Course Companion

IGCSE Physics

Every topic handout in one volume

全部专题讲义合集

exercises.lol

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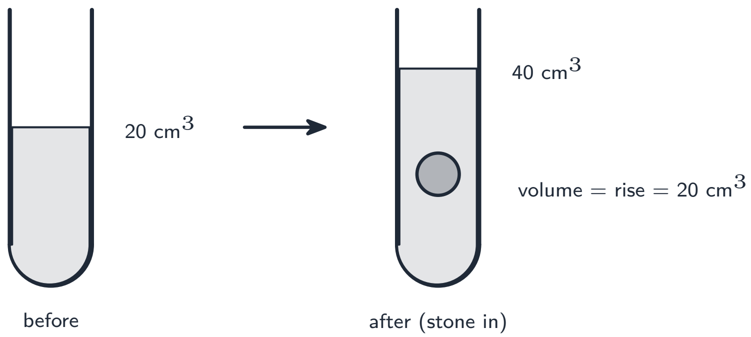
Motion, forces and energy

IGCSE Physics

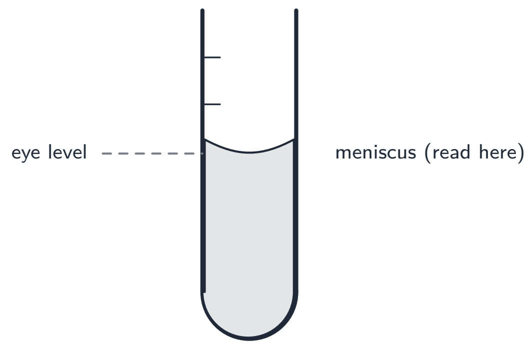
Measurement 测量

Length and volume

Use a **ruler** 直尺 to measure length. Read the scale with your eye straight in front of the mark to avoid a reading error.



The water an irregular solid pushes up gives its volume



Read a measuring cylinder at the bottom of the meniscus, with your eye level

Use a **measuring cylinder** 量筒 to measure the volume of a liquid. Read the scale at the bottom of the curved surface (the **meniscus** 弯月面), with your eye level with it.

Measuring small amounts

A single small length or a short time is hard to measure well. The trick is to **measure many and divide** 测多个再相除:

- To find the thickness of one page, measure 100 pages and divide by 100.
- To find the time for one swing of a **pendulum** 摆, measure the time for 20 swings and divide by 20. One full swing is called the **period** 周期.

This makes the **uncertainty** 不确定度 (the size of the error) much smaller.

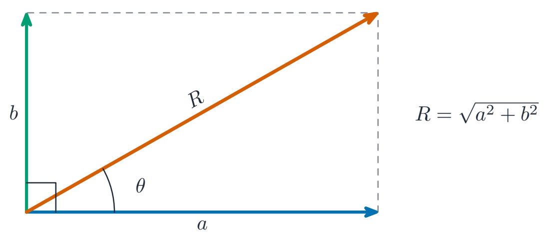
Scalars and vectors

A **scalar** 标量 has size (**magnitude** 大小) only. A **vector** 矢量 has size **and** direction.

- Scalars: distance, speed, time, mass 质量, energy 能量, temperature 温度.
- Vectors: force 力, weight 重力, velocity 速度, acceleration 加速度, momentum 动量.

To add two vectors at right angles (90°), draw them as two sides of a rectangle. The **resultant** 合矢量 is the diagonal. Find its size with Pythagoras and its direction with trigonometry.

$$R = \sqrt{a^2 + b^2}$$



Two vectors at right angles add to a resultant R, the diagonal of the rectangle

Motion 运动

Speed and velocity

Speed 速率 is the distance travelled per unit time.

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

Velocity is speed in a stated direction. So velocity is a vector but speed is a scalar.

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

Acceleration

Acceleration is the change in velocity per unit time.

$$a = \frac{\Delta v}{\Delta t}$$

Here Δv means "the change in velocity". A **deceleration** 减速 (slowing down) is a negative acceleration.

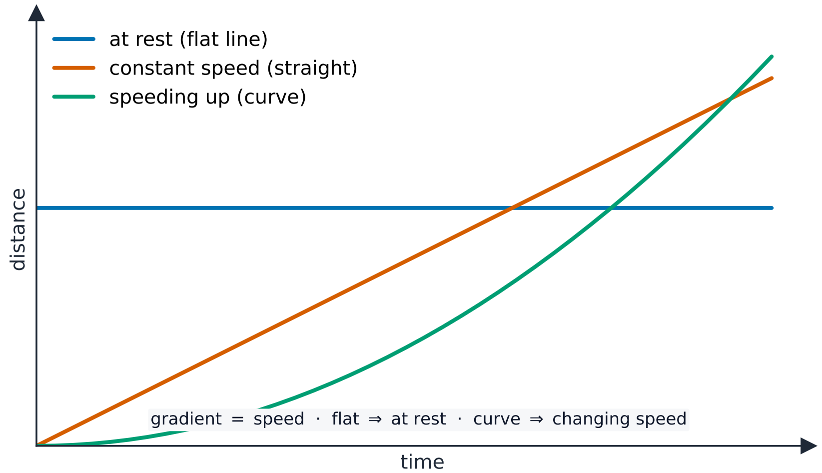
Worked example. A car speeds up from 8 m/s to 20 m/s in 4.0 s. Find its acceleration.

$$a = \frac{\Delta v}{\Delta t} = \frac{20 - 8}{4.0} = 3.0\ \text{m/s}^2$$

Motion graphs

A **distance–time graph** 距离-时间图 shows how far an object has gone:

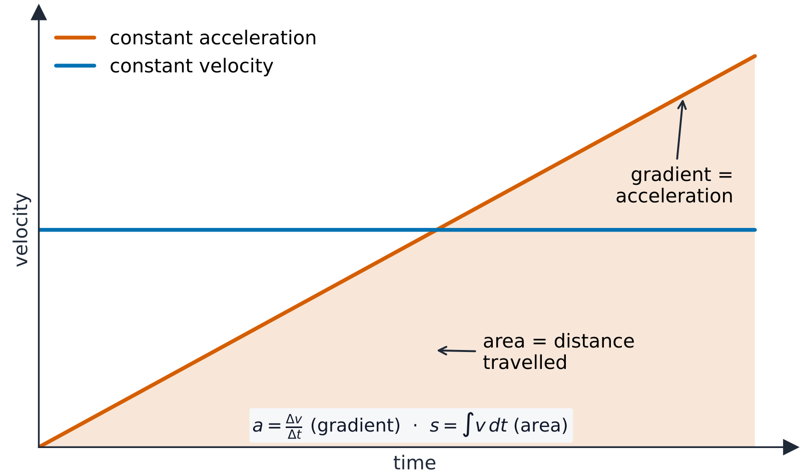
- A flat (horizontal) line means the object is **at rest** 静止.
- A straight slope means constant speed. The **gradient** 斜率 (steepness) is the speed.
- A curve that gets steeper means the object is speeding up.



The shape of a distance–time line: flat is at rest, a straight slope is constant speed, a rising curve is speeding up

A **speed–time graph** 速度-时间图 shows how fast an object is going:

- A flat line means constant speed.
- A straight slope means constant acceleration. The gradient is the acceleration.
- The **area under the line** 线下面积 is the distance travelled.

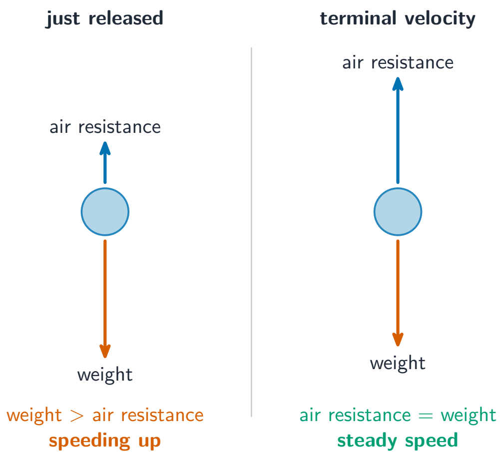


On a velocity–time graph the gradient is the acceleration and the area under the line is the distance travelled

Falling objects

Near the Earth, all objects speed up as they fall at the same rate. This is the **acceleration of free fall** 自由落体加速度, $g \approx 9.8$ m/s^2.

When an object falls through air, **air resistance** 空气阻力 (a drag force) acts upward. As it speeds up, air resistance grows. When air resistance equals the weight, the resultant force is zero and the object stops speeding up. It then falls at a steady **terminal velocity** 收尾速度.



At first the weight is bigger than the air resistance, so the object speeds up; at terminal velocity the two are equal and the speed is steady

Mass and weight

Mass is the amount of **matter** 物质 in an object. It is measured in kilograms (kg) and does not change when you move the object.

Weight is the force of gravity on a mass. It is measured in newtons (N). Weight can change: it is smaller on the Moon because the Moon's gravity is weaker.

Gravitational field strength 重力场强度 is the force per unit mass:

$$g = \frac{W}{m}$$

This g has the same value as the acceleration of free fall (≈ 9.8 N/kg). You can compare masses with a **balance** 天平.

A laboratory balance measures mass; weight is the gravitational force on that mass

Density 密度

Density is the mass per unit volume.

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

The symbol ρ is the Greek letter "rho". The unit is kg/m^3 or g/cm^3.

To find density: measure the mass with a balance, find the volume, then divide.

- **Regular solid** 规则固体 (like a box): measure the sides and calculate the volume.
- **Irregular solid** 不规则固体 (a strange shape): lower it into water in a measuring cylinder. The rise in water level is its volume. This is the **displacement method** 排水法.

An object **floats** 漂浮 if its density is less than the density of the liquid. It sinks if its density is greater.

Worked example. A stone of mass 54 g is lowered into a measuring cylinder. The water level rises from 20 cm^3 to 40 cm^3. Find the density of the stone.

The volume of the stone is the rise in water level, $40 - 20 = 20$ cm^3, so

$$\rho = \frac{m}{V} = \frac{54}{20} = 2.7 \text{ g/cm}^3$$

An iceberg floats with most of its volume hidden: ice is slightly less dense than water

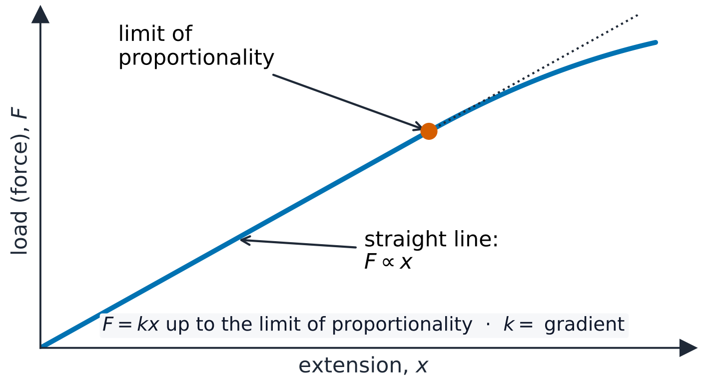
Forces

A force is a push or a pull. A force can change the **shape** 形状, the speed, or the direction of an object.

Stretching (Hooke's law)

When you hang a load on a spring, it stretches. The stretch is called the **extension** 伸长量.

On a **load–extension graph** 载荷-伸长图 the line is straight at first: extension is proportional to load. The point where the line stops being straight is the **limit of proportionality** 比例极限.



Load is proportional to extension until the limit of proportionality, then the line curves

The **spring constant** 弹簧常数 is the force per unit extension:

$$k = \frac{F}{x}$$

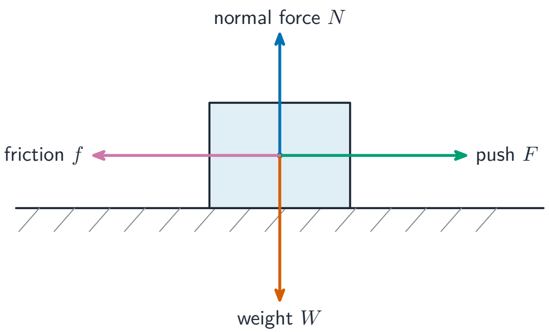
A large k means a stiff spring.

Resultant force and Newton's laws

Add forces on a straight line to get the **resultant force** 合力 (forces one way are positive, the other way negative).

- If the resultant force is zero, the object stays at rest **or** keeps moving in a straight line at constant speed. (Newton's first law.)
- If the resultant force is not zero, the object accelerates in the direction of the force:

$$F = ma$$



A free-body diagram shows every force on the box as a labelled arrow

Worked example. A 1200 kg car has a 3000 N driving force and 600 N of friction. Find its acceleration.

First find the resultant force: $3000 - 600 = 2400$ N. Then

$$a = \frac{F}{m} = \frac{2400}{1200} = 2.0 \text{ m/s}^2$$

Friction

Friction 摩擦力 is the force between two surfaces that touch. It tries to stop motion and makes things heat up. Drag (friction in a liquid or gas, like air resistance) also slows objects down.

Moments — the turning effect

The **moment** 力矩 of a force is its turning effect about a **pivot** 支点.

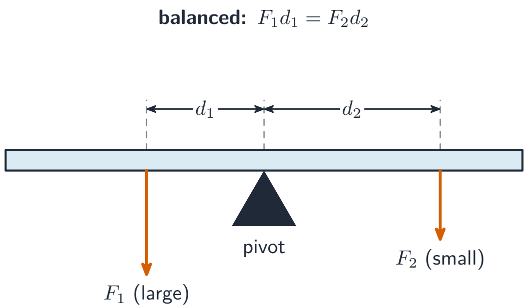
$$\text{moment} = \text{force} \times \text{perpendicular distance from the pivot}$$

The unit is the newton metre (N m).

Principle of moments 力矩原理: when an object is balanced (in **equilibrium** 平衡),

$$\text{total clockwise moment} = \text{total anticlockwise moment}$$

An object is in equilibrium when there is no resultant force **and** no resultant moment.



The beam balances when the clockwise moment equals the anticlockwise moment

Worked example. A 30 N weight sits 0.20 m to the left of a pivot. How far to the right must a 20 N weight sit to balance the beam?

Balanced, so anticlockwise moment = clockwise moment:

$$30 \times 0.20 = 20 \times d \quad \Rightarrow \quad d = \frac{6.0}{20} = 0.30 \text{ m}$$

Centre of gravity

The **centre of gravity** 重心 is the single point where all the weight of an object seems to act.

For a flat shape (**lamina** 薄片), hang it from a pin and let it settle; draw a vertical line down from the pin using a plumb line. Repeat from another point. The centre of gravity is where the lines cross.

An object is more **stable** 稳定 when its centre of gravity is low and its base is wide. It tips over when the centre of gravity passes outside the base.

Momentum

Momentum is mass times velocity. It is a vector.

$$p = mv$$

Impulse 冲量 is the force times the time it acts, and it equals the change in momentum:

$$\text{impulse} = F\,\Delta t = \Delta(mv)$$

So the resultant force is the change in momentum per unit time:

$$F = \frac{\Delta p}{\Delta t}$$

Conservation of momentum 动量守恒: when objects collide and no outside force acts, the total momentum before equals the total momentum after.

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

(Here u is a velocity before and v is a velocity after.)

Worked example. A 2.0 kg trolley moving at 3.0 m/s hits a stationary 1.0 kg trolley and they stick together. Find their common velocity afterwards.

Total momentum is conserved, so

$$(2.0 \times 3.0) + (1.0 \times 0) = (2.0 + 1.0)\,v \quad \Rightarrow \quad v = \frac{6.0}{3.0} = 2.0 \text{ m/s}$$

Energy, work and power

Energy stores

Energy can be **stored** 储存 in different ways: kinetic 动能, gravitational potential 重力势能, chemical 化学能, elastic (strain) 弹性势能, nuclear 核能, electrostatic 静电能, and internal (thermal) 内能.

Energy is **transferred** 转移 between stores by forces (mechanical work), by electric currents, by heating, and by waves (such as light and sound).

Wind turbines transfer energy from the kinetic store of the moving air to electricity

Kinetic and potential energy

Kinetic energy is the energy of a moving object:

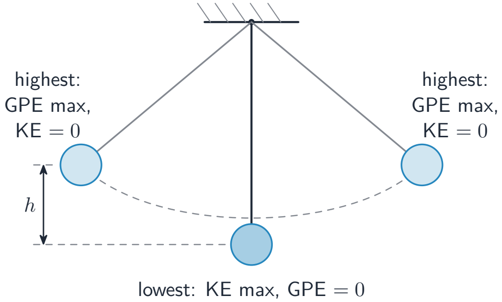
$$E_k = \frac{1}{2}mv^2$$

The change in **gravitational potential energy** when an object goes up or down by a height Δh:

$$\Delta E_p = mg\,\Delta h$$

Conservation of energy

The **principle of conservation of energy** 能量守恒定律 says energy is never made or destroyed; it only moves between stores. A falling object turns gravitational potential energy into kinetic energy. A **Sankey diagram** 桑基图 shows how the input energy splits into useful energy and **wasted** 浪费 energy.



Energy moves between gravitational potential energy (at the highest points) and kinetic energy (at the lowest point)

On a roller-coaster, gravitational potential energy stored at the top of the hill becomes kinetic energy as the cars speed down

Worked example. A 0.50 kg ball is dropped from a height of 1.8 m. Ignoring air resistance, find its speed just before it lands. (Take $g = 10\ \text{m/s}^2$.)

All the gravitational potential energy becomes kinetic energy, so $\frac{1}{2}mv^2 = mg\,\Delta h$. The mass cancels, leaving $v^2 = 2g\,\Delta h$:

$$v = \sqrt{2 \times 10 \times 1.8} = \sqrt{36} = 6.0\ \text{m/s}$$

Because the mass cancels, every object dropped from this height would land at the same speed.

Work

Work done 做功 equals the energy transferred. When a force moves an object:

$$W = Fd = \Delta E$$

The unit of work and energy is the **joule** 焦耳 (J).

Power

Power 功率 is the work done (or energy transferred) per unit time.

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

The unit is the **watt** 瓦特 (W). 1 W = 1 J/s.

Efficiency

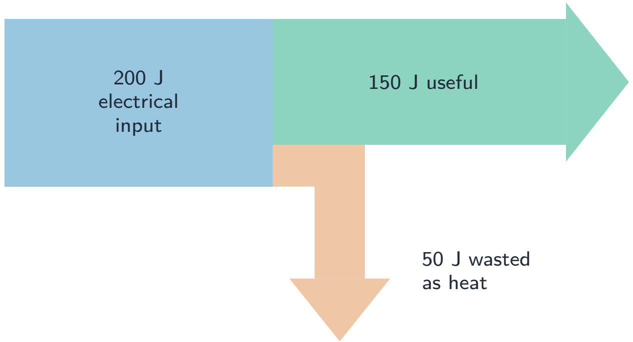
Efficiency 效率 tells you how much of the input energy becomes useful energy.

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy input}} \times 100\%$$

Efficiency is always less than 100% because some energy is always wasted (usually as heat).

Worked example. A motor is supplied with 200 J of electrical energy and lifts a load, giving it 150 J of gravitational potential energy. Find its efficiency.

$$\text{efficiency} = \frac{150}{200} \times 100\% = 75\%$$



A Sankey diagram for this motor: the band widths are proportional to the energy, so the 200 J input splits into 150 J useful and 50 J wasted as heat

Energy resources

We generate electricity from many **energy resources**. Most spin a **turbine** that drives a **generator** – often by boiling water to make steam (**fossil fuels**, **nuclear fuel**, **geothermal**, **biofuels**), or directly by moving water or air (**hydroelectric**, **waves**, **tides**, **wind**). **Solar cells** make electricity from sunlight directly; **solar panels** heat water.

Resource	Renewable?	Notes
fossil fuels (coal, oil, gas)	no	reliable, high output, but CO_2 and pollution
nuclear fuel	no	huge output, no CO_2, but radioactive waste
biofuels	yes	roughly carbon-neutral if replanted
hydroelectric	yes	reliable, but a dam floods land
wind	yes	clean, but intermittent
solar	yes	clean, but only in daylight
geothermal / tidal	yes	reliable but limited to certain places

Most of these trace back to the **Sun** (fossil fuels are ancient stored sunlight; wind and waves come from solar heating) – the exceptions are **geothermal**, **nuclear**, and **tidal** energy. The Sun itself is powered by **nuclear fusion** 核聚变, joining hydrogen nuclei into helium.

Pressure 压强

Pressure is the force per unit area.

$$p = \frac{F}{A}$$

The unit is the **pascal** 帕斯卡 (Pa). 1 Pa = 1 N/m^2.

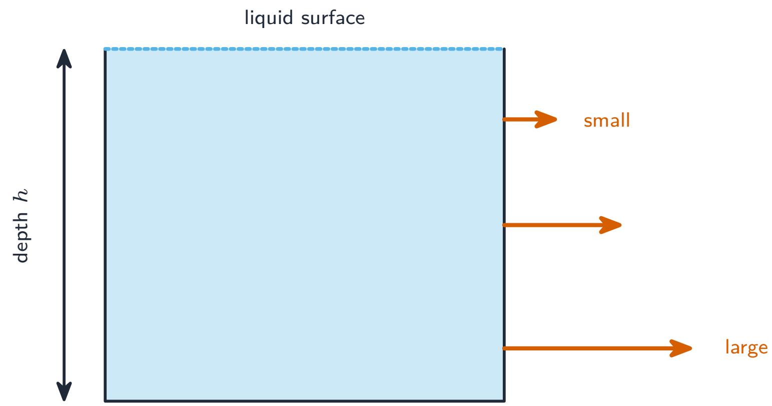
A small area gives a large pressure (a sharp knife cuts well). A large area gives a small pressure (snowshoes stop you sinking).

Pressure in a liquid

In a liquid, pressure increases with **depth** 深度 and with the liquid's density:

$$\Delta p = \rho g \, \Delta h$$

This is why a dam is built thicker at the bottom, where the water pressure is greatest. Pressure in a liquid acts in all directions.



The deeper the liquid, the greater the pressure, so the outward push on the wall grows with depth

A real dam is built much thicker at the bottom, because the water pushes hardest where it is deepest

Worked example. Find the extra pressure at a depth of 2.0 m in water (density 1000 kg/m^3, $g = 10$ N/kg).

$$\Delta p = \rho g \, \Delta h = 1000 \times 10 \times 2.0 = 20\,000 \text{ Pa}$$

Exam tips

- On a **distance–time** graph the gradient is the speed; on a **speed–time** graph the gradient is the acceleration and the *area* under the line is the distance travelled. Never read one graph as if it were the other.
- **Mass** (kg) is the amount of matter and is the same everywhere; **weight** (N) is the force of gravity, $W = mg$. On the Moon your mass is unchanged but your weight is smaller.
- **Speed** is a scalar; **velocity** is a vector. Something moving at steady speed around a curve is still accelerating, because its direction keeps changing.
- In **Hooke's law**, load is proportional to extension only up to the **limit of proportionality**. Use the *extension* (stretched length − original length), never the whole length.
- **Momentum** $p = mv$ is conserved in a collision. Give each velocity a + or − sign for its direction *before* you add them.
- Convert units first (cm → m, g → kg). Use $p = F/A$ for a solid pressing on a surface, but $p = \rho g h$ for the pressure *inside* a liquid — they are different formulas.

Thermal physics

IGCSE Physics

States of matter 物态

Matter exists in three states: **solid** 固体, **liquid** 液体 and **gas** 气体.

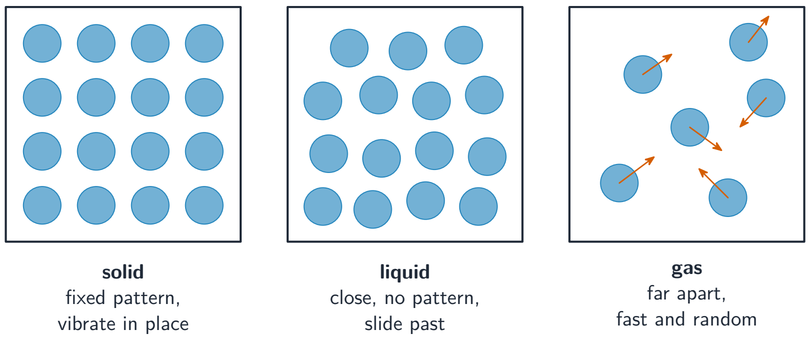
State	Shape	Volume	Particles
Solid	fixed	fixed	close together, in a regular pattern, vibrating
Liquid	takes the shape of the container	fixed	close together, no pattern, can move past each other
Gas	fills the container	changes	far apart, fast, random motion

The changes of state are: melting (solid → liquid), boiling/evaporating (liquid → gas), **condensation** 凝结 (gas → liquid) and **solidification** 凝固 (liquid → solid).

The kinetic particle model 分子动理论

All matter is made of tiny **particles** 粒子 that are always moving. This is the kinetic particle model.

- In a solid the particles only **vibrate** 振动 about fixed positions.
- In a liquid they are still close but can slide past each other.
- In a gas they are far apart and move quickly in random directions.



The same particles in three states: fixed and ordered in a solid, close but disordered in a liquid, far apart and fast in a gas

Temperature and particle energy

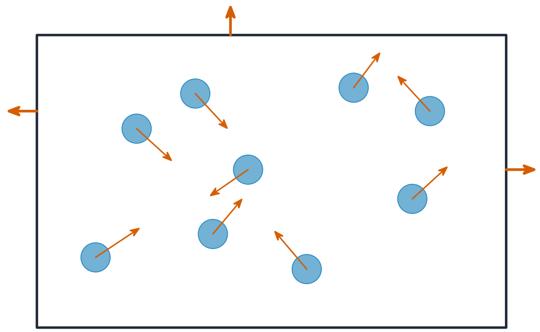
When you heat a substance, its particles move faster, so they have more **kinetic energy** 动能. **Temperature** 温度 is a measure of the average kinetic energy of the particles.

The lowest possible temperature is **absolute zero** 绝对零度, $-273\,°\mathrm{C}$. At this point the particles have the least possible energy.

A digital thermometer measures temperature by sensing the kinetic energy of the particles it touches

Gas pressure

Gas particles hit the walls of their container. Each hit is a tiny push. The **pressure** 压强 of the gas is the total force of these hits per unit area.



gas particles hit the walls — each hit is a tiny force.
Pressure = force per unit area

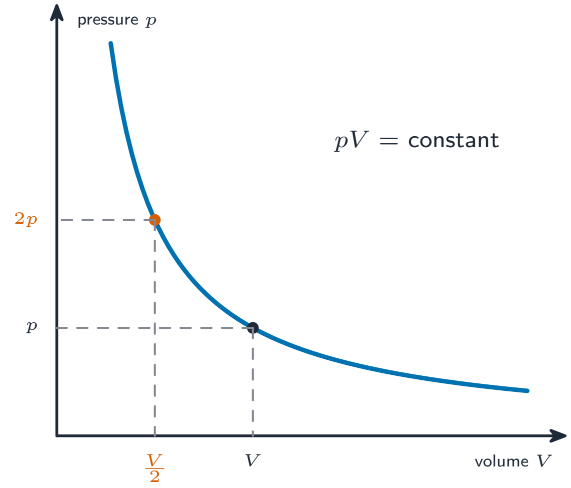
The gas pressure is the total force of countless particle hits on each unit area of the wall

- Heating a gas (at constant volume) makes particles move faster and hit harder and more often, so the pressure rises.
- Squeezing a gas into a smaller volume (at constant temperature) means more hits per second on each unit of area, so the pressure rises.

For a fixed mass of gas at constant temperature:

$$pV = \text{constant}$$

So if the volume halves, the pressure doubles.



At constant temperature the pressure–volume graph is a curve: halve the volume and the pressure doubles, so pV stays constant

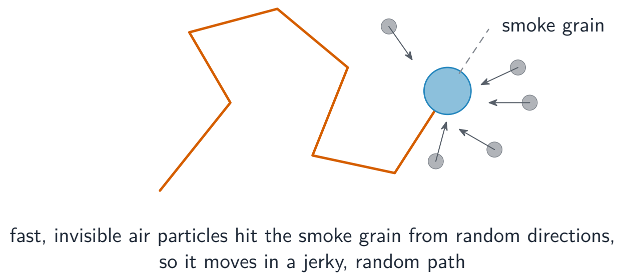
Worked example. A gas has a volume of 200 cm^3 at a pressure of 100 kPa. It is squeezed to 50 cm^3 at constant temperature. Find the new pressure.

Since pV stays constant, $p_1V_1 = p_2V_2$:

$$100 \times 200 = p_2 \times 50 \quad \Rightarrow \quad p_2 = \frac{20\,000}{50} = 400 \text{ kPa}$$

Brownian motion

If you look at smoke in air under a microscope, you see tiny specks moving in a jerky, random way. This is **Brownian motion** 布朗运动. The specks are pushed by fast, invisible air particles hitting them. It is strong evidence for the kinetic particle model.



Random hits from fast air particles push a smoke grain along a jerky, random path

The kelvin scale

Scientists often use the **kelvin** 开尔文 (K) temperature scale, which starts at absolute zero. To convert:

$$T \text{ (in K)} = \theta \text{ (in °C)} + 273$$

So 0 °C = 273 K.

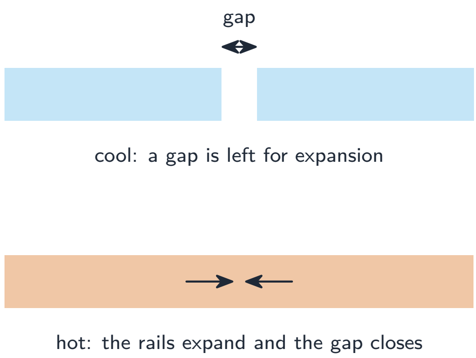
Worked example. Convert 25 °C to kelvin, and 200 K to degrees Celsius.

$$25 + 273 = 298 \text{ K}, \qquad 200 - 273 = -73\,°\text{C}$$

Thermal expansion 热膨胀

When matter is heated, its particles move more and take up more space, so the material expands. Gases expand the most, then liquids, then solids.

Everyday examples: gaps are left between railway lines; bridges sit on rollers; a tight metal lid loosens when heated.



A small gap is left between rails when cool, so when they expand in the heat the gap closes instead of buckling the track

Internal energy and specific heat capacity

The **internal energy** 内能 of an object is the total energy of all its particles. Heating an object raises its internal energy and usually its temperature.

The **specific heat capacity** 比热容 is the energy needed to raise the temperature of 1 kg of a material by 1 °C.

$$c = \frac{\Delta E}{m\,\Delta\theta}$$

A material with a high specific heat capacity (like water) needs a lot of energy to warm up and cools down slowly.

Worked example. How much energy is needed to heat 2.0 kg of water from 20 °C to 70 °C? The specific heat capacity of water is 4200 J/(kg °C).

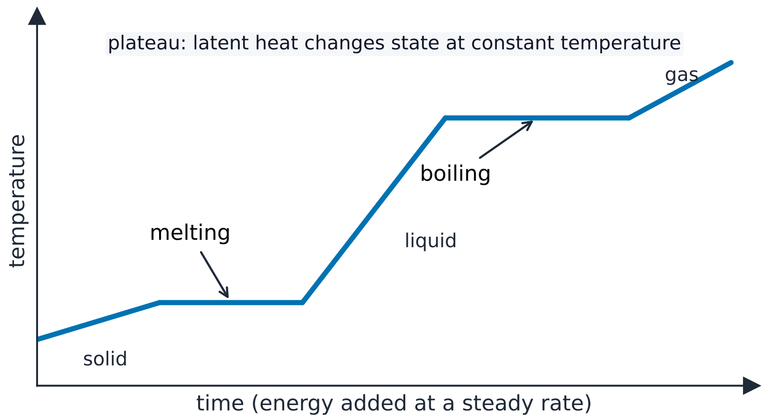
Rearranging $c = \frac{\Delta E}{m\,\Delta\theta}$ gives $\Delta E = mc\,\Delta\theta$, with $\Delta\theta = 70 - 20 = 50\,°\text{C}$:

$$\Delta E = 2.0 \times 4200 \times 50 = 420\,000 \text{ J} = 420 \text{ kJ}$$

Boiling water: internal energy rises with temperature; specific heat capacity is energy per kg per °C

Melting, boiling and evaporation

Melting 熔化 and **boiling** 沸腾 need energy, but the temperature stays the same while the state changes. This energy breaks the forces between particles. For water at normal air pressure, melting is at 0 °C and boiling at 100 °C.



While the substance melts and while it boils the temperature stays flat, even though energy is still being added

Evaporation 蒸发 is when a liquid changes to a gas at its surface, below the boiling point. The fastest particles escape from the surface. Because the fastest (most energetic) particles leave, the average energy of those left behind falls, so the liquid **cools down** 冷却.

Evaporation is faster when the temperature is higher, the surface area is larger, and there is more air movement over the surface.

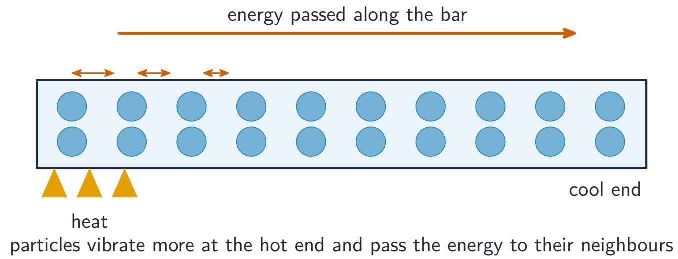
Transfer of thermal energy 热能传递

Thermal energy moves from hotter places to colder places in three ways.

Conduction

Conduction 热传导 is the transfer of thermal energy through a material without the material moving. Heated particles vibrate more and pass the energy to their neighbours. In metals, free (**delocalised**) **electrons** 自由电子 carry energy quickly, so metals are good **thermal conductors** 热导体.

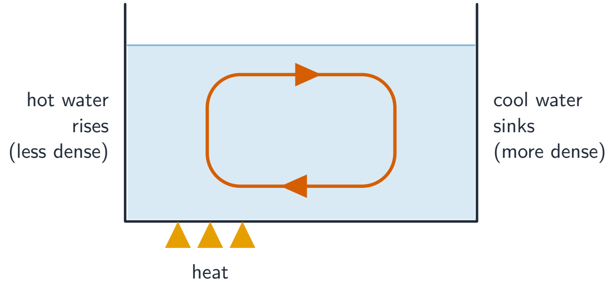
Materials that conduct badly (like air, wood and plastic) are **thermal insulators** 热绝缘体.



In conduction the vibrating particles pass energy to their neighbours, so energy flows from the hot end to the cool end

Convection

Convection 对流 happens in liquids and gases. When a fluid is heated it expands, becomes less dense, and rises. Cooler, denser fluid sinks to take its place. This circle of moving fluid is a **convection current**.



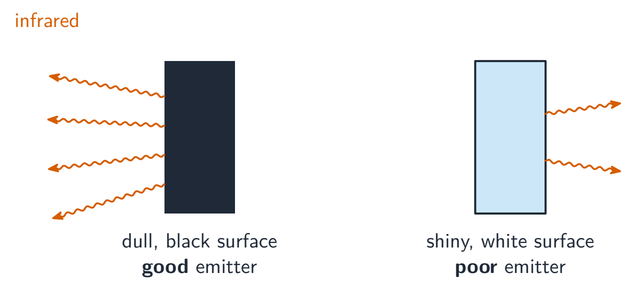
Heated fluid rises and cooler fluid sinks, setting up a convection current

Convection cannot happen in a solid because the particles cannot move from place to place.

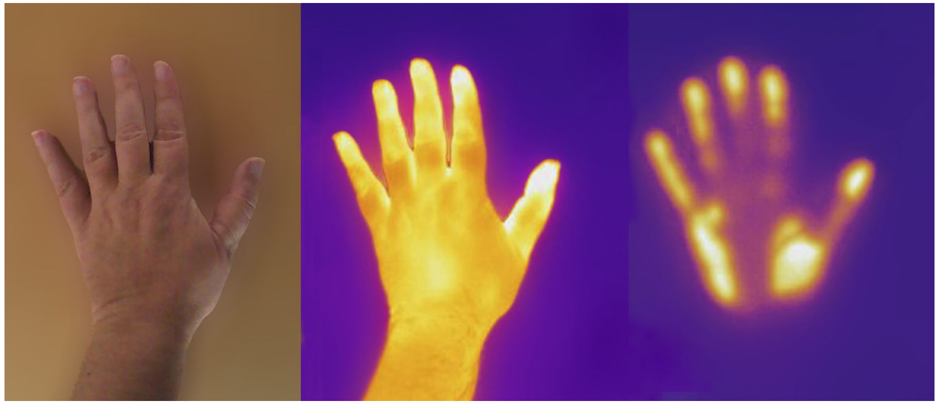
Radiation

Thermal radiation 热辐射 is energy carried by **infrared** 红外线 waves. All objects emit it, and it needs no material to travel through — it can cross empty space (this is how energy reaches us from the Sun).

A surface that is **dull** 暗淡 and black is a good **emitter** 发射体 and a good **absorber** 吸收体 of infrared. A surface that is shiny and white is a poor emitter and a good **reflector** 反射体.



A dull black surface emits (and absorbs) infrared much better than a shiny, white one



A thermal (infrared) camera turns the infrared given off by a warm hand into a picture; brighter means hotter

An object stays at a constant temperature when it emits energy at the same rate as it absorbs energy. The rate of emission is greater when the surface is hotter and larger.

Exam tips

- In the **kinetic particle model**, heating a gas makes its particles move faster and hit the walls harder and more often, so the pressure rises. The particles themselves do not get bigger.
- **Evaporation** happens only at the surface and at any temperature; **boiling** happens throughout the liquid at one fixed temperature. Evaporation cools the liquid left behind, because the fastest particles escape.
- During **melting** and **boiling** the temperature stays constant even though energy is still being supplied — that energy breaks the forces between particles.
- For **specific heat capacity** use $\Delta E = mc\,\Delta\theta$, where $\Delta\theta$ is the *change* in temperature, not the final temperature.
- Dull black surfaces are the best **emitters and absorbers** of infrared; shiny, light surfaces are the best reflectors. **Convection** needs a fluid to flow, so it cannot happen in a solid.

Waves

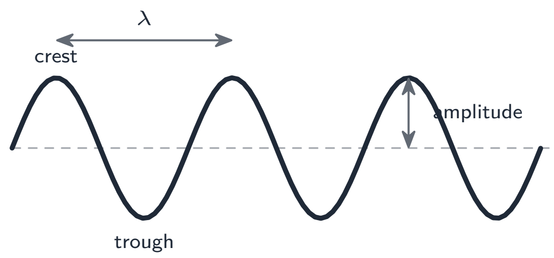
IGCSE Physics

General properties of waves

A **wave** 波 carries **energy** 能量 from place to place **without** carrying matter. For example, a water wave makes a floating cork bob up and down, but the cork does not travel along with the wave.

Describing a wave

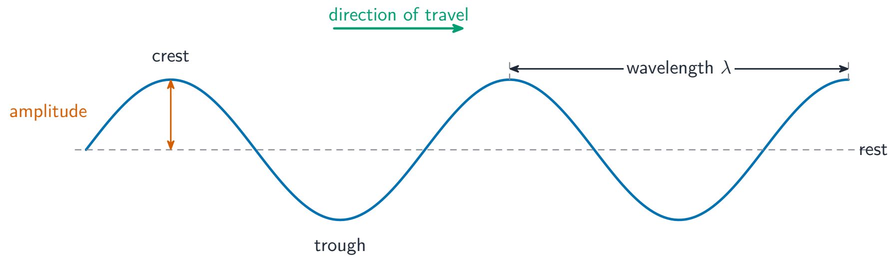
- **wavefront** 波前: a line joining points on a wave that move together (for example, the top of one ripple)
- **wavelength** 波长 (λ): the distance between two neighbouring wavefronts (one full wave)
- **frequency** 频率 (f): the number of waves passing a point each second, measured in hertz (Hz)
- **crest** 波峰 (top) and **trough** 波谷 (bottom)
- **amplitude** 振幅: the largest distance a point moves from its rest position
- **wave speed** 波速 (v): how fast a wavefront travels



The parts of a wave: wavelength, amplitude, crest and trough

These are linked by the **wave equation**:

$$v = f\lambda$$



The wavelength is the distance between two crests; the amplitude is the height from the rest position to a crest

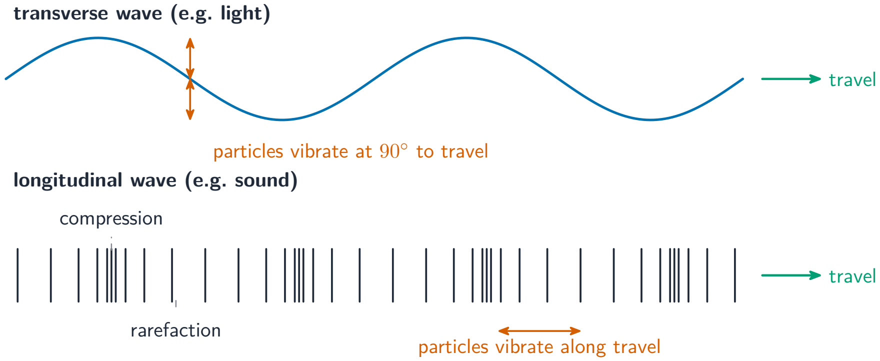
Worked example. A sound wave travels at 340 m/s and has a frequency of 170 Hz. Find its wavelength.

Rearranging $v = f\lambda$ gives $\lambda = \dfrac{v}{f}$:

$$\lambda = \frac{340}{170} = 2.0 \text{ m}$$

Two types of wave

- In a **transverse wave** 横波 the particles vibrate at right angles (90°) to the direction the wave travels (its **propagation** 传播). Light and water waves are transverse.
- In a **longitudinal wave** 纵波 the particles vibrate along the same direction as the wave travels. Sound is longitudinal.

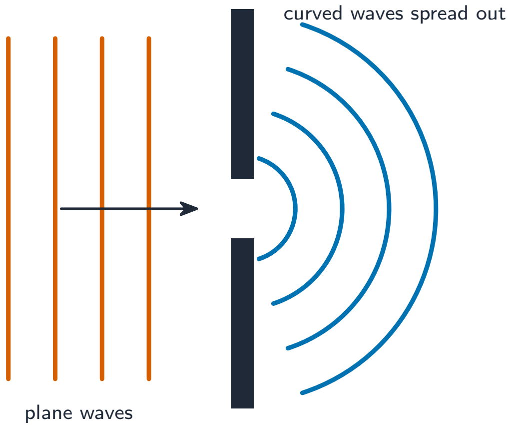


In a transverse wave the particles vibrate across the travel direction; in a longitudinal wave they vibrate along it, making compressions and rarefactions

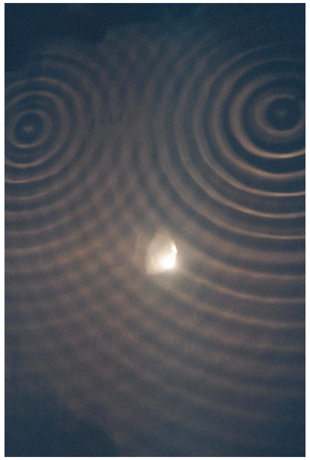
Wave behaviour

All waves can show three behaviours, which you can see in a **ripple tank** 波纹水槽:

- **reflection** 反射: the wave bounces off a surface.
- **refraction** 折射: the wave changes speed (and usually direction) when it enters a different material or depth.
- **diffraction** 衍射: the wave spreads out after passing through a gap or around an edge. The spreading is greatest when the gap is about the same size as the wavelength.



Plane waves passing through a narrow gap spread out into curved waves — diffraction is strongest when the gap is about one wavelength wide



Two dippers in a ripple tank make circular water waves that overlap — a quick way to study how waves behave

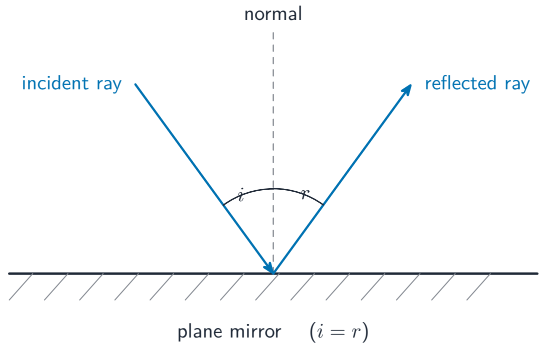
Light 光

Reflection

When light hits a mirror, it reflects. We measure angles from the **normal** 法线 (a line at 90° to the surface).

The **law of reflection**: the **angle of incidence** 入射角 equals the **angle of reflection** 反射角.

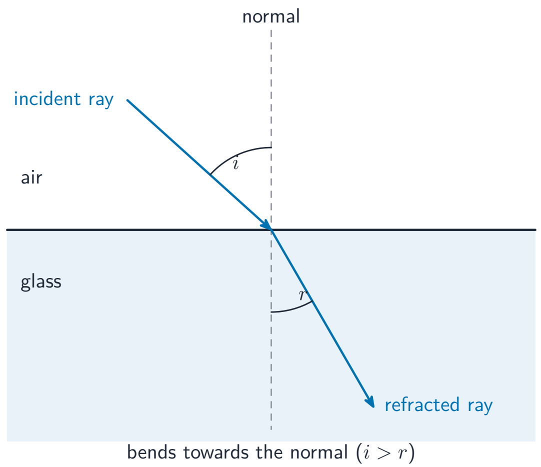
A **plane mirror** 平面镜 forms an image that is the same size as the object, the same distance behind the mirror, and **virtual** (it cannot be caught on a screen).



At a plane mirror the angle of incidence i equals the angle of reflection r, both measured from the normal

Refraction

When light passes from one material into another, it changes speed and bends. The angle in the second material is the **angle of refraction** 折射角.



Going from air into glass the light slows down and bends towards the normal, so $i > r$

The **refractive index** 折射率 n compares the speed of light in the two materials:

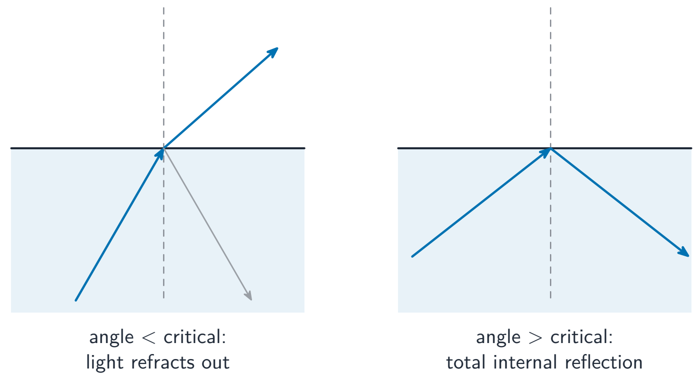
$$n = \frac{\sin i}{\sin r}$$

Worked example. A ray of light passes from air into glass. The angle of incidence is 60° and the angle of refraction is 35°. Find the refractive index of the glass. (Take $\sin i = 0.87$ and $\sin r = 0.57$.)

$$n = \frac{\sin i}{\sin r} = \frac{0.87}{0.57} = 1.5$$

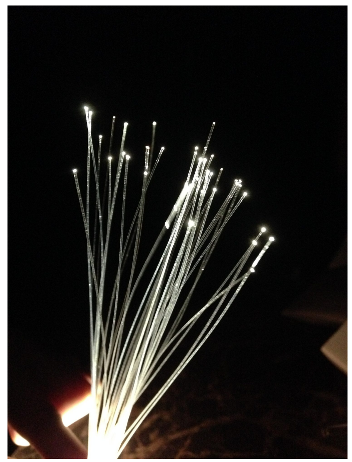
When light tries to leave glass or water and the angle is too large, it cannot get out and instead reflects completely. This is **total internal reflection** 全反射. It happens when the angle inside is bigger than the **critical angle** 临界角 c:

$$n = \frac{1}{\sin c}$$



Below the critical angle the light refracts out; above it the light is totally internally reflected

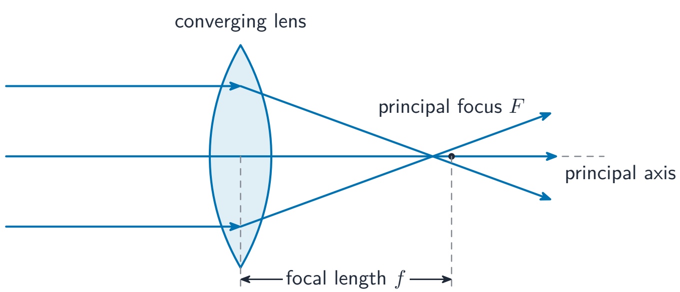
This effect is used in **optical fibres** 光纤, thin glass threads that carry light signals for telephones and the internet.



Total internal reflection keeps light bouncing along each fibre until it shines out at the tip

Lenses

A **converging lens** 凸透镜 (fat in the middle) bends parallel rays inwards to a point called the **principal focus** 焦点. The distance from the lens to this point is the **focal length** 焦距. A **diverging lens** 凹透镜 (thin in the middle) spreads rays out.



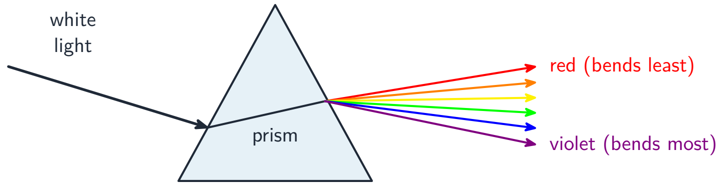
A converging lens bends parallel rays to meet at the principal focus; the focal length f is the lens-to-focus distance

A converging lens can form a **real image** 实像 (rays really meet; can be shown on a screen) or, when the object is very close, a **virtual image** 虚像 (rays only seem to come from it). Used close to the eye, a converging lens is a **magnifying glass** 放大镜.

Held away from the eye, a converging lens forms a real image – here the houses behind it appear upside down

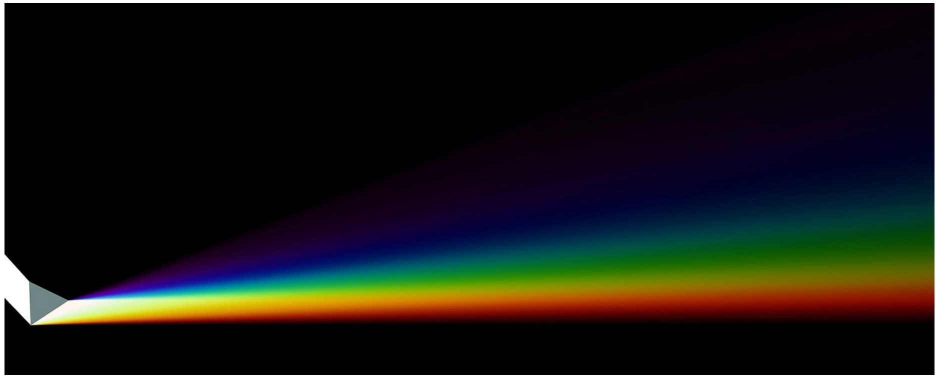
Dispersion

A glass **prism** 棱镜 splits white light into the colours of the **spectrum** 光谱. This splitting is called **dispersion** 色散.



A prism refracts violet light most and red light least, so white light spreads into a spectrum

The order of colours is red, orange, yellow, green, blue, indigo, violet. Red light has the longest wavelength and the lowest frequency; violet is the opposite. Light of a single frequency (one pure colour) is **monochromatic** 单色.



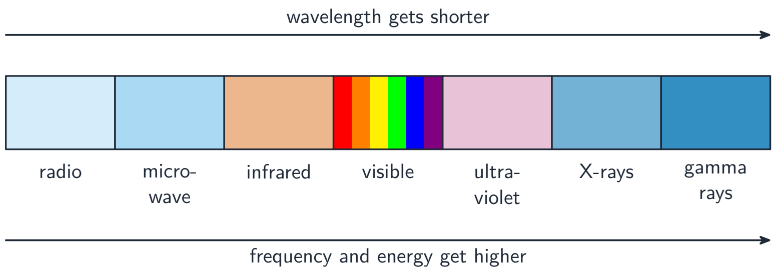
White light entering a real glass prism spreads into the full spectrum of colours

The electromagnetic spectrum 电磁波谱

The **electromagnetic spectrum** is a family of waves that all travel at the same high speed in a **vacuum** 真空, 3.0×10^8 m/s. In order from longest wavelength (lowest frequency) to shortest:

Region	A typical use	Danger from too much
radio waves 无线电波	radio and TV signals	—
microwaves 微波	mobile phones, satellite TV, cooking	heating of body cells
infrared 红外线	remote controls, thermal imaging, grills	skin burns
visible light	seeing, photography	—
ultraviolet 紫外线	sterilising water, checking bank notes	skin cancer, eye damage
X-rays X 射线	medical and security scans	damage to cells
gamma rays 伽马射线	sterilising equipment, treating cancer	mutation of cells

As you go from radio waves to gamma rays, the frequency rises, the wavelength falls, and the energy (and danger) rises.



From radio waves to gamma rays the wavelength falls while the frequency and energy rise

Digital and analogue signals

Radio waves and microwaves carry information as signals, and a signal is either **analogue** 模拟 or **digital** 数字. An **analogue signal** varies **continuously** and can take any value; a **digital signal** is a stream of just two values, on or off (`1` or `0`).

Modern communication prefers **digital** signalling for two reasons the exam asks for:

- a **higher rate** of data transmission;
- a **greater range**: a weak digital signal can be **regenerated** back to a clean `1`/`0` exactly, because only two levels have to be told apart, so noise picked up along the way is removed. An analogue signal cannot be cleaned up this way, so its noise builds up.

Sound 声音

Sound is made by a vibrating object. It is a **longitudinal wave**: the air is squeezed into a **compression** 压缩 (particles close together) and stretched into a **rarefaction** 稀疏 (particles far apart).

- Sound needs a **medium** 介质 (a material) to travel through, so it cannot travel through a vacuum.
- Humans can hear frequencies from about 20 Hz to 20 000 Hz.
- Sound travels much slower than light (about 340 m/s in air), and faster in liquids and solids than in gases.
- A **larger amplitude** makes a louder sound (greater **loudness** 响度); a **higher frequency** makes a higher **pitch** 音调. So a dolphin's rapid clicks are high-pitched, and a hard drum-hit (big vibration) is loud.

A reflected sound is an **echo** 回声. You can find the speed of sound by timing an echo over a known distance.

Worked example. A student stands 85 m from a large wall and claps once. The echo returns 0.50 s later. Find the speed of sound.

The sound travels to the wall and back, a distance of $2 \times 85 = 170$ m, in 0.50 s:

$$v = \frac{s}{t} = \frac{170}{0.50} = 340 \text{ m/s}$$

Ultrasound 超声波 is sound above 20 000 Hz – too high for humans to hear. Its uses rely on reflection: **sonar** measures water depth, **medical scanning** images a baby or soft tissue, and **non-destructive testing** finds cracks inside metal without cutting it open. Like an echo, an ultrasound pulse travels **there and back**, so halve the total distance to reach the object.

Worked example. A sonar pulse returns from the seabed 0.10 s after it is sent; sound travels at 1500 m/s in water. The pulse covers $s = v \times t = 1500 \times 0.10 = 150$ m there and back, so the sea is $150/2 = 75$ m deep.

A microphone converts sound vibrations in air into an electrical signal

Exam tips

- Learn $v = f\lambda$ and be ready to rearrange it. Measure all angles of incidence, reflection and refraction from the **normal** (the line at 90° to the surface), never from the surface itself.
- **Transverse** waves vibrate across the direction of travel (light, water); **longitudinal** waves vibrate along it (sound). Sound needs a **medium**, so it cannot cross a vacuum; light can.
- **Total internal reflection** happens only when light travels from a denser material to a less dense one *and* the angle inside is bigger than the **critical angle**.
- Know the **electromagnetic spectrum** in order — radio, microwave, infrared, visible, ultraviolet, X-ray, gamma. All travel at the same speed in a vacuum; frequency and energy rise from radio to gamma.
- Going into a denser material (air → glass) light slows down and bends *towards* the normal; leaving it (glass → air) light speeds up and bends *away*.

Electricity and magnetism

IGCSE Physics

Magnetism

A **magnet** 磁体 can attract some metals. Every magnet has two ends, called **poles** 磁极: a **north pole** 北极 (N pole) and a **south pole** 南极 (S pole).

Like poles repel; unlike poles attract

The rule for two poles is like the rule for charges:

- Poles that are the same (N and N, or S and S) **repel** 排斥 (push apart).
- Poles that are different (N and S) **attract** 吸引 (pull together).

A magnet attracts a **magnetic material** 磁性材料, such as iron, steel, cobalt and nickel. Other materials (copper, plastic, wood) are non-magnetic and feel no force.

Induced magnetism

Put a piece of iron near or touching a magnet, and the iron becomes a magnet itself. This is **induced magnetism** 感应磁性. The end of the iron nearest the magnet gains the opposite pole, so the two then attract.

Temporary and permanent magnets

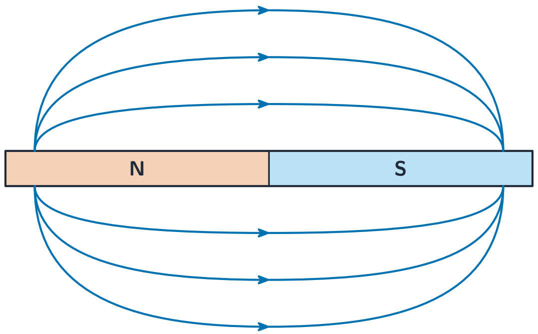
- **Soft iron** 软铁 is easy to **magnetise** 磁化 but loses its magnetism quickly. It is used for a **temporary magnet** 临时磁体.
- **Steel** 钢 is harder to magnetise but keeps its magnetism. It is used for a **permanent magnet** 永磁体.

So an **unmagnetised** 未磁化 piece of soft iron is the best core for an electromagnet, while steel is best for a bar magnet.

Magnetic fields

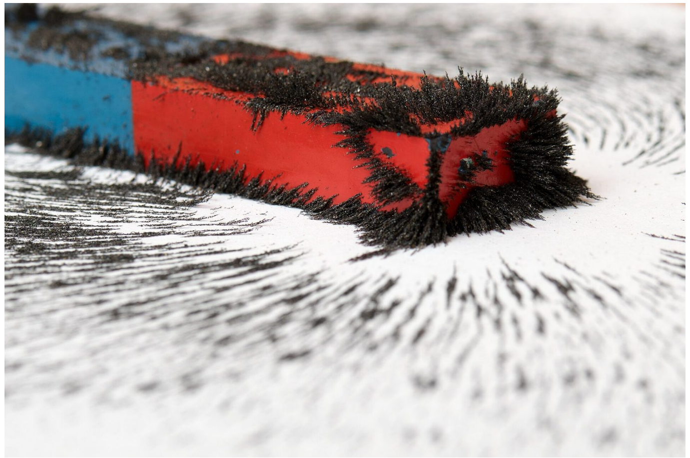
A **magnetic field** 磁场 is a **region** 区域 where a magnetic pole feels a force. We draw it with **magnetic field lines** 磁场线:

- The lines come *out of* the N pole and go *into* the S pole.
- The field direction at a point is the direction of the force on the N pole of a small test magnet placed there.
- Where the lines are close together the field is strong; where they are far apart the field is weak.



The field lines of a bar magnet come out of the N pole and go into the S pole

You can show the pattern by sprinkling **iron filings** 铁屑 on paper over a magnet, or by moving a small plotting **compass** 指南针 around it (the needle points along the field).



Iron filings line up along the field lines, showing the field pattern of a bar magnet

Uses of magnets

- **Permanent magnets**: fridge door catches, compass needles, loudspeakers.
- **Electromagnets** 电磁铁 (magnetic only while a current flows): cranes that lift scrap iron, electric bells, relays. An electromagnet can be switched on and off and made stronger, which a permanent magnet cannot.

Magnetic forces happen because the fields of the two magnets push and pull on each other.

Static electricity

There are two kinds of **electric charge** 电荷: **positive charge** 正电荷 and **negative charge** 负电荷. The rule is like the rule for poles — same charges repel, different charges attract.

Every hair picks up the same charge from the dome, and like charges repel — so the hairs push apart

Charging by friction

When you rub two different materials together, **electrons** 电子 (tiny negative particles) move from one to the other. This is **charging by friction** 摩擦起电.

- The material that gains electrons becomes negative.
- The material that loses electrons becomes positive.

Only the negative electrons move; the positive charge stays in place. For example, a plastic rod rubbed with a cloth becomes negative because electrons move from the cloth onto the rod, leaving the cloth positive.

Conductors and insulators

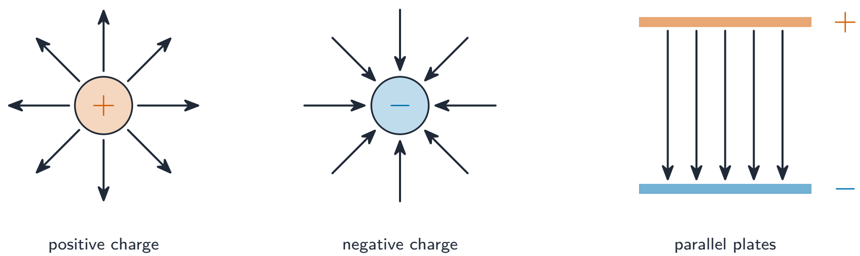
- A **conductor** 导体 (copper and other metals) lets charge flow through it easily, because it has free electrons that can move.
- An **insulator** 绝缘体 (plastic, rubber, glass) does not let charge flow, because its electrons cannot move freely.

To test a material, join it in a circuit with a lamp and a battery: the lamp lights only for a conductor.

Electric fields and ions

Charge is measured in **coulombs** 库仑 (C). An **electric field** 电场 is a region where an electric charge feels a force. Its direction at a point is the direction of the force on a positive charge. Simple field patterns (the arrows show the direction):

- around a **point charge** 点电荷: straight lines, pointing away from a positive charge and towards a negative charge;
- around a charged ball (sphere): the same, spreading out evenly all around;
- between two parallel plates with opposite charges: straight, evenly spaced lines from the positive plate to the negative plate.



Electric field lines point away from a positive charge and towards a negative one; between parallel plates the field is uniform

An atom is normally neutral. If it loses electrons it becomes a positive **ion** 离子; if it gains electrons it becomes a negative ion.

Electric current

An **electric current** 电流 is a flow of electric charge. It is measured in **amperes** 安培 (A) with an **ammeter** 电流表, joined in series in the circuit.

Current is the charge that passes a point each second:

$$I = \frac{Q}{t}$$

Here I is current (A), Q is charge (C) and t is time (s). Rearranged, $Q = It$.

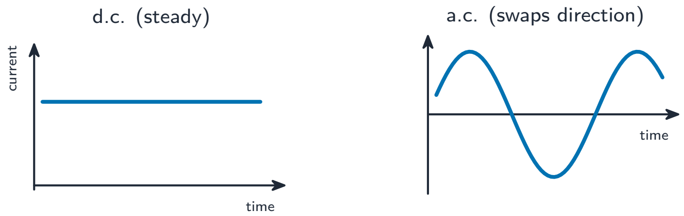
Worked example. A current of 3.0 A flows through a lamp for 20 s. How much charge passes through it?

$$Q = It = 3.0 \times 20 = 60 \text{ C}$$

In a metal the current is a flow of **free electrons** 自由电子. There are two "directions" to know:

- **Conventional current** 常规电流 is taken to flow from + to − round the outside of the cell.
- The free electrons really drift the other way, from − to +.

A **direct current** 直流电 (d.c.) always flows one way, as from a battery. An **alternating current** 交流电 (a.c.) keeps swapping direction many times each second, as from the **mains supply** 市电.



Direct current is steady in one direction; alternating current keeps swapping direction, crossing zero many times each second

E.m.f. and potential difference

A cell gives **energy** 能量 to the charges that move through it. Two quantities describe this, and both are measured in **volts** 伏特 (V).

- The **electromotive force** 电动势 (e.m.f.) of a source is the electrical work it does to drive unit charge all the way round a complete **circuit** 电路.
- The **potential difference** 电势差 (p.d.) across a component is the work done by unit charge as it passes *through that component.*

A **voltmeter** 电压表 measures e.m.f. or p.d. It is joined in parallel (across the component).

*A voltmeter across the **cell** reads the e.m.f. (energy each coulomb is given); a voltmeter across the **lamp** reads the p.d. (energy each coulomb spends there).*

Both are work done per unit charge:

$$E = \frac{W}{Q}, \qquad V = \frac{W}{Q}$$

where W is the energy transferred (J) and Q is the charge (C). For example, if a cell does 120 J of work moving 60 C of charge round a circuit, its e.m.f. is $120/60 = 2$ V.

Resistance

Resistance 电阻 measures how hard it is for current to flow. A bigger resistance gives a smaller current. It is measured in **ohms** 欧姆 (Ω).

$$R = \frac{V}{I}$$

To find the resistance of a component, join an ammeter in series (to read I) and a voltmeter across it (to read V), then divide.

Worked example. A 12 V battery drives a current of 0.50 A through a lamp. Find the lamp's resistance.

$$R = \frac{V}{I} = \frac{12}{0.50} = 24\ \Omega$$

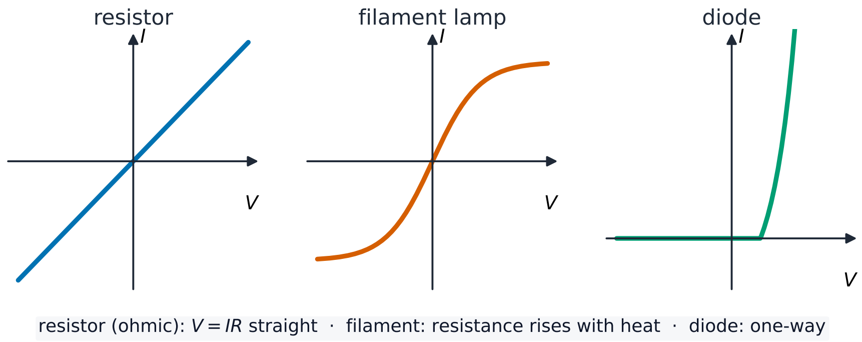
For a metal wire at constant temperature:

- a longer wire has a bigger resistance — resistance is **directly proportional** 成正比 to length, $R \propto l$;
- a thicker wire has a smaller resistance — resistance is **inversely proportional** 成反比 to **cross-sectional area** 横截面积, $R \propto \frac{1}{A}$.

So doubling the length doubles the resistance; doubling the area halves it. (Area depends on the diameter squared, so a small change in diameter changes the resistance a lot.)

Current–voltage graphs show how three components behave:

Component	Shape of the I–V graph	What it tells you
resistor 电阻器 (fixed)	straight line through the origin	resistance is constant, so $I \propto V$
filament lamp 灯丝灯泡	S-shaped, getting flatter as V rises	the wire heats up, so its resistance rises
diode 二极管	current one way only	very high resistance the "wrong" way



A resistor gives a straight line; a filament lamp curves as it heats up; a diode lets current pass only one way

Electrical energy and power

A circuit transfers energy from a source (a cell or the mains) to the components, and then into the surroundings (often as heat, light or sound).

Electrical power 电功率 is the energy transferred each second, measured in **watts** 瓦特 (W):

$$P = IV$$

The **electrical energy** 电能 transferred in a time t, measured in **joules** 焦耳 (J), is:

$$E = IVt$$

Worked example. A 12 V motor draws a current of 2.0 A. Find its power, and the energy it transfers in 30 s.

$$P = IV = 2.0 \times 12 = 24 \text{ W}$$

$$E = Pt = 24 \times 30 = 720 \text{ J}$$

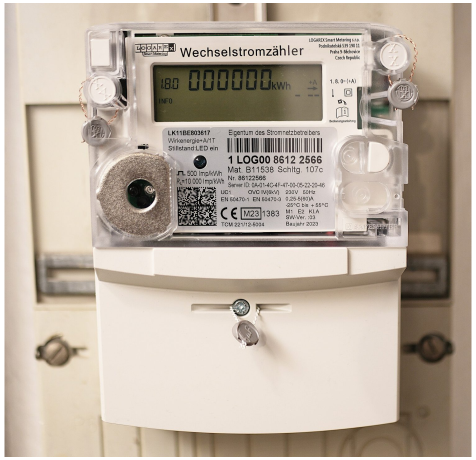
The kilowatt-hour

Home electricity bills use a bigger energy unit, the **kilowatt-hour** 千瓦时 (kWh). One kilowatt-hour is the energy used by a 1 kW **appliance** 电器 in 1 hour.

$$\text{energy (kWh)} = \text{power (kW)} \times \text{time (h)}$$

$$\text{cost} = \text{energy (kWh)} \times \text{price per kWh}$$

For example, a 2 kW **heater** 加热器 used for 3 hours uses $2 \times 3 = 6$ kWh. If one kWh costs 20 cents, the cost is $6 \times 20 = 120$ cents.



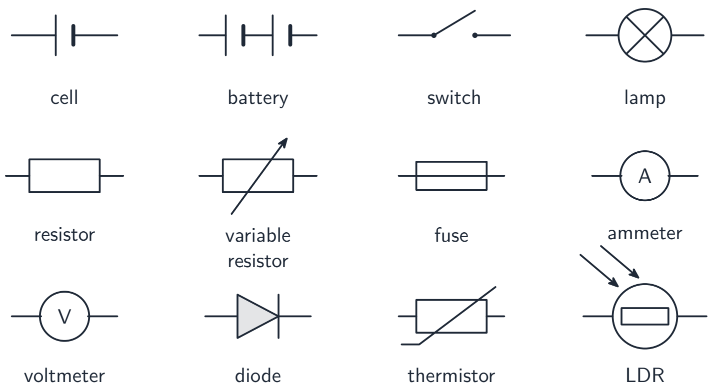
A household electricity meter counts the energy used, in kilowatt-hours (kWh) — the number it shows is what you pay for

Circuits

Circuit components

You should know these components and how they behave:

Component	What it does
cell 电池 / **battery** 电池组	drives current round the circuit (a battery is two or more cells)
power supply 电源	a source of d.c. or a.c.
switch 开关	breaks or completes the circuit
resistor (fixed)	gives a fixed resistance
variable resistor 可变电阻器	a resistance you can change, to control the current
fuse 保险丝	melts and breaks the circuit if the current is too big
lamp / **heater**	turns electrical energy into light / into heat
thermistor 热敏电阻	its resistance falls as it gets hotter
light-dependent resistor 光敏电阻 (LDR)	its resistance falls as the light gets brighter
diode / **light-emitting diode** 发光二极管 (LED)	lets current one way only; an LED also gives out light
relay 继电器	a switch worked by an electromagnet (small current controls a big one)
motor 电动机	turns electrical energy into movement
bell 电铃	makes a sound
transformer 变压器	changes the size of an a.c. voltage



The standard symbols used to draw circuit diagrams

Real resistors: the coloured bands give each one's resistance in ohms

Series and parallel

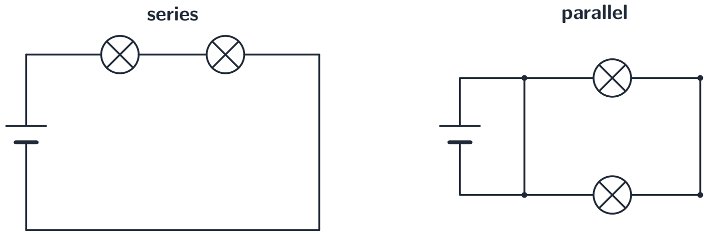
In a **series** 串联 circuit the parts form one single loop:

- the current is the same at every point;
- the supply p.d. is shared between the components;
- cells in series add their e.m.f.s (when they point the same way);
- resistors in series add up: $R_{\text{total}} = R_1 + R_2 + \ldots$

In a **parallel** 并联 circuit the parts are on separate branches:

- each branch gets the full supply p.d.;
- the current splits, so the current from the source is bigger than the current in any one branch;
- the **total resistance** 总电阻 is less than the smallest single resistance.

Lamps in a home are wired in parallel: each gets the full voltage, and if one fails the others stay on.



In a series circuit the components share one loop; in a parallel circuit each lamp has its own branch

For calculations (with the rules above):

- at a **junction** 节点, the total current flowing in equals the total current flowing out;
- in series, the supply p.d. equals the sum of the p.d.s across the components;
- in parallel, the p.d. across each branch is the same;
- two resistors in parallel combine as

$$\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2}$$

Worked example. A 6 Ω resistor and a 3 Ω resistor are connected in parallel. Find their combined resistance.

$$\frac{1}{R_{\text{total}}} = \frac{1}{6} + \frac{1}{3} = \frac{1}{6} + \frac{2}{6} = \frac{3}{6} = \frac{1}{2} \quad \Rightarrow \quad R_{\text{total}} = 2\ \Omega$$

Notice the combined resistance (2 Ω) is smaller than the smaller of the two resistors.

Potential dividers

Two resistors in series share the supply voltage. This is a **potential divider** 分压器. For the same current, a bigger resistance has a bigger p.d. across it, so the bigger resistor takes the bigger share:

$$\frac{R_1}{R_2} = \frac{V_1}{V_2}$$

A *variable* potential divider (or a variable resistor) lets you change the output voltage smoothly, for example from 0 V up to the full supply. If you use a thermistor or an LDR as one of the resistors, the output voltage changes with temperature or light — handy for switching a heater or a lamp on and off automatically.

Electrical safety

A home is fed by the mains. The mains is dangerous if it is used wrongly.

Hazards

These are **hazards** 危险 (dangers) with mains electricity:

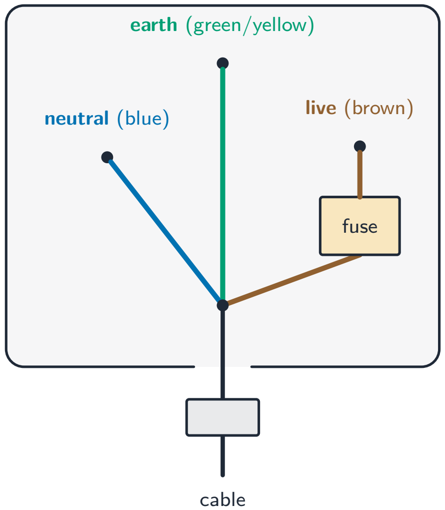
- damaged **insulation** 绝缘层 — bare wires can give a shock or start a fire;
- **overheating** 过热 cables — too much current makes a cable hot, which can start a fire;
- **damp** 潮湿 conditions — water lets current pass into a person, raising the risk of a shock;
- **overloading** 过载 — plugging too many appliances into one **socket** 插座 draws too much current.

Live, neutral and earth

A mains cable has three wires:

- the **live wire** 火线 carries the high voltage;
- the **neutral wire** 零线 completes the circuit at about zero voltage;
- the **earth wire** 地线 is a safety wire joined to the ground.

A switch (and a fuse) must be fitted in the *live* wire. Then, when the switch is off, the appliance is cut off from the high voltage and is safe to touch.



*In a three-pin plug the **live** (brown) and **neutral** (blue) carry the current, the **earth** (green/yellow) is the safety wire, and the **fuse** always sits in the live wire.*

Fuses, trip switches and earthing

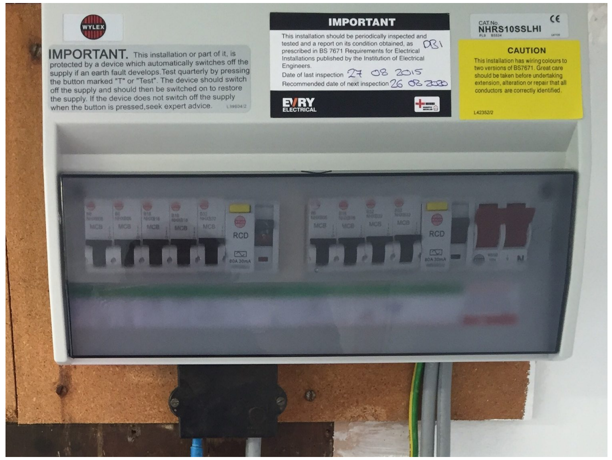
A fuse is a thin wire that melts if the current gets too big, breaking the circuit before the cable overheats. Choose a **fuse rating** 额定值 just above the normal working current — for example a 13 A fuse for an appliance that normally uses about 10 A.

A **trip switch** 跳闸开关 (circuit breaker) does the same job but acts faster and can be reset instead of replaced.

The metal **casing** 外壳 of an appliance must be made safe in one of two ways:

- **earthed** 接地: the casing is joined to the earth wire. If a live wire touches the casing, a large current flows to earth and blows the fuse.

- **double-insulated** 双重绝缘: the casing is plastic, so it can never become live. Such an appliance needs no earth wire; its fuse still protects the cable.



A home consumer unit: each MCB is a trip switch that cuts off its circuit when the current gets too big; the RCD (80 A, 30 mA) cuts off even faster if it detects a fault to earth

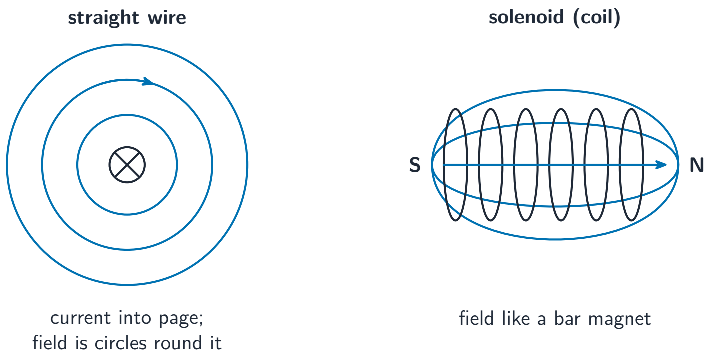
Electromagnetic effects

The magnetic effect of a current

A current in a wire makes a magnetic field around it.

- Around a straight wire the field lines are circles around the wire; the field is stronger close to the wire. Reverse the current and the field reverses.
- A **solenoid** 螺线管 (a long **coil** 线圈 of wire) makes a field just like a bar magnet, with a N pole at one end and a S pole at the other. The field inside is strong and even.

You can show both patterns with iron filings or a plotting compass. The field gets stronger if you increase the current, add more turns, or place a soft-iron core inside.



A current makes circular field lines around a straight wire, and a bar-magnet-like field for a solenoid

The magnetic effect is used in a relay and in a loudspeaker: in a **loudspeaker** 扬声器 a changing current in a coil makes the coil push and pull a paper cone, which moves the air and makes sound.

Electromagnetic induction

When a wire moves across a magnetic field, or the field through a coil changes, an e.m.f. is **induced** in the wire. If the wire is part of a complete circuit, this e.m.f. drives a current. This is **electromagnetic induction** 电磁感应.

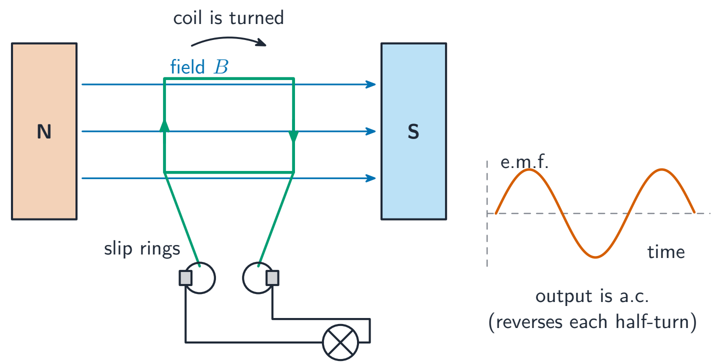
To show it: move a magnet in and out of a coil joined to a sensitive meter, and watch the needle flick. The induced e.m.f. is bigger when you use a stronger magnet, move

faster, or use more turns on the coil. The induced e.m.f. always acts to *oppose* the change that causes it.

The a.c. generator

An **a.c. generator** 交流发电机 turns movement into electricity. A coil is spun in a magnetic field (or a magnet is spun near a coil). As it turns, the field through the coil keeps changing, so an alternating e.m.f. is induced.

- **Slip rings** 滑环 and carbon **brushes** 电刷 carry the current out to the circuit while the coil keeps turning.
- The e.m.f. is largest when the coil is flat (moving fastest across the field) and zero when the coil is upright (moving along the field). So the e.m.f.–time graph is a wave: peak, zero, opposite peak, zero, for each turn.



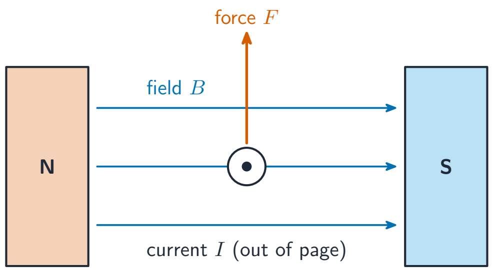
Turning the coil induces an alternating e.m.f.; the slip rings carry the a.c. out to the circuit

Force on a current-carrying conductor

When a current-carrying wire lies in a magnetic field, the field of the wire and the field of the magnet push on each other, so the wire feels a force. This is the **motor effect**.

- Reverse the current, *or* reverse the field, and the force reverses.
- Make the current bigger or the field stronger, and the force is bigger.

The force, the field and the current are at right angles to one another. You can find the force direction with the left-hand rule: thumb = force (motion), first finger = field (N to S), second finger = current.



F, B and I are all at $90°$ (Fleming's left-hand rule)

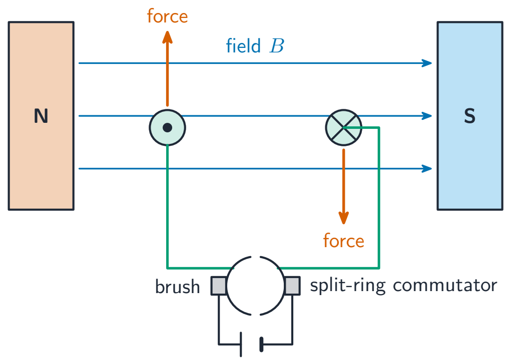
A current-carrying wire in a magnetic field feels a force at right angles to both the field and the current

A moving stream of charged particles is a current, so a magnetic field pushes it sideways too — it **deflects** 偏转 the beam. (Remember electrons flow opposite to the conventional current.)

The d.c. motor

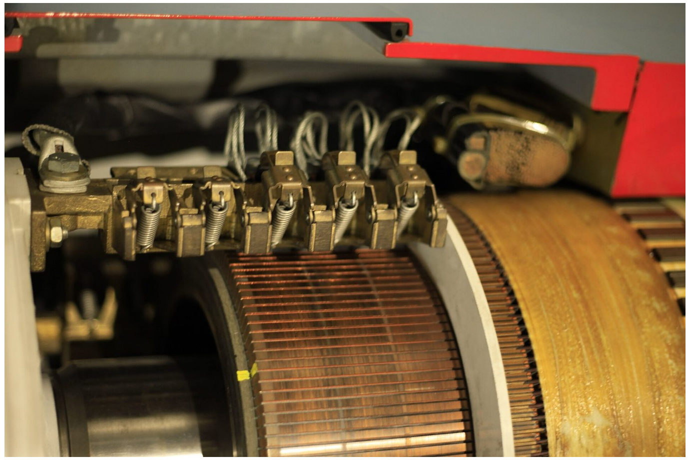
A coil carrying a current in a magnetic field feels a **turning effect** 转动效应, because the forces on its two sides act in opposite directions. This is a **d.c. motor** 直流电动机. The turning effect is bigger with more turns on the coil, a bigger current, or a stronger field.

A **split-ring commutator** 换向器 swaps the current direction in the coil every half-turn. This keeps the coil turning the same way instead of stopping after half a turn.



the two forces form a couple that turns the coil

The forces on the two sides of the coil form a couple; the split-ring commutator keeps it turning one way



In a real d.c. machine, carbon brushes press on the copper commutator bars to feed current to the spinning coil

The transformer

A **transformer** changes the size of an a.c. voltage. It has two coils wound on a **soft-iron core** 软铁芯:

- the **primary coil** 原线圈 takes in the a.c. voltage;
- the **secondary coil** 副线圈 gives out the changed voltage.

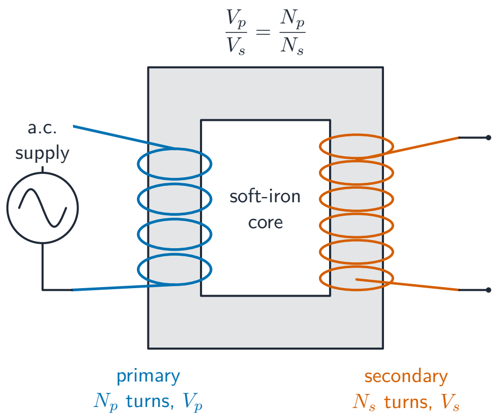
The a.c. in the primary makes a changing magnetic field in the core. The core carries this field to the secondary, where it induces an a.c. e.m.f. The voltages and the numbers of turns are linked by:

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

Worked example. A transformer has 1200 turns on the primary coil and 100 turns on the secondary coil. The primary is connected to a 240 V a.c. supply. Find the secondary voltage.

$$\frac{240}{V_s} = \frac{1200}{100} = 12 \quad \Rightarrow \quad V_s = \frac{240}{12} = 20 \text{ V}$$

Fewer turns on the secondary, so this is a step-down transformer.



The changing field in the core links the two coils; the voltage ratio equals the turns ratio

A real transformer on a power pole steps the high voltage in the cables down to a safer voltage for homes

If the secondary has more turns it is a **step-up** 升压 transformer (voltage rises); fewer turns make a **step-down** 降压 transformer (voltage falls). For example, a transformer changing 240 V to 12 V is a step-down type, and the primary has 20 times as many turns as the secondary.

If a transformer is 100% efficient, the power in equals the power out:

$$I_p V_p = I_s V_s$$

So a step-up transformer raises the voltage but lowers the current.

Why we use high voltage to send power

Electricity is sent across the country by **high-voltage transmission** 高压输电. The power lost as heat in the cables is

$$P = I^2 R$$

where R is the resistance of the cables. A step-up transformer raises the voltage and so lowers the current for the same power ($P = IV$). A smaller current means much less power wasted in the cables. A step-down transformer then lowers the voltage again to a safe value before it reaches homes.

Pylons hold the cables that carry electricity at very high voltage, which keeps the current — and the wasted power — low

Exam tips

- **Current** is the same everywhere in a **series** circuit; in a **parallel** circuit it splits between the branches. Voltage (p.d.) is shared out in series, but is the same across every parallel branch.
- Adding resistors in **series** increases the total resistance ($R_1 + R_2$); adding them in **parallel** makes the total *less* than the smallest single resistor.

- An **ammeter** goes in *series* and has very low resistance; a **voltmeter** goes in *parallel* across a component and has very high resistance.
- In a **transformer** $\frac{V_p}{V_s} = \frac{N_p}{N_s}$: more turns on the secondary steps the voltage *up*, fewer steps it *down*. Transformers only work on a.c.
- Power is sent across country at **high voltage** so the current — and the heat wasted in the cables, $P = I^2R$ — is small.
- Fit the **switch and the fuse in the live wire**, and choose a fuse rating just above the appliance's normal working current.

Nuclear physics

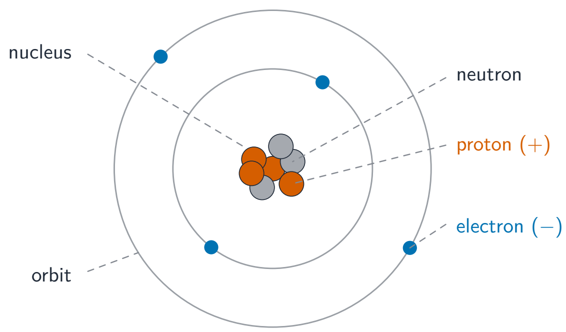
IGCSE Physics

The atom

An **atom** 原子 is made of a tiny central **nucleus** 原子核 with **electrons** 电子 moving around it (in **orbit** 轨道, like planets around the Sun).

- The nucleus has a positive **charge** 电荷.
- The electrons have a negative charge.
- The atom as a whole is neutral, because the positive and negative charges are equal.

Almost all the **mass** 质量 is in the nucleus, but the nucleus is very small compared with the whole atom. So an atom is mostly empty space.



The nuclear atom: a tiny dense nucleus of protons and neutrons, with electrons in orbits around it

Ions

An atom is neutral, but it can gain or lose electrons to become an **ion** 离子.

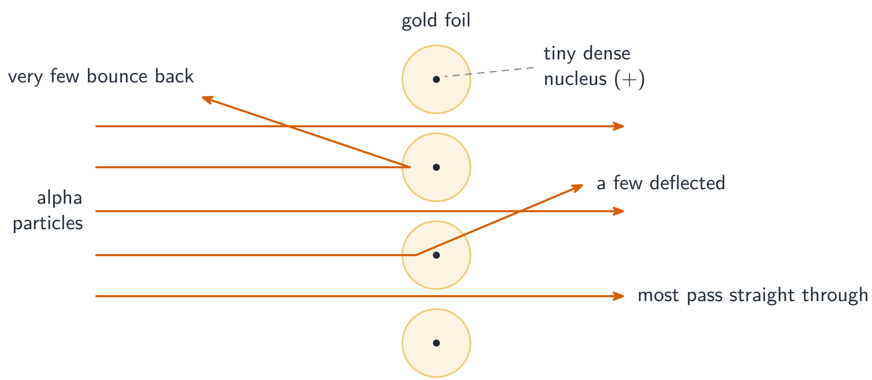
- Lose one or more electrons → a positive ion (now there are more protons than electrons).
- Gain one or more electrons → a negative ion.

The alpha-scattering experiment

This experiment gave the evidence for the nuclear model. **Alpha particles** α 粒子 (small, fast, positive) were fired at a very thin **gold foil** 金箔, and the **scattering** 散射 (the way they bounced off) was watched.

The results and what they tell us:

- Almost all the alpha particles went straight through. → The atom is mostly empty space.
- A few were **deflected** 偏转 (bent) through small angles. → The nucleus has a positive charge, which pushes the positive alpha particles away.
- A very few bounced almost straight back. → The nucleus is very small and very heavy, and holds most of the mass of the atom.



Most alpha particles pass straight through; a few are deflected and a very few bounce back off the tiny dense nucleus

Inside the nucleus

The nucleus is made of two kinds of particle, together called **nucleons** 核子:

- **protons** 质子, which have a **relative** 相对 charge of +1;
- **neutrons** 中子, which have a relative charge of 0 (they are neutral).

An electron has a relative charge of −1. A proton and a neutron each have a **relative mass** of about 1; an electron is almost massless in comparison.

Two numbers describe a nucleus:

- the **proton number** 质子数 Z (also called the atomic number) — the number of protons;
- the **nucleon number** 核子数 A (also called the mass number) — the number of protons plus neutrons.

So the number of neutrons is $A - Z$.

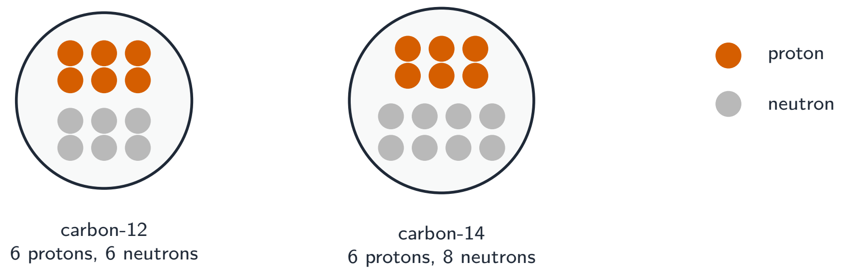
We write a nucleus in **nuclide** 核素 notation:

$$^{A}_{Z}\mathrm{X}$$

where X is the chemical symbol. For example, $^{197}_{79}\mathrm{Au}$ has 79 protons and $197 - 79 = 118$ neutrons. The relative charge of the whole nucleus is just $+Z$ (here $+79$), and its relative mass is about A.

Isotopes

Isotopes 同位素 are atoms of the same element (the same Z) but with different numbers of neutrons (different A). They behave the same in chemistry but differently in the nucleus. For example, $^{12}_{6}\mathrm{C}$ and $^{14}_{6}\mathrm{C}$ are both carbon.

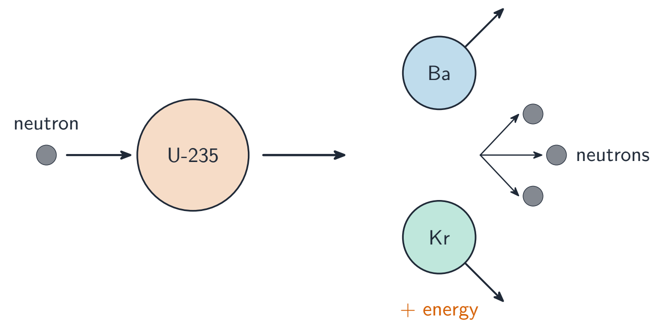


Isotopes of carbon have the same six protons but different numbers of neutrons, so they are the same element with a different mass

Nuclear fission and fusion

In **nuclear fission** 核裂变, a heavy nucleus absorbs a neutron and then splits into two smaller nuclei, giving out two or three neutrons and a lot of **energy** 能量:

$$^{235}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \rightarrow \ ^{141}_{56}\mathrm{Ba} + ^{92}_{36}\mathrm{Kr} + 3\,^{1}_{0}\mathrm{n}$$

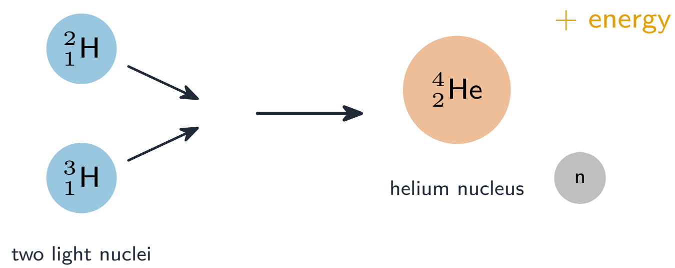


A neutron splits a U-235 nucleus into two smaller nuclei, releasing more neutrons and energy

The top numbers (nucleon numbers) balance on both sides, and so do the bottom numbers (proton numbers). You can use this to find a missing number — for example, how many neutrons are released.

In **nuclear fusion** 核聚变, two light nuclei join to make a heavier one, also giving out energy. This is how the Sun makes its energy, joining **hydrogen** 氢 nuclei to make **helium** 氦. The reaction below — two heavy forms of hydrogen (deuterium and tritium) joining into helium — is the one used in fusion reactors on Earth:

$$^{2}_{1}\mathrm{H} + ^{3}_{1}\mathrm{H} \rightarrow \ ^{4}_{2}\mathrm{He} + ^{1}_{0}\mathrm{n}$$



In fusion two light nuclei join into a heavier one, releasing a neutron and energy — the deuterium–tritium reaction used in fusion reactors

In both fission and fusion, a small amount of mass is lost and turned into energy.

A nuclear power station uses the energy from fission to make electricity; the towers release waste heat as steam

Radioactivity

A nucleus that is **unstable** 不稳定 will sooner or later break down and give out **radiation** 辐射. This is **radioactive** 放射性 **decay** 衰变. A nucleus may be unstable because it has too many neutrons, or because it is too heavy.

Decay is **spontaneous** 自发 (it happens on its own, and you cannot speed it up or slow it down) and **random** 随机 (you cannot say which nucleus will decay next, or exactly when).

Background radiation

Some radiation is around us all the time. This is **background radiation** 背景辐射. Its main sources are:

- **radon** 氡 gas in the air (usually the biggest source);
- rocks and buildings;
- food and drink;
- **cosmic rays** 宇宙射线 from space.

Measuring radiation

Radiation can be measured with a **detector** 探测器 joined to a **counter** 计数器. The **count rate** 计数率 is the number of counts each second (or each minute).

To find the true count rate from a source, first measure the background count rate on its own, then subtract it. The answer is the **corrected** 修正 count rate:

$$\text{corrected count rate} = \text{measured count rate} - \text{background count rate}$$

Worked example. A detector placed next to a source reads 250 counts/min. With the source taken away, the background count rate is 30 counts/min. Find the corrected count rate.

$$250 - 30 = 220 \text{ counts/min}$$

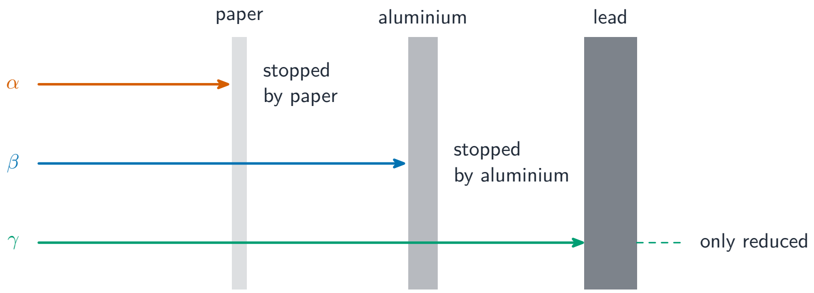
A Geiger counter detects radiation and shows the count rate, here in counts per minute (CPM)

The three types of radiation

The radiation can be one of three types. Each type is **ionising** 电离, which means it can knock electrons off atoms in its path.

Type	What it is	Ionising effect	Stopped by
alpha (α)	a helium nucleus: 2 protons + 2 neutrons, charge +2	strongest	a sheet of paper, or a few cm of air
beta (β)	a fast-moving electron, charge −1	medium	a few mm of **aluminium** 铝
gamma (γ)	a high-energy **electromagnetic wave** 电磁波, no charge	weakest	thick **lead** 铅 or concrete (only reduced, never fully stopped)

So an **alpha particle** is the most **ionising** but the least **penetrating** 穿透 (it is easily **absorbed** 吸收). A **beta particle** β 粒子 is in the middle. **Gamma radiation** γ 射线 is the least ionising but the most penetrating.

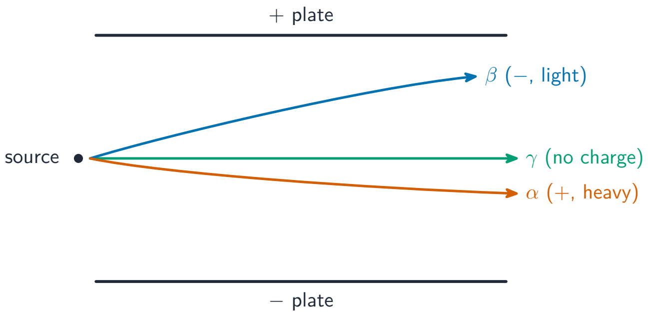


Paper stops alpha, a few millimetres of aluminium stops beta, and thick lead only reduces gamma

We can explain the ionising effects from charge and **kinetic energy** 动能: an alpha particle has a large charge (+2) and is slow and heavy, so it pulls strongly on the electrons it passes and ionises a lot. A beta particle has a smaller charge and moves faster, so it ionises less.

Deflection in fields

Because alpha and beta particles are charged, they are deflected by an **electric field** 电场 and by a **magnetic field** 磁场. They bend in *opposite* directions, because their charges have opposite signs, and the lighter beta particle bends more. Gamma rays have no charge, so they are not deflected at all.



Alpha and beta bend in opposite directions; the lighter beta bends more, and uncharged gamma is not deflected

Decay equations

When a nucleus decays, the nucleon and proton numbers must balance on both sides.

Alpha decay — the nucleus loses 2 protons and 2 neutrons, so A falls by 4 and Z falls by 2. It becomes a *different element*:

$$^{A}_{Z}\mathrm{X} \rightarrow\ ^{A-4}_{Z-2}\mathrm{Y} + ^{4}_{2}\alpha$$

Worked example. A radium nucleus $^{226}_{88}\mathrm{Ra}$ emits an alpha particle. Find the nucleon number and proton number of the new nucleus.

Alpha decay lowers A by 4 and Z by 2:

$$^{226}_{88}\mathrm{Ra} \rightarrow\ ^{222}_{86}\mathrm{Rn} + ^{4}_{2}\alpha$$

So the new nucleus (radon) has nucleon number 222 and proton number 86.

Beta decay — inside the nucleus a neutron changes into a proton plus an electron:

$$\text{neutron} \rightarrow \text{proton} + \text{electron}$$

The fast electron leaves as the beta particle. So A stays the same but Z rises by 1, giving a different element:

$$^{24}_{11}\mathrm{Na} \rightarrow\ ^{24}_{12}\mathrm{Mg} + ^{0}_{-1}\beta$$

Gamma emission — the nucleus loses only energy, so A and Z do not change. Alpha and beta decay leave the nucleus more **stable** 稳定; gamma is often given out at the same time to carry away spare energy.

Half-life

Because decay is random, we cannot follow one nucleus. Instead we describe a large **sample** 样品 using its half-life.

The **half-life** 半衰期 of an isotope is the time taken for half the unstable nuclei in a sample to decay. After each half-life, the count rate (or the number of unstable nuclei left) falls to half.

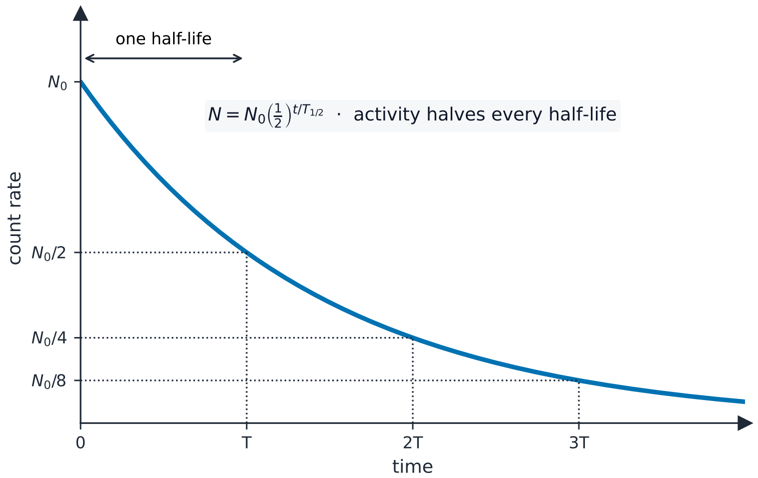
For example, if a source has a count rate of 800 counts/min and a half-life of 3 hours:

Time / hours	0	3	6	9
Count rate / (counts/min)	800	400	200	100

After 6 hours (two half-lives) the count rate has halved twice: 800 → 400 → 200. You can read a half-life off a decay graph by finding the time for the count rate to drop from any value to half of it.

Worked example. The activity of a source falls from 800 counts/min to 100 counts/min. Its half-life is 5 days. How long did this take?

Count the halvings: 800 → 400 → 200 → 100 is three half-lives, so the time is $3 \times 5 = 15$ days.



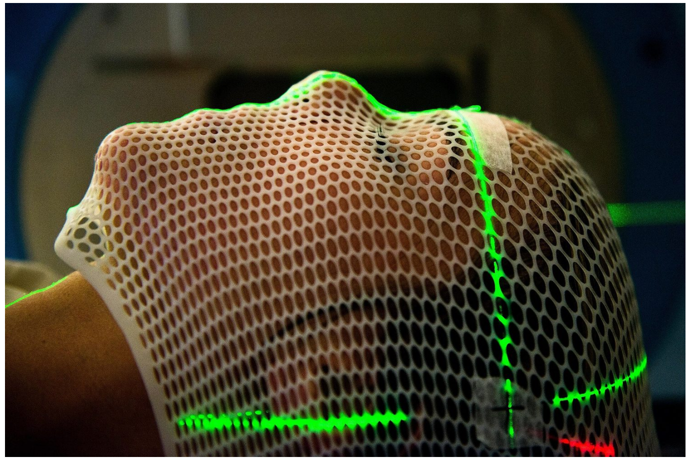
Each half-life T the count rate halves: $N_0 \to N_0/2 \to N_0/4 \to N_0/8$

Uses of radioactivity

The isotope chosen for a job depends on its type of radiation and its half-life:

- **smoke alarms** 烟雾报警器 use an alpha source (alpha is easily blocked, so it is safe outside the alarm, and a long half-life means it lasts for years);
- using radiation on food, or on equipment, kills **bacteria** 细菌 and germs — this needs penetrating gamma rays to **sterilise** 消毒 the sealed item;
- measuring and controlling the thickness of paper or metal sheets uses a beta source (the amount that passes through changes with the thickness);

- gamma rays are used to find and to treat **cancer** 癌症 inside the body, because they can pass out of (or into) the body.



Radiotherapy: a mesh mask holds the patient still while alignment lasers aim gamma rays precisely at a tumour to treat cancer

Safety

Ionising radiation harms **living cells** 细胞. It can cause cell death, **mutations** 突变 (changes to the genes) and cancer.

When working with radioactive sources, keep the **dose** 剂量 (the amount of radiation received) low by:

- reducing the **exposure** 照射 time — spend as little time near the source as possible;
- increasing the distance between you and the source;
- using **shielding** 屏蔽, such as lead, between the source and your body.

Radioactive sources should be handled with tongs (not bare hands), kept pointing away from people, and stored in a lead-lined box.

Exam tips

- The **nucleon number** (top) is protons + neutrons; the **proton number** (bottom) is protons only. Number of neutrons = nucleon number − proton number.
- **Isotopes** have the same proton number but different nucleon numbers — the same element with a different number of neutrons.

- Rank the radiations two ways: **alpha** is the most ionising but least penetrating (stopped by paper); **gamma** is the least ionising but most penetrating (needs thick lead). Beta is in between (stopped by a few mm of aluminium).
- In every **decay equation** the top numbers must balance and the bottom numbers must balance. Alpha decay: $A-4$, $Z-2$. Beta decay: A unchanged, $Z+1$.
- Always subtract the **background count rate** before using a source's readings. After n half-lives the count rate has halved n times — count the halvings rather than guessing from the total time.

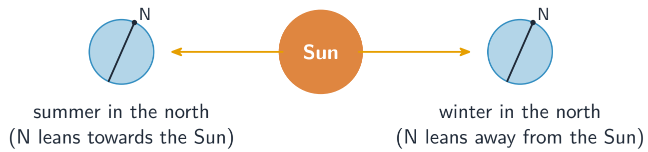
Space physics

IGCSE Physics

The Earth, the Sun and the Moon

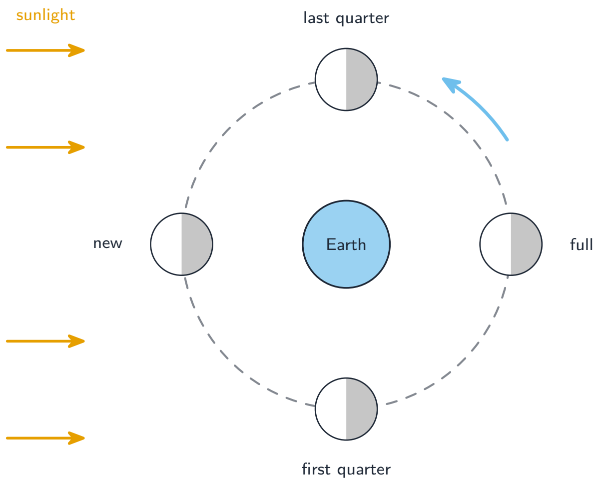
The Earth spins (**rotates** 自转) on its **axis** 轴 once in about 24 hours. The axis is **tilted** 倾斜 (not straight up). This spin gives us day and night, and makes the **Sun** 太阳 appear to move across the sky each day.

The Earth also moves around the Sun in an **orbit** 轨道, once in about 365 days (one year). Because the axis is tilted, different parts of the Earth lean towards the Sun at different times of the year. This gives the **seasons** 季节: it is summer in the half of the Earth that leans towards the Sun.



The axis keeps the same tilt all year, so each hemisphere leans toward the Sun for one half of the orbit and away for the other

The **Moon** 月球 orbits the Earth once in about one month. As it goes round, we see different amounts of its lit side, which gives the **phases** 月相 of the Moon (new moon, half moon, full moon).



The Moon's lit half always faces the Sun, so as it orbits we see different amounts of it: a new moon between us and the Sun, a full moon opposite the Sun, and half moons in between

So, from shortest to longest: one day (Earth's spin) $<$ one month (Moon's orbit) $<$ one year (Earth's orbit).

The full Moon, Earth's natural satellite

Orbital speed

For an object going round a circle, the distance for one full orbit is the **circumference** 周长 $2\pi r$, where r is the radius of the orbit. The **orbital speed** 轨道速率 is this distance divided by the **period** 周期 T (the time for one orbit):

$$v = \frac{2\pi r}{T}$$

The same equation works for planets, moons and satellites.

Worked example. A space station orbits the Earth at a radius of $r = 7000$ km and takes $T = 5800$ s for one orbit. Find its orbital speed.

First convert the radius to metres: $7000 \text{ km} = 7.0 \times 10^6$ m. Then

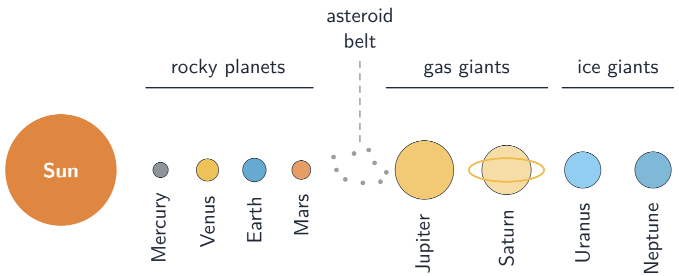
$$v = \frac{2\pi r}{T} = \frac{2\pi \times 7.0 \times 10^6}{5800} \approx 7600 \text{ m/s}$$

The ISS in orbit: orbital speed is the speed that keeps a satellite in free-fall circular motion

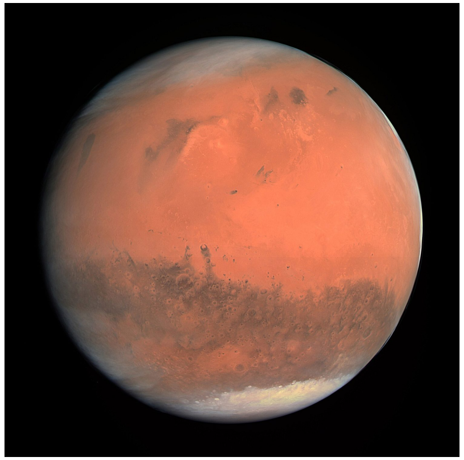
The Solar System

The **Solar System** 太阳系 has one star, the Sun, at its centre. Around it move the eight **planets** 行星. In order from the Sun they are: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune.

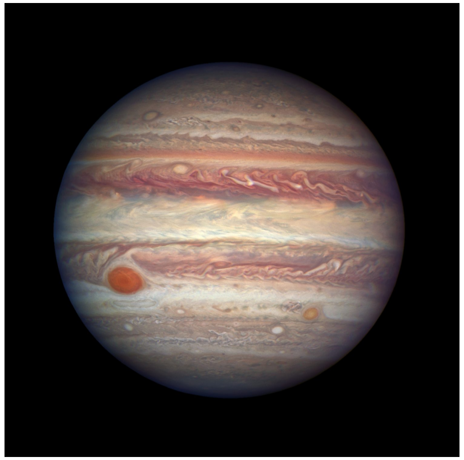
- The four planets nearest the Sun are small and **rocky** 岩石.
- The four planets furthest from the Sun are large and **gaseous** 气态 — they are made mostly of gas 气体, with no solid surface to stand on.
- The two nearer giants, Jupiter and Saturn, are **gas giants** 气态巨行星. The two outer giants, Uranus and Neptune, are **ice giants** 冰巨行星: they hold much more ice, so they are not true gas giants.



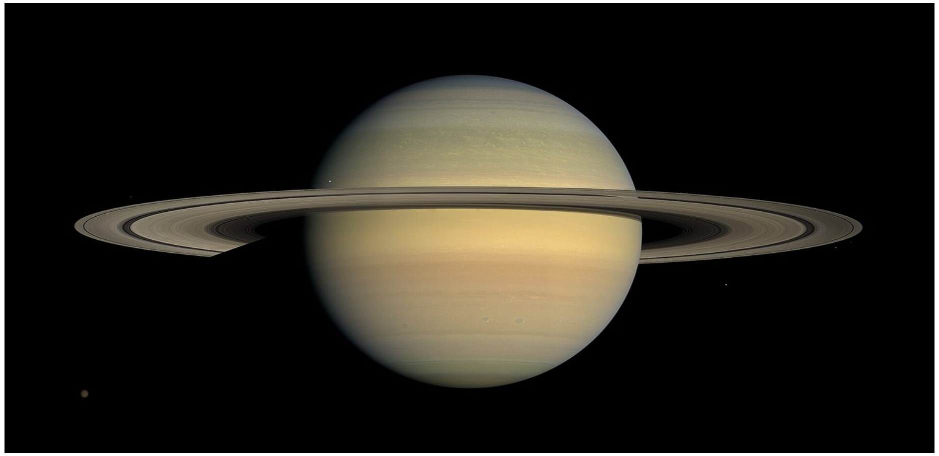
The Sun and its eight planets in order: four small rocky planets, then the asteroid belt, then four large gaseous planets — the gas giants Jupiter and Saturn and the ice giants Uranus and Neptune (not to scale)



Mars, the red planet, one of the rocky inner planets



Jupiter, the largest planet, with its swirling bands of gas



Saturn and its rings, photographed by the Cassini spacecraft

The Solar System also contains:

- minor planets, such as **dwarf planets** 矮行星 like Pluto, and **asteroids** 小行星 (most lie in the asteroid belt between Mars and Jupiter);
- moons (natural **satellites** 卫星) that orbit the planets;
- **comets** 彗星 and other small bodies.

Orbits and gravity

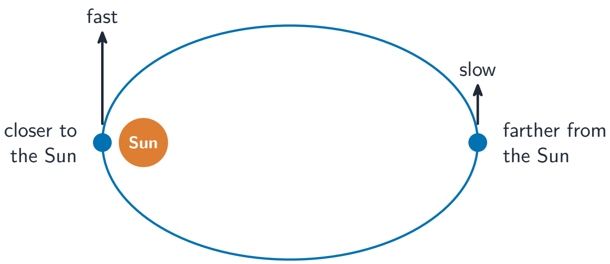
The Sun holds most of the mass of the Solar System. Its **gravity** 引力 (gravitational pull) reaches out and keeps the planets in their orbits. This force is the gravitational attraction of the Sun.

The **gravitational field strength** 重力场强度 tells you how strong gravity is:

- at the surface of a planet it is bigger for a planet with more mass;
- around a planet it gets weaker as you move further away.

In the same way, the Sun's gravity gets weaker further out, so the outer planets move more slowly (smaller orbital speed) than the inner ones.

Most orbits are not perfect circles but **ellipses** 椭圆 (a stretched circle), and the Sun is not at the centre of the ellipse. A comet has a very stretched orbit. An object in an elliptical orbit moves **faster** when it is closer to the Sun. We explain this with the **conservation of energy** 能量守恒 — the total **energy** 能量 stays the same, so as the object's **gravitational potential energy** 重力势能 falls (coming closer), its **kinetic energy** 动能 rises (it speeds up).



The Sun sits at one focus of the ellipse; the planet speeds up as it comes closer and slows down as it moves away

Light travel time

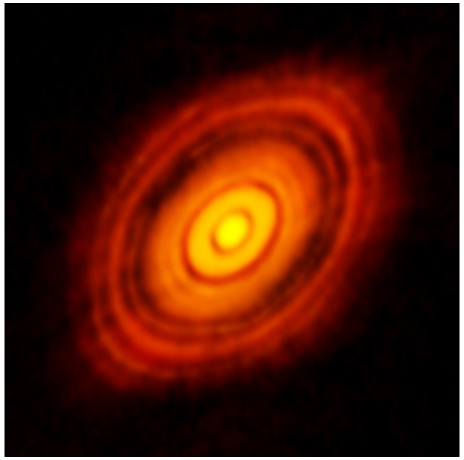
Distances in space are huge, so we often work out how long light takes to cross them. Light travels at 3.0×10^8 m/s. Using time $= \frac{\text{distance}}{\text{speed}}$, light from the Sun (about 1.5×10^{11} m away) takes about 500 s, which is roughly 8 minutes, to reach the Earth.

How the Solar System formed

The planets formed from a giant cloud of **gas** and **dust** 尘埃 in space, which contained many chemical **elements** 元素. This is the **accretion** 吸积 model:

- gravity pulled the cloud together;
- the cloud was spinning, so it flattened into a spinning **accretion disc** 吸积盘;
- most of the matter fell to the centre and became the Sun, while the planets grew from the leftover material in the disc.

Near the hot young Sun, only rock and metal could stay solid, so the inner planets are rocky. Far out, where it was cold, gases could also collect, so the outer planets grew large and gaseous.

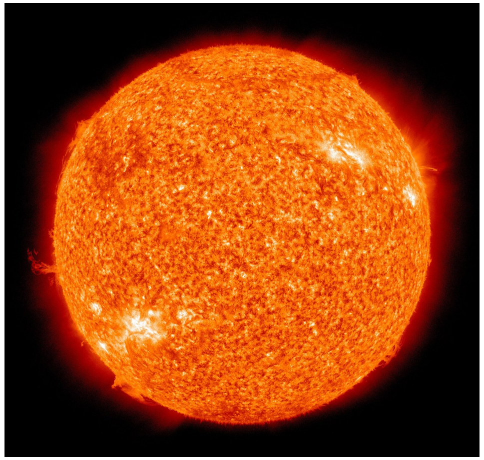


A real accretion disc around the young star HL Tauri: the dark gaps are where new planets are gathering up the dust — our Solar System began the same way

The Sun as a star

The Sun is a **star** 恒星 of medium size, made mostly of **hydrogen** 氢 and **helium** 氦. It radiates most of its **energy** in the infrared, visible light and **ultraviolet** 紫外线 parts of the **electromagnetic spectrum** 电磁波谱.

A star is powered by **nuclear reactions** 核反应 in its core. In a stable star, the reaction is **nuclear fusion** 核聚变: hydrogen nuclei join to make helium, releasing huge amounts of energy.



The Sun, our nearest star, seen in ultraviolet light

Stars, galaxies and the Universe

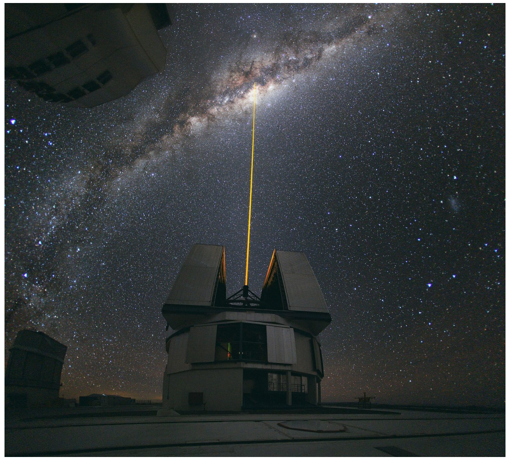
A **galaxy** 星系 is a group of many billions of stars held together by gravity. Our Sun is one star in the galaxy called the **Milky Way** 银河系. All the other stars in the Milky Way are very much further from the Earth than the Sun is.

A spiral galaxy: billions of stars held together by gravity

Distances between stars are so big that we measure them in **light-years** 光年. One light-year is the distance light travels in one year (in the vacuum of space), which is

about 9.5×10^{15} m.

The Milky Way is about 100 000 light-years across (its **diameter** 直径). It is just one of many billions of galaxies. All of these galaxies together make up the **Universe** 宇宙.



A giant telescope studies the night sky; the laser helps it make sharp images of distant stars

The life cycle of a star

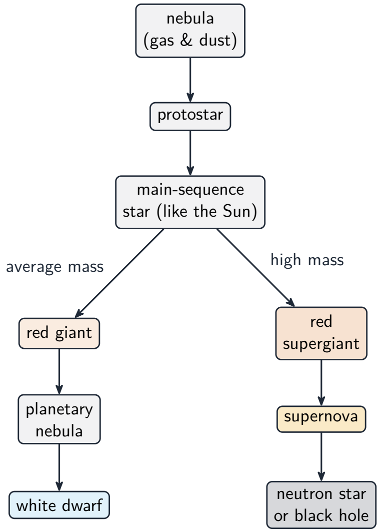
A star is born, lives and dies over a very long time:

1. A star forms from an **interstellar cloud** 星际云 of gas and dust that contains hydrogen.
2. Gravity pulls the cloud inwards, and it heats up. This collapsing, heating cloud is a **protostar** 原恒星.
3. The protostar becomes a **stable** 稳定 star when the inward pull of gravity is balanced by an outward push caused by the very high temperature in its centre.
4. In time, every star runs out of hydrogen **fuel** 燃料 for fusion.

What happens next depends on the mass of the star:

- A medium star (like the Sun) swells into a **red giant** 红巨星. It then throws off its outer layers as a glowing cloud called a planetary **nebula** 星云, leaving a small, hot **white dwarf** 白矮星 at the centre.
- A much heavier star swells into a **red supergiant** 红超巨星 and then explodes as a **supernova** 超新星. This blast spreads out a nebula containing hydrogen and

new, heavier elements, and leaves behind a **neutron star** 中子星 or a **black hole** 黑洞.

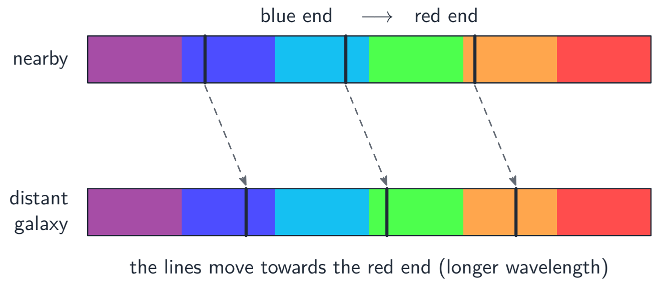


Every star begins in a nebula; how it ends depends on its mass

The nebula from a supernova can later form new stars, with planets orbiting them — so our own Solar System came from earlier stars.

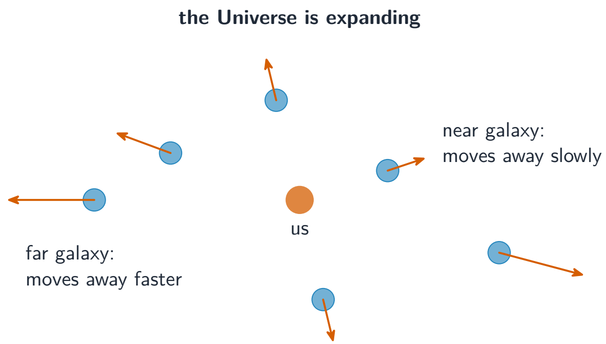
The expanding Universe

When a star or galaxy moves away from us (it is **receding** 退行), the light we receive from it has a longer **wavelength** 波长 than normal — it is shifted towards the red end of the spectrum. This is **redshift** 红移.



The dark lines in a distant galaxy's spectrum are shifted toward the red end — this is redshift

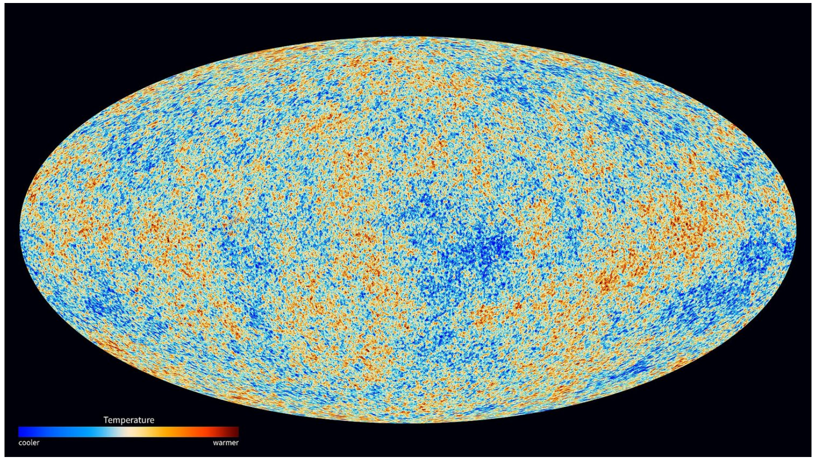
The light from distant galaxies is redshifted, and the further away a galaxy is, the bigger its redshift. This tells us that the galaxies are moving apart: the Universe is **expanding** 膨胀. Running this backwards, everything was once together at a single point — this is the evidence for the **Big Bang** 大爆炸 theory.



Every galaxy is moving away from us, and the farther ones move away faster — the Universe is expanding

More evidence and the age of the Universe

Faint **microwave 微波 radiation 辐射** is found coming from every direction in space. This is the **cosmic microwave background radiation 宇宙微波背景辐射** (CMBR). It was made as high-energy radiation soon after the Big Bang, and has been stretched out into the microwave part of the spectrum as the Universe expanded.



The whole sky mapped in microwaves: this faint glow reaches us from every direction as the leftover heat of the young Universe — strong evidence for the Big Bang

For a distant galaxy:

- its speed v of moving away can be found from the redshift of its starlight;
- its distance d can be found from the brightness of a **supernova** seen in it.

The **Hubble constant 哈勃常数** H_0 links these two:

$$H_0 = \frac{v}{d}$$

Its value today is about 2.2×10^{-18} per second. Turning this around gives an estimate for the age of the Universe:

$$\frac{d}{v} = \frac{1}{H_0}$$

Worked example. The Hubble constant is about $H_0 = 2.2 \times 10^{-18}$ per second. Estimate the age of the Universe.

$$\frac{1}{H_0} = \frac{1}{2.2 \times 10^{-18}} \approx 4.5 \times 10^{17}\ \text{s}$$

That is roughly 14 billion years.

This works because every galaxy seems to have started from the same single point at the same time — more support for the Big Bang.

Exam tips

- In $v = \dfrac{2\pi r}{T}$, r is the orbit radius and T is the time for one full orbit in seconds — convert km to m and hours to seconds first.
- Planets closer to the Sun feel stronger gravity, so they orbit faster and take less time. In an elliptical orbit a body speeds up as it nears the Sun (gravitational potential energy turns into kinetic energy).
- A **light-year** is a *distance*, not a time — how far light travels in one year.
- A star is **stable** when the inward pull of gravity is balanced by the outward push from the energy released by **fusion** in its core. What it becomes when its fuel runs out depends on its **mass**.
- **Redshift** — light from distant galaxies shifted to longer (redder) wavelengths, with a bigger shift the further away — is the evidence that the Universe is **expanding**, which supports the Big Bang.