Physics (0625)

IGCSE • Core • CAIE

Comprehensive Cheat Sheet

The Practice Book
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1 Electricity and magnetism

KEY FORMULAS

Electric current

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

Current is the rate of flow of charge, measured in amperes (A). Use to find the current I from the charge Q in coulombs that passes a point in time t in seconds, or rearrange as $Q = It$ to find the charge.

Electrical power

$$P = IV$$

Power P is the rate at which a device transfers electrical energy, in watts (W). Use with the current I through a device and the p.d. V across it.

Resistance and Ohm's law

$$V = IR$$

Resistance R, in ohms, opposes the current. Use to relate the p.d. V across a component to the current I through it; rearrange as $R = V/I$ to calculate a resistance from measured values.

Total resistance in series

$$R = R_1 + R_2$$

For resistors connected in *series* the total resistance is the sum of the separate resistances. Use for any number of resistors joined one after another in a single loop.

Electrical energy

$$E = IVt$$

Energy E transferred, in joules, by a device of p.d. V carrying current I for time t. This is equivalent to $E = Pt$ using the power. Use to find the energy delivered to or by a component.

KEY CONCEPTS

- **E.m.f. and potential difference**: Both are measured in *volts* (V). The *electromotive force* (e.m.f.) of a source is the electrical energy it gives to each unit of charge driven through it. The *potential difference* (p.d.) across a component is the energy delivered by each unit of charge as it passes through that component.
- **Electric charge and charging by friction**: There are two types of charge, *positive* and *negative*; like charges repel and unlike charges attract. An insulator is charged by *friction*, which transfers *electrons* from one material to the other. The material that gains electrons becomes negative and the one that loses electrons becomes positive. Only electrons move.
- **Electromagnetic induction**: When a conductor and a magnetic field move relative to each other, a voltage (e.m.f.) is *induced* across the conductor; if the circuit is complete an induced current flows. The induced e.m.f. is larger when the movement is faster, the magnet is stronger, or the coil has more turns. A steady, unchanging field induces nothing.
- **Magnetic poles and field lines**: Every magnet has a north pole and a south pole. *Like poles repel and unlike poles attract*. A magnetic field is the region in which a magnet exerts a force, shown by

field lines that point *from north to south* outside the magnet. Where the lines are closer together the field is stronger.

- **The motor effect**: A current-carrying conductor placed in a magnetic field experiences a *force*, an effect called the *motor effect*, unless the current runs along the same line as the field. The force is greatest when the conductor is at right angles to the field. Increasing the current or using a stronger magnet increases the force.
- **Magnetic materials and induced magnetism**: The magnetic materials are *iron, steel, cobalt and nickel*; most other materials are non-magnetic. Bringing a magnet near an unmagnetised magnetic material turns it into a temporary magnet, called *induced magnetism*, which is why a magnet can pick up a chain of paper clips. Soft iron loses this magnetism easily, whereas steel keeps it.
- **Parallel circuit rules**: In a *parallel* circuit the components sit on separate branches. Each branch has the *same* potential difference across it, the branch currents *add up* to the total current drawn from the source, and the combined resistance is *less than* the smallest single resistor because the current has more paths to follow.
- **Potential dividers**: Two resistors connected in *series* across a supply *share* the supply voltage between them. Because the same current flows through both, the larger resistance takes the larger share of the voltage (from $V = IR$). This lets a fixed pair of resistors provide a smaller, steady output voltage.
- **Reading circuit diagrams and symbols**: A circuit diagram is a standard map of a real circuit. You should recognise and draw the symbols for a *cell* and *battery*, a *switch*, a *lamp*, fixed and *variable resistors*, an *ammeter* (A in a circle), a *voltmeter* (V in a circle), a *fuse*, a *diode*, an *LED*, a *thermistor* and an *LDR*. Draw components with straight wires and right-angle corners.
- **The magnetic effect of a current**: An electric current produces a magnetic field around itself. A straight wire has circular field lines around it. Winding the wire into a *solenoid* (a coil) produces a field like that of a bar magnet, with a north end and a south end. Reversing the current reverses the direction of the field.
- **What affects the resistance of a wire**: For a wire of a given material the resistance increases with its *length* and decreases as its *cross-sectional area* (thickness) increases, so a long thin wire has more resistance than a short fat one. The resistance of a metal also rises as its temperature increases, which is why the line for a filament lamp curves on a current-voltage graph.
- **Electromagnets and their uses**: Adding a *soft-iron core* to a solenoid makes an *electromagnet*, which is magnetic only while the current flows and so can be switched on and off. The field is made stronger by increasing the current, adding more turns, or using the iron core. Electromagnets are used in *relays*, electric *bells*, *loudspeakers* and scrapyard lifting magnets.
- **Mains electricity: live, neutral and earth**: A mains plug has three wires: *live* (brown) carries the alternating voltage, *neutral* (blue) completes the circuit, and *earth* (green and yellow) is a safety wire connected to a metal case. The *fuse* and the *switch* are placed in the *live* wire so that a fault disconnects the dangerous voltage from the appliance.
- **Paying for electrical energy**: Because the joule is a very small unit, electrical energy for billing is measured in *kilowatt-hours* (kWh): the energy used by a 1 kW device in one hour. The cost is the energy in kWh multiplied by the price of one unit, so a high-power appliance used for a long time costs the most to run.
- **Special components: diode, thermistor and LDR**: A *diode* allows current to flow in one direction only. A *thermistor* has a resistance that *decreases* as its temperature rises. A *light-dependent resistor* (LDR) has a resistance that *decreases* as the light falling on it gets brighter. These components are widely used in sensing and control circuits.
- **The a.c. generator**: Rotating a coil in a magnetic field (or rotating a magnet near a coil) continuously changes the field linking the coil, so an alternating e.m.f. is induced. This is how an *a.c. generator*, and the generators in power stations, produce electricity. Spinning the coil faster increases both the size and the frequency of the output voltage.
- **The d.c. motor and the split-ring commutator**: In a *d.c. motor* a current-carrying coil sits between magnet poles. The two sides of the coil carry current in opposite directions, so one side is pushed up and the other down, making the coil rotate. A *split-ring commutator* reverses the current in the coil every half turn so that it keeps turning the same way. More current, more turns or a stronger magnet make it spin faster.
- **The transformer**: A *transformer* changes the size of an alternating voltage using a *primary* coil and a *secondary* coil wound on a soft-iron core. Alternating current in the primary creates a changing magnetic field that induces an alternating voltage in the secondary. A *step-up* transformer has more

turns on the secondary and increases the voltage; a *step-down* transformer has fewer and decreases it. Transformers work on a.c. only, because they need a changing field.

- **Why electricity is transmitted at high voltage**: Electrical power is sent across the country at very high voltage. For a given power a higher voltage means a *smaller current*, and a smaller current wastes far less energy heating the transmission cables. *Step-up* transformers raise the voltage for transmission and *step-down* transformers lower it again to a safe value for homes.

EXAM TIPS

TIP A *conductor* such as a metal allows charge to flow because it has free electrons; an *insulator* such as plastic or rubber holds charge in place. In all charging by friction it is the *electrons* that move, never the positive charges, so a positively charged object is simply one that has *lost* electrons.

TIP A *voltmeter* measures potential difference and is always connected *in parallel*, across the two ends of the component being measured. This contrasts with the ammeter, which goes in series. A simple memory aid is "voltmeter across, ammeter along".

TIP The direction of the force on a current-carrying conductor is found with *Fleming's left-hand rule*: the thumb shows the thrust (force), the first finger the field (north to south) and the second finger the current (positive to negative). Reversing *either* the current or the field reverses the force; reversing *both* leaves it unchanged.

TIP Current is measured with an *ammeter* connected *in series* with the component. *Conventional current* is drawn flowing from the *positive* to the *negative* terminal, although the electrons in a metal actually drift the opposite way. Direct current (d.c.) flows one way; alternating current (a.c.) repeatedly reverses direction.

TIP Replacing one resistor in a potential divider with a *thermistor* or a *light-dependent resistor* (LDR) makes the output voltage change automatically with temperature or light. A thermistor's resistance falls as it warms and an LDR's resistance falls in brighter light, which is the basis of simple temperature alarms and automatic lighting.

TIP A fuse contains a thin wire that melts and breaks the circuit if the current rises above its rating, preventing the wiring from overheating. Choose the *smallest* standard fuse rated just *above* the appliance's normal current, found from $I = P/V$. A metal-cased appliance is protected by the *earth wire* and fuse together, while a plastic-cased one may instead use *double insulation*.

2 Motion, forces and energy

KEY FORMULAS

Acceleration

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

Use to find the rate of change of velocity, in m/s². Here Δv is the change in velocity and t is the time taken. A negative value means the object is slowing down.

Density

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

Use to find density from mass m and volume V, in kg/m³ or g/cm³. A more dense material packs more mass into the same volume.

Kinetic energy

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

Use to find the energy stored in a moving object of mass m travelling at speed v, in joules.

Moment of a force

$$\text{moment} = F \times d$$

Use to find the turning effect of a force about a pivot, in newton metres (N m). Here d is the *perpendicular* distance from the pivot to the line of action of the force.

Newton's second law

$$F = ma$$

Use to find the resultant force on a mass m that accelerates at a, or the acceleration produced by a known resultant force. Force is in newtons.

Power

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

Use to find the rate of transferring energy or doing work, in watts (1 W = 1 J/s). Here ΔE is the energy transferred in time t.

Pressure

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

Use to find the pressure produced by a force F acting at right angles to an area A, in pascals (1 Pa = 1 N/m²).

Speed

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

Use to find how fast an object travels, in metres per second (m/s) when distance is in metres and time in seconds. *Velocity* is the speed in a stated direction.

Weight

$$W = mg$$

Use to find the weight, the gravitational force on a mass m, in newtons. Here g is the gravitational field strength, about 9.8 N/kg on Earth.

Work done

$$W = F \times d$$

Use to find the energy transferred when a force F moves an object a distance d in the direction of the force, in joules.

Change in gravitational potential energy

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

Use to find the energy stored when a mass m is raised through a height Δh in a gravitational field of strength g, in joules.

Efficiency

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

Use to find the percentage of the energy input that is transferred to a useful output. The rest is wasted, usually as thermal energy.

Pressure in a liquid

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

Use to find the increase in pressure with depth Δh in a liquid of density ρ, in pascals. Pressure in a liquid increases with depth, which is why a dam is built thicker at its base.

KEY CONCEPTS

- **Centre of gravity**: The *centre of gravity* is the single point at which the whole weight of an object can be taken to act. For a symmetrical object of uniform density it lies at the centre of symmetry.
- **Conservation of energy**: Energy is held in different stores, including *kinetic*, *gravitational potential*, *chemical* and *elastic*. The principle of conservation of energy states that energy is never created or destroyed, only transferred from one store to another, so the total energy stays the same.
- **Measuring length, volume and time**: Length is measured with a *ruler*, the volume of a liquid with a *measuring cylinder* (reading the bottom of the *meniscus* at eye level), and time with a *clock* or *stopwatch*. Each quantity is recorded with its correct SI unit: the metre, the cubic metre (or litre), and the second.
- **Resultant force**: The *resultant force* is the single force that has the same effect as all the forces acting on an object combined. A non-zero resultant changes the object's velocity (speeding up,

slowing down or changing direction); a zero resultant means the object stays at rest or keeps a constant velocity.

- **Floating and sinking**: An object floats in a liquid if its density is *less* than the density of the liquid, and sinks if its density is *greater*. A steel ship floats because its hollow hull gives it a low average density, even though steel itself is denser than water.
- **Hooke's law for a spring**: Below its *limit of proportionality* the extension of a spring is directly proportional to the load, so doubling the load doubles the extension. Beyond the limit of proportionality the load-extension line curves and the spring may not return to its original length.
- **Mass versus weight**: *Mass* is the quantity of matter in an object, measured in kilograms, and is the same everywhere. *Weight* is the gravitational force on that mass, measured in newtons, and depends on the gravitational field strength, so an object weighs less on the Moon than on Earth even though its mass is unchanged.
- **Pressure and area**: For a fixed force, a *smaller* area gives a *higher* pressure. A sharp knife or a drawing pin concentrates the force on a tiny area to cut or pierce easily, while snowshoes or wide tyres spread the force over a large area to reduce the pressure on soft ground.
- **Principle of moments**: When an object is in equilibrium and not turning, the *principle of moments* applies: the total clockwise moment about a pivot equals the total anticlockwise moment about that same pivot.
- **Reading motion graphs**: On a *distance-time* graph the gradient gives the speed, and a horizontal line means the object is stationary. On a *speed-time* graph the gradient gives the acceleration, and the area beneath the line gives the distance travelled.
- **Renewable and non-renewable resources**: *Non-renewable* resources will run out and include the fossil fuels (coal, oil and gas) and nuclear fuel. *Renewable* resources are replaced as fast as they are used and include wind, hydroelectric, tidal, wave, solar, geothermal and biofuels. Most power stations use a heat source to boil water to steam, which drives a turbine that turns a generator.
- **Stability and toppling**: An object is more stable when it has a *low centre of gravity* and a *wide base*. It begins to topple when it is tilted far enough that the vertical line through its centre of gravity falls outside its base, because the weight then provides a turning moment that tips it over.
- **Work as energy transfer**: *Work done* is the energy transferred when a force moves an object, measured in joules, the same unit as energy. The distance is measured in the direction of the force, and if the object does not move then no work is done, however large the force.

EXAM TIPS

TIP To measure a very small length or a short time accurately, measure *many* and divide. Find the combined thickness of 100 sheets of paper and divide by 100, or time 20 swings of a pendulum and divide by 20. Spreading the reading and reaction-time errors over many items makes the error per item far smaller.

TIP *Friction* and *air resistance* are contact forces that always act against the direction of motion. They reduce the resultant force, so an object speeds up more slowly, and they transfer kinetic energy to the surroundings as thermal energy. A falling object reaches *terminal velocity* when air resistance grows to balance its weight, giving zero resultant force and constant speed.

TIP Most energy resources can be traced back to the *Sun*, which drives the weather (wind and waves), the water cycle (hydroelectric) and plant growth (fossil fuels and biofuels). The exceptions are *nuclear*, *geothermal* and *tidal* energy, where the tides are caused mainly by the Moon.

TIP To find the volume of a small irregular solid, lower it into a known volume of water in a measuring cylinder and read the new level. The rise in the water level equals the volume of the solid. Combined with its mass, this gives the density.

3 Nuclear physics

KEY FORMULAS

Alpha decay equation

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

In *alpha decay* the nucleus emits an alpha particle, so the nucleon number A falls by 4 and the proton number Z falls by 2. Use when a question states a source decays by alpha emission; the daughter is a different element.

Nuclide notation and neutron number

$$^{A}_{Z}\mathrm{X}, \quad \text{neutrons} = A - Z$$

Read any nuclide as $^{A}_{Z}\mathrm{X}$: the bottom number is the *proton number* Z (it fixes the element) and the top number is the *nucleon number* A (protons plus neutrons). Use to count particles: protons $= Z$, neutrons $= A - Z$, and electrons $= Z$ in a neutral atom.

Beta decay equation

$$^{A}_{Z}\mathrm{X} \rightarrow \, ^{A}_{Z+1}\mathrm{Y} + \, ^{0}_{-1}\beta$$

In *beta decay* a neutron changes into a proton and a fast electron (the beta particle) is emitted, so the nucleon number A is unchanged and the proton number Z rises by 1. The beta particle is written with a bottom number of -1 so that charge balances.

Corrected count rate

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

A detector also picks up ever-present *background radiation*, so a source reading is really source plus background. Use this to find the count rate due to the source alone; always measure the background first with the source removed.

Fraction remaining after n half-lives

$$\text{fraction remaining} = \left(\tfrac{1}{2}\right)^{n}$$

After each half-life the amount remaining halves, so after n half-lives the fraction left is $\left(\frac{1}{2}\right)^{n}$: a half, then a quarter, then an eighth, and so on. Use it once you know how many half-lives n have passed in the given time.

KEY CONCEPTS

- **Dangers of ionising radiation**: Ionising radiation knocks electrons off atoms in living cells. This can *kill cells* or *damage DNA*, which may cause mutations or cancer. The larger the dose received, the greater the risk, so exposure must always be kept as low as possible.
- **Detecting radiation and count rate**: Unstable nuclei emit radiation that is detected with a *Geiger-Müller tube* connected to a counter, which records a *count rate* (counts per second or per minute). A higher count rate means more radiation is reaching the detector.
- **Nature and charge of the three radiations**: *Alpha* (α) is a helium nucleus, 2 protons and 2 neutrons, with charge $+2$. *Beta* (β) is a fast-moving electron with charge -1. *Gamma* (γ) is a high-energy electromagnetic wave with no charge and no mass.
- **Nuclear model of the atom**: An atom is a tiny, dense *nucleus* of *protons* and *neutrons* surrounded by *electrons* in orbits far outside it. Almost all the mass and all the positive charge sit in the nucleus, while almost all the volume is empty space. A neutral atom has equal numbers of protons and electrons.

- **Penetration and ionising power**: *Alpha* is the most ionising but the least penetrating, stopped by a sheet of paper or skin. *Beta* is moderately ionising and is stopped by a few mm of aluminium. *Gamma* is the least ionising but the most penetrating, reduced only by thick lead or concrete. The rule is that the more ionising a radiation is, the less penetrating it is.
- **What half-life means**: The *half-life* of a radioactive isotope is the time taken for half of the unstable nuclei in a sample to decay, which is also the time for the count rate to fall to half its value. Because decay is random, the same fraction always decays in equal times, so the amount keeps halving but never quite reaches zero.
- **Background radiation**: *Background radiation* is the low-level radiation present everywhere, even with no source nearby. Most of it is natural, coming from radon gas, rocks and the ground, cosmic rays from space, and even food and our own bodies. A smaller human-made part comes from medical procedures such as X-rays and from nuclear fallout.
- **Evidence from alpha-particle scattering**: The nuclear model is supported by the *alpha-scattering experiment*. Alpha particles fired at thin gold foil mostly pass straight through, which shows the atom is mostly empty space. A few are deflected, showing a concentrated positive charge, and a very small number bounce almost straight back, showing that charge is tiny, dense and heavy. That tiny dense centre is the nucleus.
- **Isotopes**: *Isotopes* are atoms of the same element with the same proton number Z but a different nucleon number A, so they have different numbers of neutrons. They behave *identically in chemical reactions* because chemistry depends on the electrons, and the electron number equals Z, which is the same for every isotope. Only the nuclear mass and stability differ.
- **Most dangerous inside or outside the body**: Which radiation is most dangerous depends on where the source is. *Outside* the body, *gamma* is the bigger hazard because it penetrates deep into tissue, while alpha is stopped by skin. *Inside* the body, *alpha* is by far the most dangerous because it is the most strongly ionising and deposits all its energy in nearby cells.
- **Relative charge and mass of subatomic particles**: A *proton* has relative charge $+1$ and relative mass 1; a *neutron* has charge 0 and relative mass 1; an *electron* has charge -1 and a negligible mass (about $\frac{1}{1840}$ of a proton). Because the charges of protons and electrons cancel, a neutral atom has no overall charge. Removing or adding an electron leaves a charged *ion*.
- **Uses of radioactivity**: Used in a controlled way, the same radiation is valuable. Examples include *medical tracers* and scans, *sterilising* equipment and food with gamma rays, *treating cancer* with targeted radiation, *smoke detectors* using alpha sources, *thickness gauging* of sheet metal or paper, and *carbon dating* of once-living material from its remaining carbon-14.

EXAM TIPS

TIP Radioactive decay is *spontaneous* and *random*, and nothing done to the source changes it. When completing any decay equation, make the *top numbers* (nucleon numbers) add up to the same total on both sides, and do the same for the *bottom numbers* (proton numbers). This lets you find the missing daughter nuclide.

TIP In an electric or magnetic field, *alpha* and *beta* are deflected in *opposite* directions because their charges have opposite signs. *Beta* is deflected much more than alpha because it is far lighter. *Gamma* has no charge, so it is not deflected at all.

TIP Keep your dose low in three ways: reduce the *time* spent near the source, increase the *distance* from it (handle sources with tongs, never bare hands), and place *shielding* such as lead or thick concrete between you and the source. Store sources in lead-lined boxes and never point one at people.

4 Space physics

KEY CONCEPTS

- **Gravity keeps the planets in orbit**: The Sun's *gravity* holds every planet in its orbit. This gravitational pull grows weaker with distance, so a planet further from the Sun is pulled less strongly, moves more slowly and takes longer to complete one orbit.
- **Redshift**: When the light from a distant galaxy is split into a spectrum, the lines are shifted toward the *red* (longer wavelength) end. This *redshift* shows that the galaxy is moving away from us, and a larger redshift means a faster speed of recession.
- **Structure of the Solar System**: The Solar System is one star (the Sun) together with *eight planets* and their moons, plus dwarf planets, asteroids and comets. It formed long ago from a slowly collapsing cloud of gas and dust.
- **The expanding Universe and the Big Bang**: More distant galaxies show greater redshifts, so they are moving away faster. This means the whole Universe is *expanding*. Tracing that expansion backwards points to the *Big Bang*: the Universe began from a single hot, dense point and has been expanding ever since.
- **The Sun is a star**: The Sun is a *medium-sized star* made mostly of hydrogen and helium. It releases energy by *nuclear fusion* in its core, where hydrogen nuclei join to form helium, and it is just one of the billions of stars in our galaxy.
- **The three motions in the Earth and Moon system**: Three motions run at once. The Earth *spins* on its axis once every 24 hours, the Earth *orbits* the Sun once every year (about 365 days), and the *Moon* orbits the Earth about once every month.
- **Why we have day and night**: The Earth spins once on its axis every 24 hours. The half of the Earth facing the Sun has *day* and the half turned away has *night*. Because the Earth rotates from west to east, the Sun appears to rise in the east and set in the west.
- **Phases of the Moon**: We see the Moon by reflected sunlight. As the Moon orbits the Earth, the fraction of its lit face that we can see changes, so the Moon appears to cycle through *phases* from new to full and back over about a month.
- **Rocky planets and gas giants**: The four *inner* planets (Mercury, Venus, Earth, Mars) are small and rocky. The four *outer* planets (Jupiter, Saturn, Uranus, Neptune) are large gas giants. The inner planets orbit closer to the Sun and complete an orbit in less time.
- **The light-year**: Distances in space are so large that they are measured in *light-years*. A light-year is the *distance* that light travels in one year, about 9.5×10^{15} m. It measures distance, not time.
- **The Milky Way and galaxies**: The Sun is one of the billions of stars in our galaxy, the *Milky Way*. The Milky Way is itself just one of the billions of galaxies that make up the Universe, which is why space is almost unimaginably large.
- **Comets and their elliptical orbits**: A comet orbits the Sun on a long, stretched (elliptical) path rather than a near-circle. It *speeds up* as it swings close to the Sun, where gravity is strongest, and *slows down* far away, where gravity is weakest.

EXAM TIPS

TIP Redshift tells you a galaxy is moving *away*, not that it is cooler or hotter. State that the light is shifted toward the red end of the spectrum and that the size of the shift increases with the galaxy's speed of recession.

TIP To explain a longer year for a more distant planet, link three ideas: the Sun's gravity is *weaker* further out, so the planet moves *slower*, and its orbit is also a *larger* loop. A longer path travelled at a lower speed takes much more time.

5 Thermal physics

KEY FORMULAS

Kelvin temperature conversion

$$T_K = \theta_C + 273$$

Converts a Celsius temperature θ_C to the absolute (Kelvin) scale. Use when a temperature must be expressed on the absolute scale, for example to describe how close a substance is to absolute zero.

Specific heat capacity equation

$$\Delta E = mc\Delta\theta$$

Energy needed to change the temperature of mass m by $\Delta\theta$ with no change of state. Here c is the specific heat capacity in J/(kg °C); keep m in kg and use the temperature *change*.

Rearranging for specific heat capacity

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

Rearrangement of $\Delta E = mc\Delta\theta$. Use when finding the specific heat capacity of a material from an experiment that measures the energy supplied, the mass and the temperature change.

Specific latent heat equation

$$E = mL$$

Energy needed to change the state of mass m at constant temperature. L is the specific latent heat of the substance; use it for melting and freezing, or for boiling and condensing.

KEY CONCEPTS

- **Conduction**: Conduction is the transfer of thermal energy through a material without the material itself moving. Particles at the hot end gain energy and vibrate more, then pass energy to neighbouring particles through collisions. *Metals* are the best conductors, while *non-metals and gases* are poor conductors, called insulators.
- **Convection**: Convection is the transfer of thermal energy through a *fluid* (a liquid or a gas) by the bulk movement of the fluid. Warmer fluid expands, becomes less dense and rises, while cooler, denser fluid sinks to take its place. Convection cannot occur in a solid or in a vacuum.
- **Gas pressure and the particle model**: A gas exerts pressure because its particles are in constant random motion and collide with the walls of the container. Each collision exerts a tiny force, and the combined effect of countless collisions per second is the gas pressure. Reducing the volume or raising the temperature makes the particles strike the walls more often, so the pressure rises.
- **Latent heat and change of state**: During melting at the melting point or boiling at the boiling point the temperature stays constant even though energy is still supplied. This *latent heat* energy is used to break the forces between particles and change the state, not to raise the temperature.
- **Particle model of matter**: All matter is made of tiny particles in constant motion. In a *solid* the particles vibrate about fixed positions in a regular arrangement held by strong forces; in a *liquid* they are still close together but can slide past one another; in a *gas* they are far apart and move quickly in all directions, filling any container.
- **Thermal expansion of solids, liquids and gases**: When a substance is heated its particles move more and take up more room, so the substance expands. For the same temperature rise the expansion is greatest for *gases*, smaller for *liquids* and least for *solids*, because weaker forces between particles let them move apart more easily.

- **Thermal radiation**: Thermal radiation is the transfer of thermal energy as *infrared* waves. It needs no medium, so it can travel through a vacuum, which is how energy from the Sun reaches the Earth. Every object emits thermal radiation, and a hotter object emits more.
- **Absolute zero**: *Absolute zero* is the lowest possible temperature, 0 K, which is about -273 °C. At absolute zero particle motion is at its minimum, so a substance has the least possible internal energy. The Kelvin scale begins at this point, which is why a temperature in kelvin is never negative.
- **Evaporation versus boiling**: *Boiling* happens throughout a liquid at one fixed temperature, its boiling point. *Evaporation* happens only at the surface and at any temperature below boiling. During evaporation the faster-moving molecules escape first, lowering the average kinetic energy of those left behind, so the liquid cools.
- **Reducing unwanted heat transfer**: Unwanted heat transfer is reduced by tackling each mechanism. Trapped air cuts conduction and convection because there are few particles to carry energy and the air cannot circulate, while shiny or light-coloured surfaces cut radiation. This is the basis of loft insulation, double glazing and survival blankets.
- **Convection currents in everyday life**: A convection current is a continuous circulation in a fluid: warm fluid rises, cools and sinks further away, then flows back toward the heat source. This is why a heater placed low warms a whole room, why warm air collects near a ceiling, and why the hot water in a tank gathers at the top.
- **Everyday consequences of thermal expansion**: Because solids expand when heated, structures must allow for the movement. Bridges are built with *expansion gaps* or rest on rollers, overhead cables and railway rails are laid with small gaps, and the expansion of a liquid up a narrow tube is used in a liquid-in-glass thermometer.

EXAM TIPS

TIP A *matt black* surface is both the best absorber and the best emitter of infrared radiation. A *shiny, light-coloured* surface is the poorest absorber and poorest emitter, so it is the best reflector. A good absorber is always a good emitter.

TIP In $\Delta E = mc\Delta\theta$ always use the temperature *change* $\Delta\theta$, never the starting or final temperature on its own. Keep the mass in kilograms. A change of one degree Celsius is the same size as a change of one kelvin, so the temperature change is numerically the same in either unit.

TIP Gases conduct thermal energy poorly because their particles are far apart. Materials that trap small pockets of still air, such as wool, foam and fibreglass, are good insulators, provided the air cannot circulate and carry heat away by convection.

6 Waves

KEY CONCEPTS

- **Converging and diverging lenses**: A *converging (convex)* lens bends parallel light inward to meet at the *principal focus*. A *diverging (concave)* lens spreads parallel light outward so it appears to come from a focus behind the lens. The distance from the lens to the principal focus is the *focal length*.
- **Dispersion through a prism**: White light is a mixture of all colours. A glass prism refracts each colour by a slightly different amount, *violet most* and *red least*, so the white light fans out into the visible spectrum. The colour order is red, orange, yellow, green, blue, indigo, violet (ROYGBIV).
- **Law of reflection**: When light reflects from a plane mirror the *angle of incidence* equals the *angle of reflection*, both measured from the *normal*, which is the line drawn at right angles (90°) to the mirror surface at the point where the ray strikes.
- **Refraction of light**: Refraction is the change in direction of light as it crosses between two media because its *speed* changes. Going from air into a denser medium such as glass or water the light slows and bends *toward* the normal; leaving the denser medium it speeds up and bends *away* from the normal.
- **Sound as a longitudinal wave**: Sound is produced by a *vibrating source* and travels as a *longitudinal* wave through a medium, which may be a solid, liquid or gas. Sound *cannot travel through a vacuum*, so space is silent. The audible range for a typical human is about 20 Hz to $20\,000$ Hz.
- **The electromagnetic spectrum order**: In order of *increasing frequency* and *decreasing wavelength* the regions are: radio, microwave, infrared, visible, ultraviolet, X-rays, gamma rays. All are transverse waves and all travel at the same very high speed in a vacuum.
- **The wave equation**: A wave transfers *energy* from place to place without transferring matter. Speed, frequency and wavelength are linked by $v = f\lambda$, where v is the wave speed, f is the frequency in hertz and λ is the wavelength. Rearrange as $\lambda = v/f$ or $f = v/\lambda$.
- **Transverse and longitudinal waves**: In a *transverse* wave the vibration is at right angles to the direction of travel, for example light and water ripples. In a *longitudinal* wave the vibration is along the direction of travel, forming compressions and rarefactions, for example sound.
- **Loudness, pitch and the speed of sound**: *Amplitude* sets the *loudness* and *frequency* sets the *pitch*. Sound travels fastest in *solids* and slowest in *gases*, because the particles are most closely coupled in a solid and most widely spaced in a gas. In air sound travels at roughly 330 to 350 m/s.
- **Real and virtual images from a lens**: With a converging lens an object beyond the principal focus forms a *real, inverted* image that can be caught on a screen. Beyond $2F$ the image is *diminished*, as in a camera; between F and $2F$ it is *enlarged*, as in a projector. With the object inside the focal length the image is *virtual, upright and enlarged*, as in a magnifying glass.
- **The plane-mirror image**: The image formed by a plane mirror is *virtual* (no light actually reaches it, so it cannot be caught on a screen), the *same size* as the object, *upright*, *laterally inverted*, and the same distance behind the mirror as the object is in front.
- **Total internal reflection**: When light travelling inside a denser medium meets the boundary at an angle beyond the *critical angle*, none of it escapes and it is all reflected back inside. This is *total internal reflection*, and it is used to pipe light along optical fibres and to turn light through reflecting prisms.
- **Ultrasound**: *Ultrasound* is sound with a frequency above $20\,000$ Hz, beyond the range of human hearing. It is used for cleaning delicate objects, for prenatal and other medical scanning, and for measuring distances such as the depth of water by timing a reflected pulse.
- **Uses across the spectrum**: Typical uses are: radio for broadcasting, microwave for mobile phones and satellite links and cooking, infrared for remote controls and thermal imaging, visible for sight and photography, ultraviolet for security marking and sterilising, X-rays for medical and security imaging, and gamma rays for sterilising equipment and treating cancer.
- **Wavelength, frequency and amplitude**: *Wavelength* λ is the distance for one complete cycle, measured crest to crest. *Frequency* f is the number of waves passing a point each second, measured in hertz. *Amplitude* is the maximum displacement from the rest position and sets how much energy the wave carries.

EXAM TIPS

TIP In every reflection and refraction question the angles of incidence, reflection and refraction are measured between the ray and the *normal*, never between the ray and the surface. Draw the normal first to avoid the most common marking error.

TIP Red light has the *longest wavelength* and the *lowest frequency*, and it bends the least in a prism. Violet light has the *shortest wavelength* and the *highest frequency*, and it bends the most. The order red to violet therefore runs from long wavelength to short.

TIP The energy carried rises with frequency, so the high-frequency regions are the most harmful. Microwaves heat the water in body cells, ultraviolet causes skin cancer and eye damage, and X-rays and gamma rays can damage or mutate living cells. The low-frequency radio and microwave end is far safer.

TIP Light from the bottom of a pool speeds up and bends *away* from the normal as it leaves the water into air, so the eye traces it back along a straighter line and the bottom appears raised. The same bending of light makes a straw in a glass of water look snapped at the surface.

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