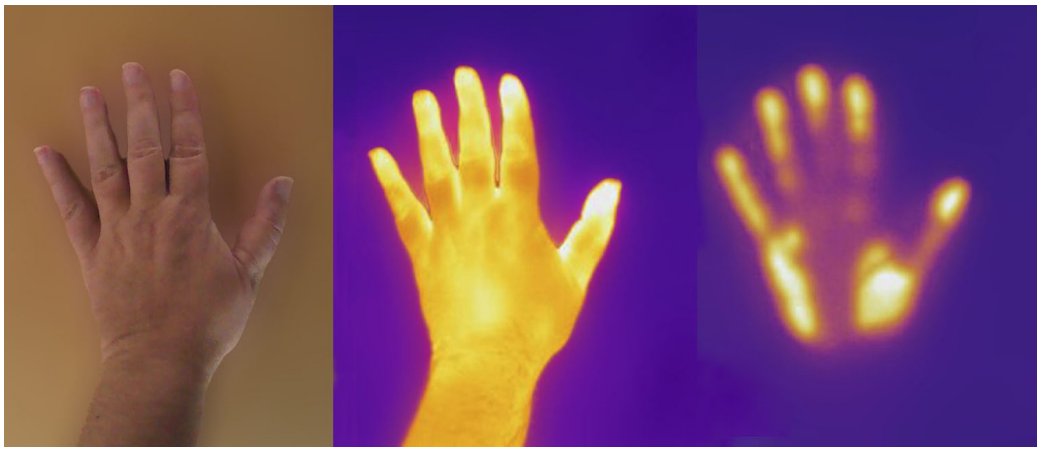


Wavelength is crest to crest; amplitude is from the rest position to a crest, not crest to trough

- Wavelength: three complete waves fit in 1.20 m, so $\lambda = 1.20 \div 3 = 0.40$ m. Check it crest to crest: from 0.10 m to 0.50 m.
- Amplitude: from the rest position (0) up to a crest, 3.0 cm. The crest-to-trough height, 6.0 cm, is twice the amplitude.
- Frequency: $f = 5 \div 2.0 = 2.5$ Hz, so $v = f\lambda = 2.5 \times 0.40 = 1.0$ m/s.

The electromagnetic spectrum

One continuous family, all transverse, all at the same speed in vacuum, ordered from radio (10^4 m and beyond) down to gamma (10^{-15} m). Visible light is the narrow band our eyes detect – different wavelengths are different colours. Every object emits and absorbs **infrared**; (P) hotter objects radiate more and at higher frequencies (**black-body radiation**), dark matt surfaces absorb and emit best, light shiny ones reflect.



A hand in visible light and through a thermal camera: every warm object emits infrared

Uses: radio – TV and radio including Bluetooth; microwaves – phones, satellite TV; infrared – remotes, night vision, heating; visible – photography, fibre optics; UV – security marking; X-rays – medical imaging; gamma – sterilising instruments and food. Hazards: microwaves heat tissue; infrared burns; UV causes skin cancer and blindness; X-rays kill cells in high doses; gamma causes mutations – limit exposure time and distance, and shield.

X-rays: very short wavelength, high energy, ionising; they affect photographic film, are absorbed by metal and bone, and are transmitted by soft tissue – the basis of CT, fracture and dental imaging, and of cancer treatment (with careful monitoring of workers' doses).

Sound and ultrasound

Sound is longitudinal, vibrating a medium, heard between **20 Hz and 20 000 Hz**; pitch follows frequency, loudness follows amplitude. Sound reflects (echoes) and diffracts. (P) **Ultrasound** 超声波 lies above 20 kHz: at a boundary between media it partially reflects, and the echo time locates the boundary:

$$s = v \times t$$

Worked check. An ultrasound pulse returns from a fetus boundary after 6.0×10^{-5} s (speed 1500 m/s in tissue): boundary depth $= 1500 \times 6.0 \times 10^{-5} / 2 = 0.045$ m $= 4.5$ cm – divide by two for the round trip. Uses: prenatal scanning, breaking kidney stones.

> **Worked example (P) (sonar).** A ship sends an ultrasound pulse to the sea bed and hears the echo 0.40 s later. Speed in sea water is 1500 m/s. The pulse travels $1500 \times 0.40 = 600$ m there and back, so the sea is $600 \div 2 = 300$ m deep.

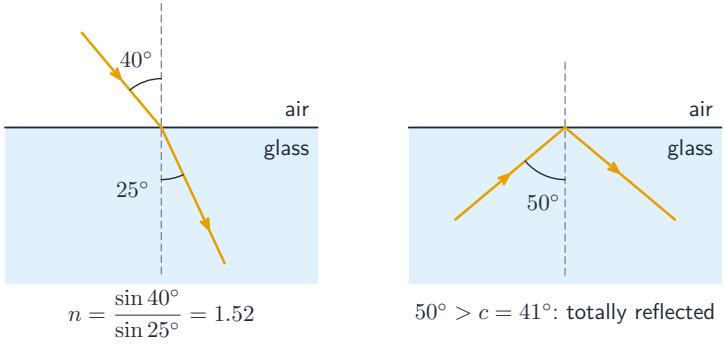
Reflection and refraction

Law of reflection: **angle of incidence = angle of reflection**, measured from the **normal**. A plane mirror gives a **virtual, upright, laterally inverted** image; construct ray diagrams with the normal drawn in. (P) Light entering a **denser** medium slows and bends **towards the normal**; into a less dense one, **away**; a prism **disperses** white light into a spectrum. Refractive index compares speeds:

$$n = \frac{\text{speed of light in vacuum}}{\text{speed in the medium}} = \frac{\sin i}{\sin r} \qquad \sin c = \frac{1}{n}$$

Beyond the **critical angle** in the denser medium, light is totally internally reflected – how **optical fibres** carry visible light and infrared for medicine (endoscopes) and communications. Required practical: refraction of light by different substances.

> **Worked example (P) (refractive index).** Light enters a glass block with angle of incidence 40° and angle of refraction 25°: $n = \sin 40°/\sin 25° = 0.643/0.423 = 1.52$. Light in this glass travels at $3.0 \times 10^8 \div 1.52 = 2.0 \times 10^8$ m/s, and the critical angle is $c = \sin^{-1}(1/1.52) = 41°$. A ray inside the glass meeting the surface at 50° (more than 41°) is totally internally reflected.

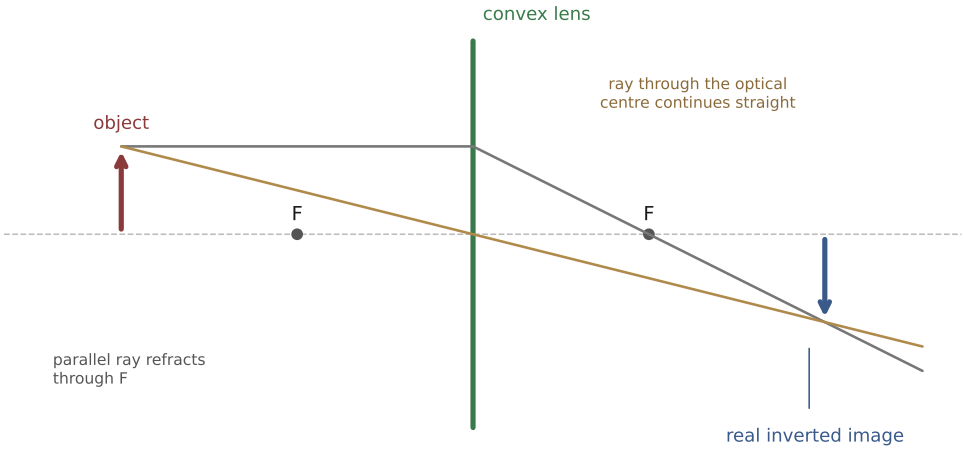


Angles are measured from the normal; inside the glass, rays beyond the critical angle cannot get out

Lenses and the eye (P)

A **convex** (converging) lens brings parallel rays to the **principal focus** (focal length from the lens); a **concave** (diverging) lens spreads them as if from the focus. Images are described as larger/smaller, upright/inverted, real/virtual – ray diagrams on graph paper show them, and **magnification = image height ÷ object height**. A converging lens held close acts as a magnifying glass (virtual, upright, enlarged).

> **Worked example (P) (magnification).** A 2.0 cm tall object gives an image 6.0 cm tall. Magnification = 6.0 ÷ 2.0 = 3.0; it has no unit. An image half the object's height has magnification 0.5.



A convex lens forms a real, inverted image of an object beyond the focus.

The eye: **retina** (detector), **cornea** (main refraction), **variable-focus lens**, **pupil/iris** (aperture), **ciliary muscle** and **suspensory ligaments** (change lens shape). Near point ≈ 25 cm; far point at infinity. **Long sight** (eyeball too short) is corrected with a **convex** lens; **short sight** (too long) with a **concave** lens; lasers can reshape the cornea in surgery. Against a camera: the eye focuses by changing lens shape, the camera by changing the lens–film distance; the retina plays the CCD's role.

Common mistakes

- Forgetting to convert kHz or MHz to Hz in $v = f\lambda$.
- Not halving the distance in an echo question. The time is for there *and* back.
- Measuring angles from the surface. Angles of incidence, reflection and refraction are measured from the normal.
- (P) Saying light bends towards the normal when it leaves glass. It speeds up and bends *away* from the normal.
- (P) Saying total internal reflection happens as light enters a denser material. It happens inside the denser material, at more than the critical angle.
- (P) Correcting short sight with a convex lens. Short sight needs a concave (diverging) lens; long sight needs a convex one.

- Saying higher-frequency electromagnetic waves travel faster. They all travel at the same speed in a vacuum.

Check yourself

1. Give the oscillation directions of transverse and longitudinal waves, with one example of each.
2. State v = fλ and calculate the speed of a 500 Hz wave of wavelength 0.68 m.
3. When is diffraction strongest through a gap?
4. Order the EM spectrum by increasing frequency.
5. Which surfaces best absorb infrared?
6. State the frequency range of human hearing.
7. (P) An ultrasound echo returns in 0.0001 s from 15 cm deep. What is the speed?
8. State the law of reflection and the nature of a plane-mirror image.
9. (P) Glass has n = 1.5. Calculate the critical angle.
10. (P) Which lens corrects short sight, and why?

Answers: 1 perpendicular – light; parallel, compressions – sound; 2 $v = 500 \times 0.68 = 340$ m/s; 3 gap ≈ one wavelength; 4 radio → microwave → IR → visible → UV → X-ray → gamma; 5 dark, matt; 6 20 Hz–20 kHz; 7 (P) $v = 0.3/10^{-4} = 3000$ m/s (round trip).
Answers continued: 8 i = r; virtual, upright, laterally inverted; 9 (P) $\sin c = 1/1.5$, $c \approx 41.8°$; 10 (P) a concave lens – it spreads light so the too-long eye focuses it on the retina.

Particle model of matter

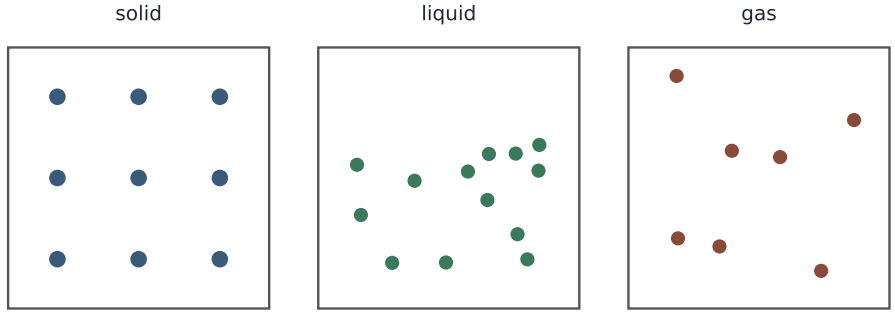
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The particle model of matter

Everything is particles. Their energy, separation and motion explain the states of matter, heating and cooling, and why bridges need gaps. OxfordAQA's fourth topic builds the model and quantifies it: specific heat capacity, the (P) latent heats, evaporation, energy-transfer design and thermal expansion.

OxfordAQA International GCSE Physics 9203, topic 3.4 (Version 5.1). Statements marked (P) are Paper-2-only.

Kinetic theory



Solids: fixed, touching particles; liquids: touching but disordered; gases: far apart and fast.

Specific heat capacity 比热容 c is the energy to raise 1 kg of a substance by 1 °C:

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

Worked check. Heating 1.5 kg of water ($c = 4200$) by 40 °C: $E = 1.5 \times 4200 \times 40 = 252\,000$ J.

Worked example (measuring c). A 50 W heater warms a 2.0 kg aluminium block for 600 s, and its temperature rises by 15 °C. Energy in $= P \times t = 50 \times 600 = 30\,000$ J, so $c = \dfrac{E}{m\Delta\theta} = \dfrac{30\,000}{2.0 \times 15} = 1000$ J/(kg °C). The accepted value is about 900 J/(kg °C): some energy heats the air, so the measured value is too high. Insulating the block makes it closer.

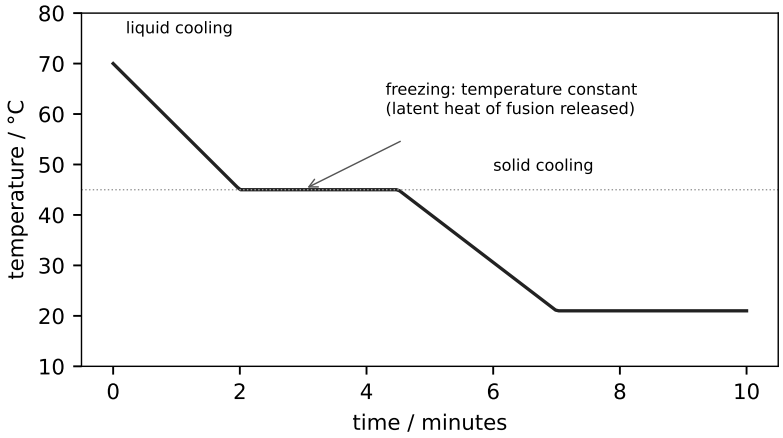
(P) Changing **state** needs energy with **no temperature change**: **latent heat of vaporisation** 汽化热 $E = m \times L_V$ (liquid → vapour) and **latent heat of fusion**

熔化热 $E = m \times L_F$ (solid → liquid). Impurities change melting and boiling points. Required practical (P): a cooling curve for stearic acid.

> **Worked example (P) (two stages).** How much energy turns 0.10 kg of ice at 0 °C into water at 20 °C? ($L_F = 334\,000$ J/kg, $c = 4200$ J/(kg °C).)

- Melting at 0 °C: $E = mL_F = 0.10 \times 334\,000 = 33\,400$ J.
- Warming the water: $E = mc\Delta\theta = 0.10 \times 4200 \times 20 = 8400$ J.

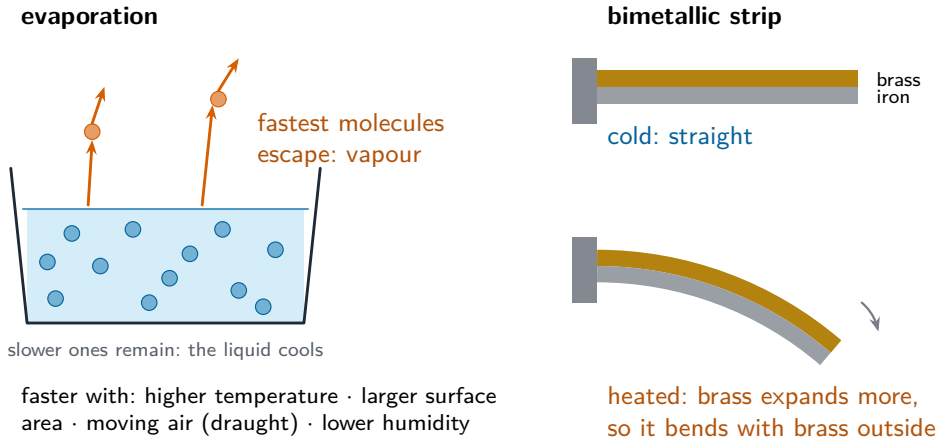
Total $= 33\,400 + 8400 = 41\,800$ J. Melting the ice takes four times more energy than warming the water by 20 °C.



A cooling curve: the plateau while freezing releases latent heat at constant temperature.

Energy transfers and particle motion

Conduction 传导 passes energy along a solid by particle vibration, helped by **free electrons** in metals; insulators lack mobile conduction electrons, so energy transfer by particle vibrations is slower. **Convection** 对流 circulates fluid: particles gain energy, move apart, the fluid becomes **less dense and rises**, cooler fluid sinks. **Evaporation** 蒸发 turns fast surface molecules to vapour, cooling what remains – faster with higher temperature, larger surface area, draughts and lower humidity; **condensation** reverses it.



Evaporation factors and the bimetallic strip that bends on heating.

The rate of energy transfer by heating grows with surface area and volume, the material, the surface in contact, and the **temperature difference**. Design follows: cooling fins maximise area; animals' relative ear size matches climate. Most substances **expand** when heated – a hazard for roofs and bridges (gaps and rollers), useful in the **bimetallic-strip thermostat** that bends as one metal expands more and breaks a circuit.

Common mistakes

- Using the final temperature instead of the *change* in temperature in $E = mc\Delta\theta$.
- Using mass in grams. c and L are per kilogram.
- (P) Using $E = mc\Delta\theta$ while a substance melts or boils. The temperature does not change then; use $E = mL$.
- (P) Reading the flat part of a cooling curve as "nothing happening". The substance is changing state and giving out energy.
- Saying metals feel cold because they are colder. They are good conductors, so they take energy from your hand faster.
- Saying heat rises. Hot fluid rises, because it expands and becomes less dense.
- Saying evaporation needs the liquid to boil. It happens at any temperature, from the surface, and it cools the liquid left behind.

Check yourself

1. Describe the particle arrangement in a liquid.
2. Define specific heat capacity.
3. Calculate the energy to heat 2 kg of aluminium (c = 900) by 30 °C.
4. (P) Why does the temperature stay constant while a substance freezes?

5. (P) 0.5 kg of a substance has L_F = 330 000 J/kg. Calculate the energy to melt it.
6. Explain conduction in metals, naming the extra carriers.
7. Explain why warm water rises.
8. Give three factors that speed evaporation.
9. Give one hazard and one use of thermal expansion.
10. Why do cooling fins have large surface area?

Answers: 1 particles touch but arranged randomly, moving past each other; 2 the energy needed to change the temperature of 1 kg of the substance by 1 °C; 3 $E = 2 \times 900 \times 30 = 54\,000$ J; 4 (P) the energy released as bonds form (latent heat of fusion) leaves at the same rate energy is removed, so the particles' kinetic energy is unchanged; 5 (P) $E = 0.5 \times 330\,000 = 165\,000$ J; 6 vibrating particles pass energy to neighbours, and free electrons carry energy quickly through the metal; 7 the warmer particles move apart, making that water less dense than its surroundings, so it rises; 8 higher temperature, larger surface area, air movement over the surface (also lower humidity); 9 hazard – expansion of bridges/roofs needs gaps; use – the bending bimetallic strip in a thermostat; 10 larger area transfers energy to the surroundings faster by heating.

Electricity and magnetism

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Electricity is charge on the move, guided by potential difference, resisted by every component – and every current makes a magnetic field. OxfordAQA's largest topic builds the circuit toolkit, the component behaviours, and the electromagnets that follow.

OxfordAQA International GCSE Physics 9203, topic 3.5 (Version 5.1). Statements marked (P) are Paper-2-only.

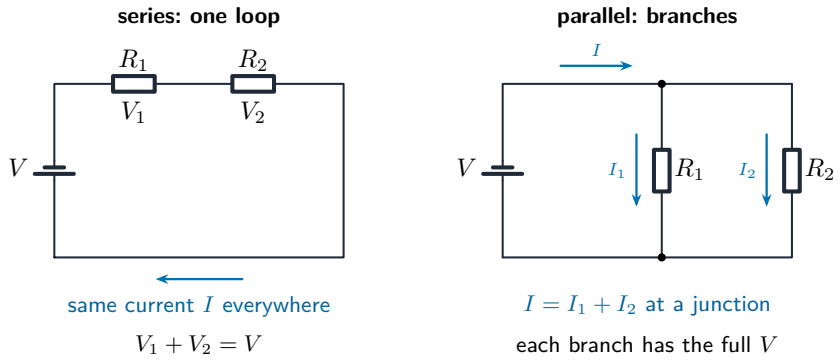
Electrical circuits

Metals conduct because they have **free electrons**; (P) an isolated charge imbalance is **static electricity**, discharged when a conducting route appears (lightning). Current is the rate of flow of charge:

$$I = \frac{Q}{t} \qquad V = \frac{E}{Q} \qquad V = I \times R$$

Voltage drives charge round a circuit; **potential difference** across a component measures the energy transferred per unit charge (volts = joules per coulomb). Learn the standard symbols – switch, lamp, fuse, cell, battery, diode, resistor, variable resistor, thermistor, LDR, LED, ammeter and voltmeter.

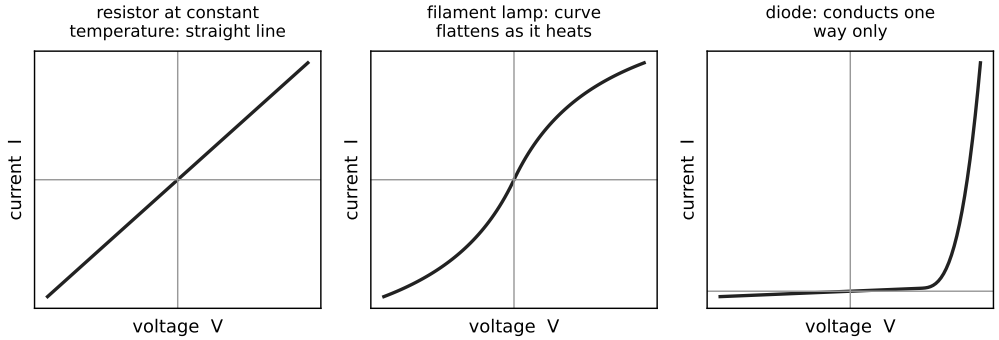
Worked example (charge and energy). A torch bulb carries 0.50 A for 2.0 minutes from a 9.0 V battery. Change the time to seconds: $t = 120$ s. Charge $Q = It = 0.50 \times 120 = 60$ C. Energy transferred $E = VQ = 9.0 \times 60 = 540$ J.



Series: one loop, same current, resistances add. Parallel: branches share the p.d., currents add.

At constant temperature a resistor's V–I graph is a straight line (ohmic); a **filament**

lamp curves as its ions vibrate more with temperature; a **diode** conducts forward only; (P) a **thermistor's** resistance falls as temperature rises (thermostats); an **LDR's** falls as light rises (automatic lighting); an **LED** emits light forward and saves energy versus filament and CFL lamps.



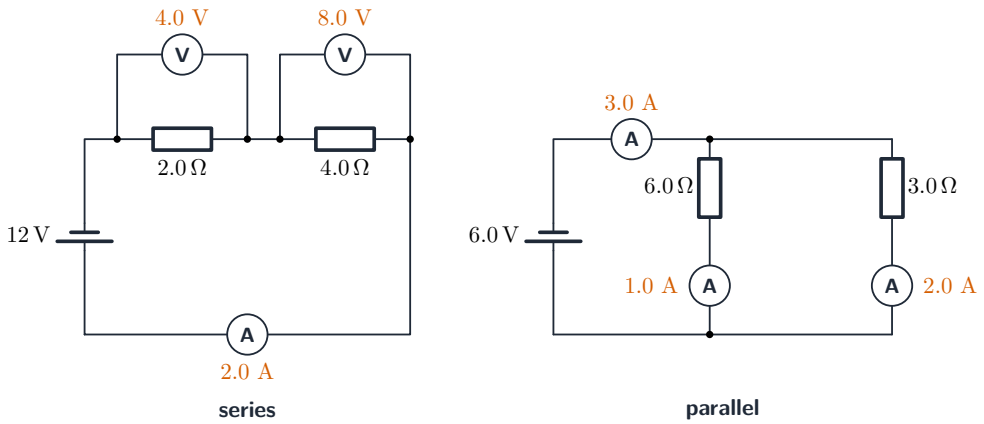
The required V-I characteristics: resistor straight line, lamp S-curve, diode one-way.

Series: same current, p.d.s shared, resistances add. **Parallel**: same p.d., currents split, combined resistance less than either. Charge colliding with the lattice heats every resistor.

Worked check. A 230 V lamp draws 0.25 A: $R = 230/0.25 = 920\ \Omega$. Two 4 Ω resistors in series across 12 V carry $I = 12/8 = 1.5$ A; in parallel, $R = 2\ \Omega$ and the supply gives $I = 12/2 = 6$ A.

Worked example (sharing the p.d. in series). A 2.0 Ω and a 4.0 Ω resistor are in series with a 12 V battery. Total resistance $= 2.0 + 4.0 = 6.0\ \Omega$, so $I = 12 \div 6.0 = 2.0$ A everywhere in the loop. P.d. across the 2.0 Ω resistor $= 2.0 \times 2.0 = 4.0$ V; across the 4.0 Ω resistor $= 2.0 \times 4.0 = 8.0$ V. Check: $4.0 + 8.0 = 12$ V. The bigger resistor takes the bigger share.

Worked example (splitting the current in parallel). A 6.0 Ω and a 3.0 Ω resistor are in parallel across 6.0 V. Each has the full 6.0 V: $I_1 = 6.0 \div 6.0 = 1.0$ A and $I_2 = 6.0 \div 3.0 = 2.0$ A. The battery supplies $1.0 + 2.0 = 3.0$ A, so the combined resistance is $6.0 \div 3.0 = 2.0\ \Omega$, less than either resistor.

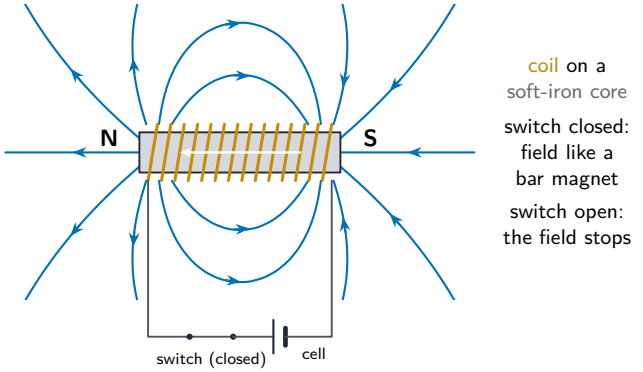


In series one current and shared p.d.s; in parallel the full p.d. on each branch and currents that add

Magnetism and electromagnetism

Poles: like repel, unlike attract – non-contact forces. Field lines run N to S outside a magnet; opposite poles facing give a **uniform** field between them. An **induced magnet** attracts while in the field and loses magnetism on removal; the Earth's field lets a plotting compass navigate.

A current-carrying wire has circular field lines around it (stronger current → stronger field; reverse current → reverse direction). A **solenoid** 螺线管 concentrates the field; with a soft-iron core it is an **electromagnet** 电磁铁 – switchable, adjustable, used in scrapyard cranes, relays and door locks. Required practical: the factors determining an electromagnet's strength.



A solenoid on a soft-iron core: the electromagnet field is that of a bar magnet, but switchable.

Common mistakes

- Leaving time in minutes in $Q = It$. Use seconds.
- Saying current is used up by a component. The current is the same all round a series loop; energy is transferred, not charge.
- Adding resistances in parallel. The combined resistance of a parallel pair is *less* than the smaller one.
- Giving every component in series the full battery p.d. The p.d.s share the battery p.d.; in parallel each branch has the full p.d.
- Drawing a voltmeter in series or an ammeter in parallel. Ammeters go in series; voltmeters go across (in parallel with) the component.
- (P) Saying a thermistor's resistance rises when it gets hot, or an LDR's rises in bright light. Both fall.
- Saying a diode lets current through both ways. It conducts in the forward direction only.

Check yourself

1. Why do metals conduct?
2. State the relationship between current, charge and time with units.
3. Calculate the charge flowing when 2 A passes for 30 s.
4. State the V-I shape for a resistor at constant temperature and for a filament lamp.
5. (P) What happens to a thermistor's resistance as temperature rises?
6. State the current and p.d. rules for series and for parallel connections.
7. Calculate R for a 12 V supply pushing 0.5 A.
8. State the pole rule and the direction of field lines outside a magnet.
9. What is an induced magnet?
10. Name two ways to strengthen an electromagnet.

Answers: 1 they contain free electrons that drift when a p.d. is applied; 2 Q = It, charge in coulombs = current in amperes × time in seconds; 3 Q = 2 × 30 = 60 C; 4 straight line through the origin; S-curve flattening as current (and so temperature) rises; 5 (P) it falls – used in thermostats; 6 series – same current everywhere, p.d.s add; parallel – same p.d. across branches, currents add; 7 R = 12/0.5 = 24 Ω; 8 like poles repel, unlike attract; N to S outside the magnet; 9 a magnetic material that becomes a magnet only while placed in a field – attraction only, losing most magnetism on removal; 10 more turns on the coil; larger current (also a soft-iron core).

Generating and distributing electricity and household use

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Generating and distributing electricity

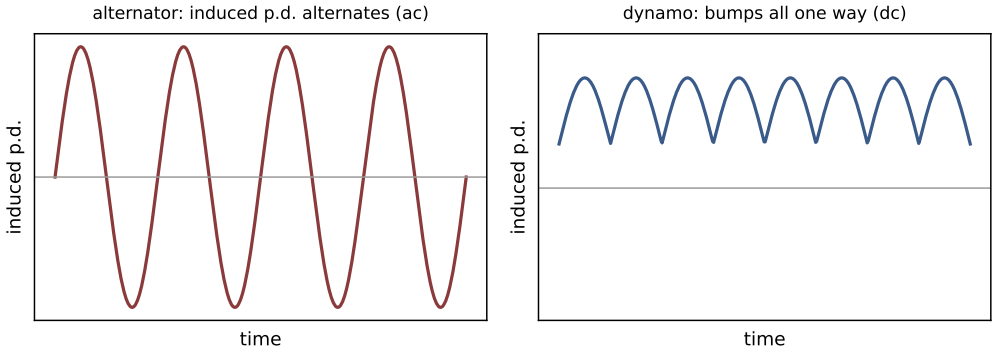
Move a magnet, move a current – a p.d. appears. OxfordAQA's sixth topic runs the full chain from the generator effect through the national grid's transformers to the appliances and safety systems of the home. All statements in this topic are Paper-2 (P).

OxfordAQA International GCSE Physics 9203, topic 3.6 (Version 5.1) – entirely (P) content.

Generating electricity (P)

The **generator effect** 发电机效应 induces a p.d. across a conductor that moves through a magnetic field, or sits in a changing field. Reverse the motion or the polarity and the induced p.d. reverses; the induced current's own field **opposes** the change. The p.d. grows with faster movement, stronger field, more turns and larger coil area.

An **alternator** spins a coil in a field to make a.c.; a **dynamo** gives d.c. – know the p.d.–time graphs. Power stations spin turbines to turn coils between magnets.



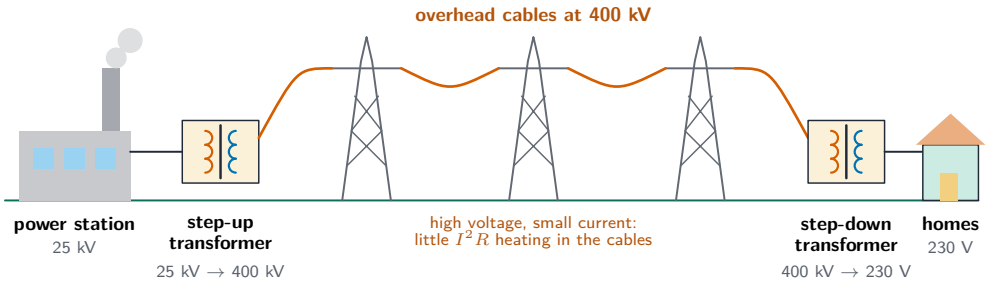
An alternator induced p.d. alternates; a dynamo bumps one way.

Transmission, transformers and the home (P)

From the station to the socket, every watt travels the same chain of coils and cables.



Pylons carry the National Grid's cables at very high voltage, so the current and the heating losses are small



The grid chain: power station, step-up transformer, high-voltage cables, step-down transformer, homes.

For a given power, high transmission voltage means **low current** and so little cable heating. A **transformer** 变压器 is two coils on a soft-iron core: alternating current in the primary makes a changing field that induces a p.d. in the secondary.

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

Step-up before the lines, step-down after; **switch-mode transformers** (50–200 kHz) are small and light – phone chargers.

Worked check. A transformer steps 25 kV up to 400 kV with 1000 primary turns: $n_s = 1000 \times 400/25 = 16\,000$ turns. At 100 MW the line current is $I = P/V = 10^8/(4 \times 10^5) = 250$ A.

Worked example (P) (a step-down transformer). A laptop transformer changes 230 V to 11.5 V; the primary has 2000 turns. $n_s = 2000 \times 11.5/230 = 100$ turns. If it gives 2.0 A to the laptop and is 100% efficient, the primary current is $I_p = V_s I_s / V_p = 11.5 \times 2.0/230 = 0.10$ A. Lower voltage on one side always means higher current on that side.

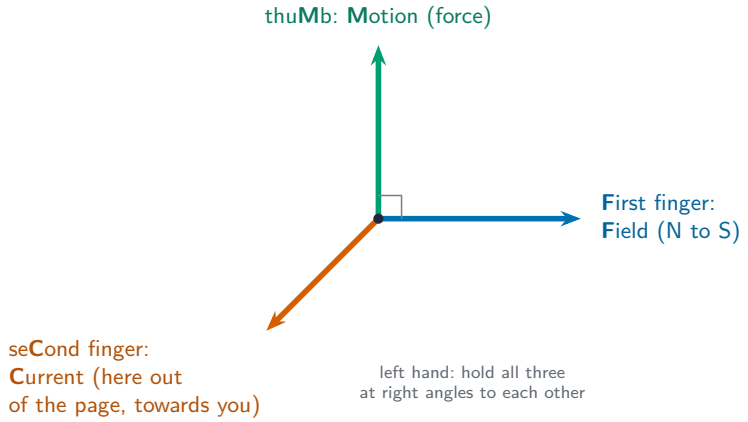
Worked example (P) (reading a trace). One complete cycle of the mains trace on an oscilloscope covers 4 squares at 5 ms per square. Period $= 4 \times 5 = 20$ ms $= 0.020$ s, so frequency $= 1 \div 0.020 = 50$ Hz.

Cells give d.c.; mains is a.c. with fixed frequency and voltage – read period and frequency from oscilloscope-style traces. Safety: **earthing** 接地 drains fault current from metal casings; a **fuse** 保险丝 melts or a **circuit breaker** trips on excess current – the breaker is resettable, and its trip time depends on its design and the fault current; double-insulated appliances need no earth.

The motor effect (P)

A current-carrying wire across a magnetic field feels a force (zero if parallel to it). Force grows with stronger field, bigger current and more wire in the field; reverse either to reverse the force – **Fleming's left-hand rule** 左手定则 predicts the direction.

Worked example (P) (using the left-hand rule). A wire sits between a N pole on the left and a S pole on the right, so the field points to the right; the current flows into the page. First finger to the right, second finger into the page: the thumb points **down**, so the wire is pushed downwards. Reverse the current (or the poles) and the force is up.



Fleming left-hand rule: field, current and force mutually at right angles.

A current-carrying **coil** in a field rotates – the electric motor.

Transferring electrical energy (P)

$$P = \frac{E}{t} \qquad P = I \times V \qquad E = V \times Q \qquad E\,(\text{kWh}) = P\,(\text{kW}) \times t\,(\text{h})$$

Appliance labels give power; compute the current to choose a fuse, and the energy in **kilowatt-hours** for billing (E = Pt; cost = kWh × price per unit, read from meter readings).

Worked check. A 2.0 kW heater for 3 h uses 6.0 kWh; at 0.9 per kWh that costs 5.4. A 230 V, 1.1 kW kettle draws I = 1100/230 ≈ 4.8 A – fit a 5 A or 13 A fuse (next rating above).

> **Worked example (P) (meter readings).** An electricity meter reads 12 345 kWh at the start of a month and 12 465 kWh at the end. Energy used = 12 465 − 12 345 = 120 kWh; at 0.9 per kWh the bill is 120 × 0.9 = 108. A 1500 W heater left on for 30 minutes uses 1.5 kW × 0.5 h = 0.75 kWh: change W to kW and minutes to hours first.

Common mistakes

- (P) Saying a transformer works on d.c. It needs a.c., because only a changing current makes a changing field in the core.
- (P) Saying a step-up transformer increases the power. It raises the voltage and lowers the current; at best the power stays the same.
- (P) Saying high voltage is used because it travels faster. It means low current, so less energy is lost heating the cables.
- (P) Using watts and seconds for kWh. Use kilowatts and hours: $E\,(\text{kWh}) = P\,(\text{kW}) \times t\,(\text{h})$.
- (P) Choosing a fuse below the working current. Use the next rating *above* the current.
- (P) Saying the motor force is biggest when the wire is parallel to the field. There is no force then; it is biggest at right angles.
- (P) Saying a voltage is induced in a still wire in a steady field. The wire must move, or the field must change.

Check yourself

1. State two ways to induce a p.d. in a conductor.
2. Give three factors that increase the size of an induced p.d.
3. Sketch the p.d.–time graphs of an alternator and a dynamo.
4. Why does the grid transmit at high voltage?
5. A transformer has 200 primary and 3000 secondary turns on 12 V a.c. Calculate the secondary p.d.
6. State the turns-ratio and power equations for a 100 % efficient transformer.
7. Explain how earthing and a fuse protect a user together.
8. State Fleming's left-hand rule.
9. Calculate the current of a 230 V, 2.3 kW heater, and a sensible fuse.
10. Calculate the energy in kWh used by a 1.5 kW kettle in 20 minutes.

Answers: 1 move the conductor through a field; place it in a changing magnetic field; 2 faster motion; stronger field; more turns (also larger coil area); 3 alternator – a sine wave about zero; dynamo – humps all above (or all below) the axis; 4 for the same power the current is smaller, so I^2R heating losses in the cables are far lower; 5 $V_s = 12 \times 3000/200 = 180$ V; 6 $V_p/V_s = n_p/n_s$ and $V_pI_p = V_sI_s$; 7 the earth wire gives the fault current a path to earth, and the surge blows the fuse, disconnecting the live wire; 8 first finger Field, second finger Current, thumb Motion – mutually at right angles; 9 I = 2300/230 = 10 A – use a 13 A fuse; 10 t = 1/3 h, so E = 1.5 × 1/3 = 0.5 kWh.

Nuclear physics

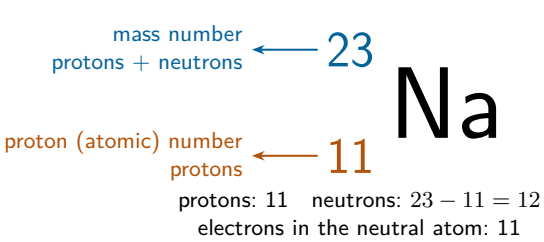
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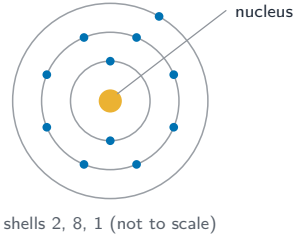
The nucleus is about a hundred-thousandth of the atom's width yet holds nearly all its mass – and unstable nuclei pour out energy as radiation, fission fragments, or the fusion that lights the stars. OxfordAQA's seventh topic covers the nuclear model, the three radiations, half-life, contamination versus irradiation, reactors and (P) fusion.

OxfordAQA International GCSE Physics 9203, topic 3.7 (Version 5.1). Statements marked (P) are Paper-2-only.

Atomic structure

An atom is about $\mathbf{10^{-10}}$ **m** across: a tiny positive nucleus (protons and neutrons, nearly all the mass) with electrons around it – Rutherford's **alpha-scattering** evidence for the concentrated nucleus. Proton mass 1 charge +1; neutron mass 1 charge 0; electron charge −1, negligible mass. A neutral atom has equal protons and electrons; atoms lose or gain electrons to become **ions**.





Nuclear notation: mass number above and proton number below the symbol.

${}^{A}_{Z}X$: A = mass number (protons + neutrons), Z = proton number; isotopes share Z and differ in neutrons.

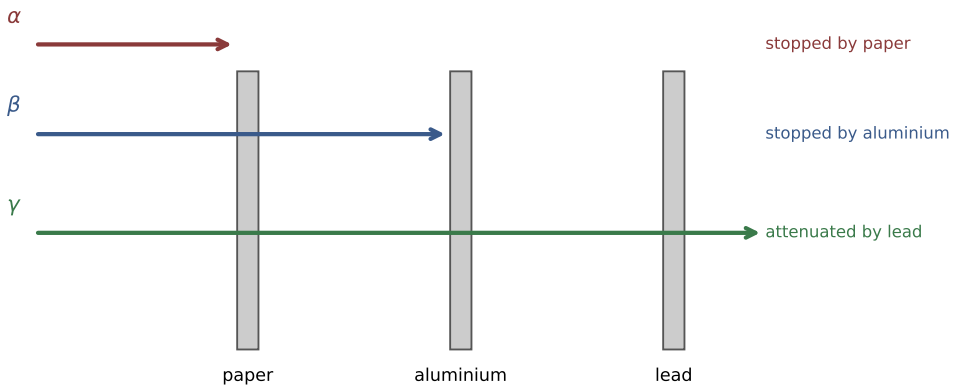
Ionising radiation from the nucleus

Unstable nuclei decay **randomly**, unaffected by chemistry or physics, emitting:



A Geiger counter detects ionising radiation and shows the count rate

Radiation	Nature	Ionising	Range in air
alpha	2p + 2n (helium nucleus)	strongest	a few cm
beta-minus	fast electron (neutron → proton)	medium	tens of cm
gamma	electromagnetic wave	weakest	metres

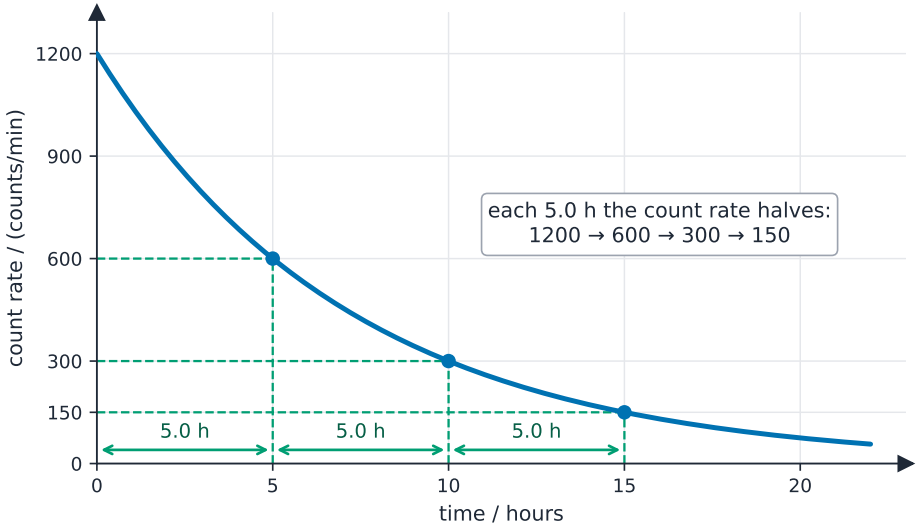


Alpha stopped by paper, beta by aluminium, gamma attenuated by lead.

Nuclear equations conserve mass number and charge: ${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$ (alpha); ${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$ (beta). **Background radiation** comes from rocks, space, food and medical devices. (P) The **half-life** 半衰期 is the time for the expected undecayed population or source activity to halve. With fixed detector geometry and efficiency, the background-corrected count rate halves on average over the same time; half-lives span a very wide range. **Contamination** 沾污 means unwanted radioactive material on or inside an object or person; the hazard can remain until it is removed, cleared or decayed. **Irradiation** 照射 means exposure to radiation without transferring radioactive material in these source-exposure examples. Dangers: mutations, cell and tissue damage.

Worked example (filling the gaps). Polonium-210 emits an alpha particle: ${}^{210}_{84}\mathrm{Po} \rightarrow {}^{A}_{Z}\mathrm{Pb} + {}^{4}_{2}\mathrm{He}$. Top numbers: $210 = A + 4$, so $A = 206$. Bottom numbers: $84 = Z + 2$, so $Z = 82$. The product is ${}^{206}_{82}\mathrm{Pb}$.

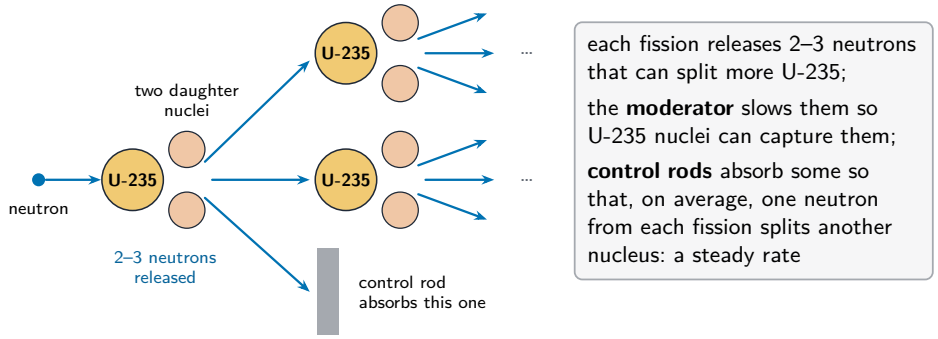
Worked example (P) (half-life). A sample's count rate falls from 1200 to 150 counts per minute in 15 hours (background already subtracted). $1200 \rightarrow 600 \rightarrow 300 \rightarrow 150$ is three half-lives, so the half-life is $15 \div 3 = 5.0$ hours. After one more half-life, 75 counts per minute are left; after four half-lives in total, $\frac{1}{16}$ of the original activity.



Read the half-life several times along the curve: each halving takes the same 5.0 hours

Nuclear fission and (P) fusion

Fission 裂变 splits a large unstable nucleus: **U-235** or **Pu-239** absorbs a neutron, splits into two smaller nuclei with 2–3 neutrons and far more energy than any chemical reaction. Neutrons striking further nuclei give a **chain reaction**; in a reactor **control rods** absorb neutrons so that, on average, only one neutron from each fission goes on to cause another fission.



A chain reaction with control rods absorbing neutrons.

Radioactive waste stays dangerous for times set by its half-life – a managed-disposal cost of nuclear power. (P) **Fusion** 聚变 joins two light nuclei into a heavier one, converting mass to energy: it powers the stars, but positive nuclei repel, so it needs **extreme temperature and pressure**.

Common mistakes

- Saying a beta particle comes from the electron shells. It is made in the nucleus as a neutron turns into a proton, so Z goes up by 1.
- Changing the mass number in beta or gamma decay. Only alpha decay changes it (down by 4).
- (P) Thinking two half-lives remove the whole sample. After two half-lives a quarter is left.
- Forgetting to subtract the background count before finding a half-life.
- Saying gamma is the most dangerous inside the body. Alpha is the most ionising, so it does the most damage inside the body; outside, it cannot pass the skin.
- Thinking an irradiated object becomes radioactive. Only contamination leaves radioactive atoms behind.
- Saying control rods slow neutrons down. They absorb neutrons to control the rate of the chain reaction.

Check yourself

1. Give the relative masses and charges of the proton, neutron and electron.
2. In $^{19}_{9}F$, how many protons and neutrons?
3. What did alpha scattering reveal about the atom?
4. Name the three radiations and their natures.
5. Which radiation is stopped by paper, and which penetrates aluminium?
6. Balance the alpha decay of $^{226}_{88}Ra$.
7. (P) Define half-life.
8. (P) Explain the difference between contamination and irradiation.
9. What do control rods do in a reactor?
10. (P) Why does fusion need extreme temperatures?

Answers: 1 proton 1, +1; neutron 1, 0; electron ~0, −1; 2 9 protons, 10 neutrons; 3 mass and charge sit in a tiny nucleus – most alphas pass, a few bounce; 4 alpha = He nucleus; beta = fast electron; gamma = EM wave; 5 alpha; gamma (thick lead); 6 $^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$; 7 (P) the time for the expected undecayed population or source activity to halve; a fixed detector has the same half-life for its background-corrected count rate; 8 (P) contamination – unwanted radioactive material on or inside you, which can remain until removed, cleared or decayed; irradiation – exposure without material transfer in these examples, ending when the source is removed or shielded; 9 absorb neutrons, so that on average one neutron from each fission causes one further fission and the chain reaction stays steady; 10 (P) positive nuclei repel, so they must collide very fast.

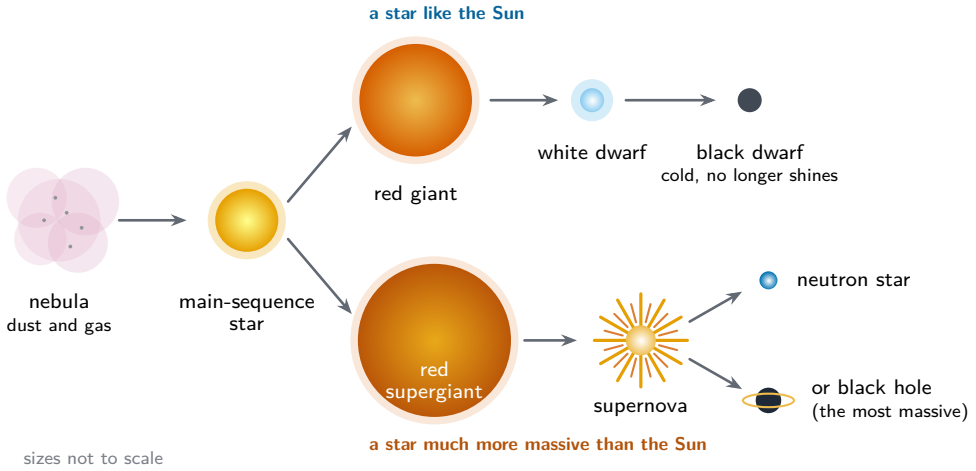
Space physics

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Gravity gathers dust into stars, stars fuse the elements, and the red-shift of distant galaxies tells us the whole universe is expanding from a beginning 14 thousand million years ago. OxfordAQA's final topic closes the course with stellar life cycles, orbits and the Big Bang evidence.

OxfordAQA International GCSE Physics 9203, topic 3.8 (Version 5.1). Statements marked (P) are Paper-2-only.

Life cycle of a star



Two tracks: Sun-like stars end as black dwarfs; massive stars end in supernovae and neutron stars or black holes.



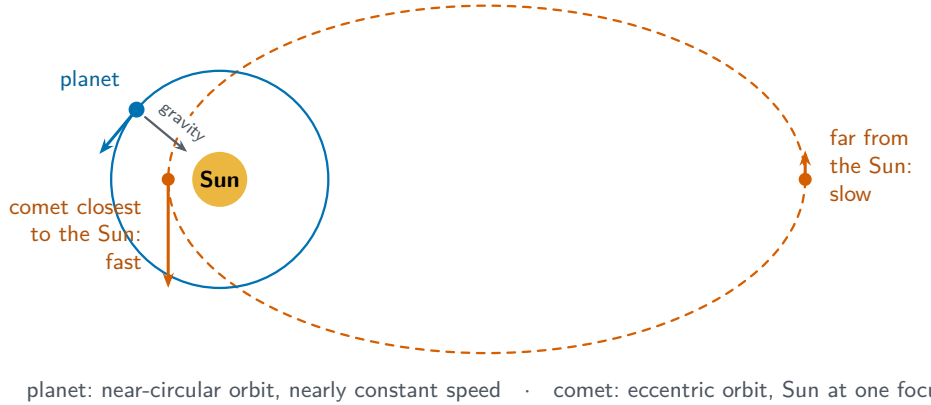
The Pillars of Creation: clouds of dust and gas (nebulae) where gravity is pulling new stars together

Stars form when **gravity** pulls dust and gas (mainly hydrogen and helium) together – smaller lumps become planets. In the long **main sequence**, hydrogen fuses to helium in the core and gravity balances the outward forces. The more massive a star, the hotter its core and the heavier the nuclei it can build by fusion.

When hydrogen runs out, mass decides the ending. A **Sun-like star** swells to a **red giant**, sheds its layers, and the exposed core cools from **white dwarf** to **black dwarf**. A **massive star** swells to a **red supergiant**, fuses ever-heavier elements (carbon, nitrogen, oxygen), then blasts apart as a **supernova** – scattering the elements (those heavier than iron are made in the explosion itself) – leaving a **neutron star** or **black hole**. Fusion in stars and supernovae made almost every naturally occurring element heavier than helium: the early universe held almost only hydrogen and helium.

Solar system and orbital motion

The solar system: eight planets orbiting the Sun, plus moons, asteroids, dwarf planets and comets. The Milky Way is one of thousands of millions of galaxies, each with thousands of millions of stars. Artificial satellites orbit Earth in **geostationary** or **low polar** orbits.



A planet near-circular orbit and a comet eccentric one, with gravity providing the centripetal pull.

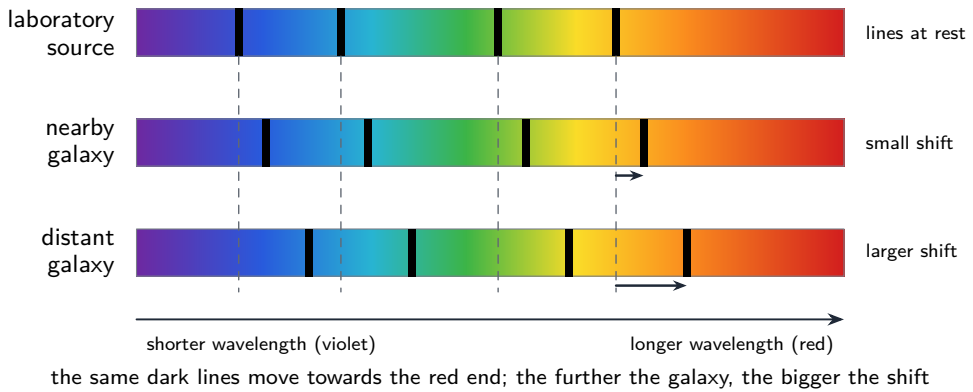
Gravity supplies the **centripetal force**: it acts towards the centre, changing the direction of motion (velocity) without changing speed. Greater separation means weaker gravity, so **lower orbital speed**: to stay at a particular radius, a satellite must move at the matching speed – change the speed and the orbit changes radius.

> **Worked example (comparing orbits).** A low polar satellite orbits about 800 km up and goes round about every 100 minutes; a geostationary satellite is about 36 000 km up and takes 24 hours, so it stays above one point on the equator. The higher satellite feels weaker gravity, so it moves more slowly *and* has further to go, so its period is much longer. If a satellite is slowed down, gravity pulls it into a lower orbit.

Red shift and the expanding universe (P)

A moving wave source changes the observed wavelength (the **Doppler effect**): receding sources stretch waves – longer wavelength, lower frequency. The further a galaxy, the faster it recedes and the bigger the **red-shift** 红移 – space itself is expanding, pointing back to a very small beginning: the **Big Bang** 大爆炸. The **cosmic microwave background** 宇宙微波背景 – radiation filling the universe from shortly after that beginning – is the second pillar; the Big Bang theory is currently the only theory that explains it.

> **Worked example (P) (reading red-shift).** The same hydrogen line is shifted by 2 nm in galaxy A and by 8 nm in galaxy B. B's shift is four times larger, so B is moving away about four times faster, and so it is further away. A line shifted to a *shorter* wavelength (blue-shift) would mean the source is moving towards us.



Three spectra: the further the galaxy, the bigger the red-shift.

Common mistakes

- Saying a satellite in a circular orbit has no acceleration. Its speed is constant but its direction changes, so its velocity changes: gravity accelerates it towards the centre.
- Saying a higher orbit needs a higher speed. Further out, gravity is weaker, so the orbital speed is lower.
- Saying every star ends as a black hole. A Sun-like star ends as a white dwarf; only the most massive stars become neutron stars or black holes.
- Saying stars make all elements by fusion in their cores. Elements heavier than iron are made in supernovae.
- (P) Saying red-shifted galaxies look red. Every line in the spectrum moves to a longer wavelength.
- (P) Saying the galaxies move through space away from one centre. Space itself is expanding, so every distant galaxy moves away from every other.

Check yourself

1. What pulls dust and gas into stars?
2. What happens in a main-sequence star's core?
3. List the three stages a Sun-like star passes through after its main sequence.
4. Which stars become supernovae?
5. Where are elements heavier than iron made?
6. Name the two artificial-satellite orbit types.
7. Why does a satellite in a higher orbit move more slowly?
8. (P) What happens to a wave's wavelength when its source recedes?
9. (P) State the two pieces of evidence for the Big Bang.
10. (P) What is the CMBR?

Answers: 1 gravitational attraction; 2 hydrogen fuses to helium, releasing energy that balances gravity; 3 red giant, white dwarf, black dwarf; 4 stars far more massive than the Sun; 5 in supernovae; 6 geostationary and low polar; 7 gravity is weaker farther out, so a smaller centripetal force and speed suffice; 8 (P) it increases (red-shift); frequency falls; 9 (P) red-shift increasing with distance; the CMBR; 10 (P) radiation filling the universe, left from soon after the Big Bang.