

Physics definitions and equations: AS and A Level

This reference sheet is for Cambridge International AS & A Level Physics (9702). It covers every AS and A Level topic in syllabus order. For each topic it gives the definitions examiners expect you to state precisely, then each equation with its symbols and SI units. The last column of each equation table says whether the equation is **Given** on the data and formulae sheet printed in your exam paper, or whether you must **Learn** it. The key constants come at the start. Common mistakes are listed at the end.

How to use this sheet. If a question says "define" or "state what is meant by", a written definition gets full marks. Where a quantity is defined by a ratio, you may usually give the equation instead, but only if you say what every symbol means. For example, "pressure = force ÷ area" is fine, but " $p = F/A$ " on its own may lose the mark. Always say "per unit" where it belongs, and always name the direction or condition (such as "perpendicular", "at constant temperature" or "from infinity"). The "Given" labels here follow the current data and formulae sheet. Before the exam, check them against a recent specimen paper, because Cambridge sometimes changes the sheet when it updates the syllabus. If you are unsure whether an equation is given, learn it.

Data: key constants (all given on the data sheet)

Quantity	Symbol	Value
acceleration of free fall (on Earth's surface)	g	9.81 m s^{-2}
speed of light in free space	c	$3.00 \times 10^8 \text{ m s}^{-1}$
elementary charge	e	$1.60 \times 10^{-19} \text{ C}$
unified atomic mass unit	1 u	$1.66 \times 10^{-27} \text{ kg}$
rest mass of proton	m_p	$1.67 \times 10^{-27} \text{ kg}$
rest mass of electron	m_e	$9.11 \times 10^{-31} \text{ kg}$
Avogadro constant	N_A	$6.02 \times 10^{23} \text{ mol}^{-1}$
molar gas constant	R	$8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Boltzmann constant	k	$1.38 \times 10^{-23} \text{ J K}^{-1}$
gravitational constant	G	$6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
permittivity of free space	ϵ_0	$8.85 \times 10^{-12} \text{ F m}^{-1}$ (and $1/(4\pi\epsilon_0) = 8.99 \times 10^9 \text{ m F}^{-1}$)
Planck constant	h	$6.63 \times 10^{-34} \text{ J s}$
Stefan–Boltzmann constant	σ	$5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$

Useful derived values you should be able to work out: $1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$; $0^\circ \text{C} = 273.15 \text{ K}$; the rest energy of an

electron is $m_e c^2 \approx 8.2 \times 10^{-14} \text{ J} \approx 0.511 \text{ MeV}$.

AS Level

Physical quantities and units

Term	Definition or fact
SI base quantities and units	The base quantities used in this syllabus are mass (kg), length (m), time (s), electric current (A), thermodynamic temperature (K) and amount of substance (mol). All the other units you meet are derived from these. (The SI has a seventh base unit, the candela, which you do not need here.)
Homogeneous equation	An equation in which every term has the same base units. Homogeneity is needed for an equation to be correct, but it does not prove the equation is correct, because pure numbers such as $\frac{1}{2}$ have no units.
Scalar	A quantity that has magnitude only (e.g. mass, speed, energy, charge).
Vector	A quantity that has both magnitude and direction (e.g. displacement, velocity, force, momentum, field strength).
Resolving and adding vectors	A vector F at angle θ to a chosen direction has a component $F \cos \theta$ along that direction and $F \sin \theta$ perpendicular to it. Add or subtract coplanar vectors by a scale drawing (tip to tail) or by adding their perpendicular components.
Random error	An error that makes readings scatter unpredictably about the true value. You reduce its effect by repeating readings and averaging.
Systematic error	An error that shifts every reading by the same amount, or in the same proportion, in one direction (e.g. a zero error). Repeating readings does not remove it.
Accuracy	How close a measurement is to the true value.
Precision	How close repeated measurements are to each other (how small the spread is).

Prefixes: pico (p) 10^{-12} , nano (n) 10^{-9} , micro (μ) 10^{-6} , milli (m) 10^{-3} , centi (c) 10^{-2} , deci (d) 10^{-1} , kilo (k) 10^3 , mega (M) 10^6 , giga (G) 10^9 , tera (T) 10^{12} .

Rule for combining uncertainties	What to do	Sheet
$y = a + b$ or $y = a - b$	Add the absolute uncertainties: $\Delta y = \Delta a + \Delta b$	Learn
$y = ab$ or $y = a/b$	Add the fractional (or percentage) uncertainties: $\Delta y/y = \Delta a/a + \Delta b/b$	Learn
$y = a^n$	Multiply the fractional uncertainty by $ n $: $\Delta y/y = n \Delta a/a$	Learn

Worked example 1: combining uncertainties

A student measures the p.d. across a resistor as $(6.0 \pm 0.1) \text{ V}$ and the current through it as $(0.50 \pm 0.02) \text{ A}$. Calculate the resistance and its absolute uncertainty. [3]

$$R = V/I = 6.0 \div 0.50 = 12.0 \, \Omega \text{ [1]}$$

$$\text{Percentage uncertainty in } V = (0.1 \div 6.0) \times 100 = 1.7\%$$

Percentage uncertainty in $I = (0.02 \div 0.50) \times 100 = 4.0\%$

Percentage uncertainty in $R = 1.7\% + 4.0\% = 5.7\%$ [1]

Absolute uncertainty in $R = 0.057 \times 12.0 = 0.68 \, \Omega \approx 0.7 \, \Omega$

$R = (12.0 \pm 0.7) \, \Omega$ [1]. The uncertainty is rounded to one significant figure, and the value is quoted to the same decimal place.

The [1] markers in the worked examples show one likely way the marks are split: usually method, substitution, then final answer with unit.

Kinematics

Term	Definition
Distance	The total length of path travelled (a scalar).
Displacement	The distance in a straight line from a fixed reference point, in a specified direction (a vector).
Speed	The rate of change of distance travelled (distance $\div$ time).
Velocity	The rate of change of displacement.
Acceleration	The rate of change of velocity.

Equation	Symbols and units	Sheet
$v = u + at$	u initial velocity, v final velocity (m s^{-1}); a acceleration (m s^{-2}); t time (s)	Learn
$s = \frac{1}{2}(u + v)t$	s displacement (m)	Learn
$s = ut + \frac{1}{2}at^2$	as above	Given
$v^2 = u^2 + 2as$	as above	Given

Often forgotten: the four equations apply only when the acceleration is *constant* in a straight line. On a displacement–time graph, the gradient is velocity. On a velocity–time graph, the gradient is acceleration and the area under the line is displacement. For a projectile with no air resistance, treat the horizontal motion (constant velocity) and the vertical motion (acceleration g downwards) separately.

Dynamics

Term	Definition
Mass	The property of an object that resists a change in its motion.
Weight	The gravitational force acting on an object's mass ($W = mg$).
Linear momentum	The product of mass and velocity.
Force	Resultant force: the rate of change of momentum.
Newton (N)	The force that gives a mass of 1 kg an acceleration of $1 \, \text{m s}^{-2}$.

Newton's first law	An object stays at rest, or keeps moving at constant velocity, unless a resultant force acts on it.
Newton's second law	The resultant force on an object is proportional to its rate of change of momentum, and acts in the same direction as that change.
Newton's third law	If body A exerts a force on body B, then B exerts a force on A that is equal in magnitude, opposite in direction and of the same type.
Principle of conservation of momentum	The total momentum of a system of interacting objects stays constant, provided no resultant external force acts on the system.
Elastic collision	A collision in which total kinetic energy is conserved. Equivalently, the relative speed of approach equals the relative speed of separation.
Inelastic collision	A collision in which total momentum is conserved but some kinetic energy is transferred to other forms.
Terminal velocity	The constant velocity reached when the drag force (plus any upthrust) equals the weight, so the resultant force and the acceleration are both zero.

Equation	Symbols and units	Sheet
$p = mv$	p momentum (kg m s ⁻¹ or N s); m mass (kg); v velocity (m s ⁻¹)	Learn
$F = ma$	F resultant force (N); a acceleration (m s ⁻²); only for constant mass	Learn
$F = \Delta p / \Delta t$	Δp change in momentum (N s); Δt time taken (s)	Learn
impulse = $F\Delta t = \Delta p$	impulse (N s); equal to the area under a force–time graph	Learn
$W = mg$	W weight (N); g gravitational field strength (N kg ⁻¹)	Learn

Forces, density and pressure

Term	Definition
Moment of a force	The force multiplied by the perpendicular distance from the pivot to the line of action of the force.
Couple	A pair of forces that are equal in size, opposite in direction, and act along different (parallel) lines of action. A couple causes rotation only, with no resultant force.
Torque of a couple	One of the forces multiplied by the perpendicular distance between their lines of action.
Principle of moments	For an object in equilibrium, the sum of the clockwise moments about any point equals the sum of the anticlockwise moments about the same point.
Equilibrium	An object is in equilibrium when the resultant force on it is zero and the resultant moment (about any point) is zero.
Centre of gravity	The point at which the whole weight of an object can be taken to act.
Density	Mass per unit volume.
Pressure	Normal (perpendicular) force per unit area.

Upthrust	The upward force on an object in a fluid. It arises because the fluid pressure on the lower surface is greater than on the upper surface. By Archimedes' principle, it equals the weight of fluid displaced.
Drag / viscous force	A resistive force on an object moving through a fluid. It acts opposite to the velocity and increases as the speed increases.

Equation	Symbols and units	Sheet
moment = Fd	F force (N); d perpendicular distance from pivot to line of action (m); moment in N m	Learn
torque = Fd	d perpendicular distance between the two lines of action of the couple (m)	Learn
$\rho = m/V$	ρ density (kg m^{-3}); V volume (m^3)	Learn
$p = F/A$	p pressure ($\text{Pa} = \text{N m}^{-2}$); A area (m^2)	Learn
$\Delta p = \rho g \Delta h$	Δp change in pressure (Pa); Δh change in depth (m); ρ fluid density	Given
$F = \rho g V$	F upthrust (N); ρ density of the <i>fluid</i> ; V volume of fluid displaced (m^3)	Given

Work, energy and power

Term	Definition
Work done	The force multiplied by the displacement in the direction of the force.
Joule (J)	The work done when a force of 1 N moves its point of application 1 m in the direction of the force.
Principle of conservation of energy	Energy cannot be created or destroyed, only transferred from one form to another. The total energy of a closed system is constant.
Power	The rate of doing work, or the work done (energy transferred) per unit time.
Watt (W)	One joule per second.
Efficiency	The ratio of useful energy output (or useful power output) to total energy input (or total power input).

Equation	Symbols and units	Sheet
$W = Fs \cos \theta$	W work done (J); s displacement (m); θ angle between force and displacement	Learn
$E_K = \frac{1}{2}mv^2$	E_K kinetic energy (J)	Learn (and be able to derive it from the equations of motion)
$\Delta E_P = mg\Delta h$	ΔE_P change in gravitational potential energy (J); Δh change in height (m). Only valid in a uniform field, i.e. near the surface.	Learn (and derive)
$P = W/t$	P power (W); t time (s)	Learn
$P = Fv$	v velocity in the direction of F (m s^{-1})	Learn

efficiency = $\frac{\text{useful output}}{\text{total input}} \times 100\%$	no unit	Learn
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Deformation of solids

Term	Definition
Hooke's law	The extension of a spring (or wire) is directly proportional to the applied force, provided the limit of proportionality is not exceeded.
Spring constant	The force per unit extension, provided the limit of proportionality is not exceeded ($k = F/x$).
Stress	Force per unit cross-sectional area.
Strain	Extension divided by the original length.
Young modulus	Stress divided by strain (within the limit of proportionality).
Elastic deformation	Deformation in which the material returns to its original shape and size once the load is removed.
Plastic deformation	Deformation in which the material does not return to its original shape once the load is removed (permanent deformation).
Limit of proportionality	The point beyond which force is no longer proportional to extension.
Elastic limit	The point beyond which deformation becomes plastic.

Equation	Symbols and units	Sheet
$F = kx$	k spring constant (N m^{-1}); x extension (m)	Learn
$\sigma = F/A$	σ stress (Pa); A cross-sectional area (m^2)	Learn
$\epsilon = x/L$	ϵ strain (no unit); L original length (m)	Learn
$E = \sigma/\epsilon$	E Young modulus (Pa)	Learn
$E_p = \frac{1}{2}Fx = \frac{1}{2}kx^2$	E_p elastic potential (strain) energy (J); only within the limit of proportionality. In general, it equals the area under the force–extension graph.	Learn

Waves

Term	Definition
Displacement (of a wave)	The distance of a point on the wave from its equilibrium position, in a specified direction.
Amplitude	The maximum displacement from the equilibrium position.
Wavelength	The distance between two adjacent points on a wave that oscillate in phase (e.g. crest to crest).
Period	The time taken for one complete oscillation.
Frequency	The number of complete oscillations per unit time.

Phase difference	How far one oscillation is ahead of or behind another, as a fraction of a cycle, measured in degrees or radians (one cycle = $360^\circ = 2\pi$ rad).
Wave speed	The distance travelled by the wave energy (wavefront) per unit time.
Progressive wave	A wave that transfers energy from one place to another without transferring matter.
Intensity	Power per unit area, where the area is at right angles to the direction the wave is travelling.
Transverse wave	A wave whose particles oscillate perpendicular to the direction of energy transfer.
Longitudinal wave	A wave whose particles oscillate parallel to the direction of energy transfer (it has compressions and rarefactions).
Doppler effect	The observed frequency changes when the source moves relative to the observer. It is higher when they approach and lower when they separate.
Polarisation	A polarised wave oscillates in only one direction perpendicular to its direction of travel. Only transverse waves can be polarised.
Electromagnetic waves	Transverse waves that all travel at $3.00 \times 10^8 \text{ m s}^{-1}$ in free space. Approximate wavelengths: radio $> 10^{-1} \text{ m}$; microwaves 10^{-3} to 10^{-1} m ; infrared 7×10^{-7} to 10^{-3} m ; visible 400 nm to 700 nm ; ultraviolet 10^{-8} to $4 \times 10^{-7} \text{ m}$; X-rays 10^{-13} to 10^{-8} m ; gamma rays 10^{-16} to 10^{-10} m (the X-ray and gamma-ray ranges overlap).

Equation	Symbols and units	Sheet
$v = f\lambda$	v wave speed (m s^{-1}); f frequency (Hz); λ wavelength (m)	Learn (and derive)
$f = 1/T$	T period (s)	Learn
$I = P/A$ and $I \propto A^2$	I intensity (W m^{-2}); P power (W); A area (m^2) in the first equation, but amplitude in the second	Learn
$f_o = f_s v / (v \pm v_s)$	f_o observed frequency; f_s source frequency (Hz); v speed of sound; v_s speed of source (m s^{-1}). Use $-$ when the source approaches and $+$ when it recedes. Only for a moving source and a stationary observer.	Given
$I = I_0 \cos^2\theta$ (Malus's law)	I_0 intensity of the plane-polarised light arriving at the analyser; θ angle between the plane of polarisation and the analyser's transmission axis	Learn

Superposition

Term	Definition
Principle of superposition	When two or more waves meet at a point, the resultant displacement is the sum of the displacements of the individual waves.
Diffraction	The spreading of a wave as it passes through a gap or around an edge. It is most noticeable when the gap is about the same size as the wavelength.
Coherent sources	Sources that have a constant phase difference, which means they must have the same frequency.

Interference	The superposition of coherent waves, which gives a steady pattern of maxima (constructive) and minima (destructive).
Conditions for two-source interference	Constructive where the path difference is $n\lambda$ (sources in phase). Destructive where it is $(n + \frac{1}{2})\lambda$. Seeing the pattern needs coherent sources with similar amplitudes, and polarised waves need the same polarisation.
Stationary wave	A wave formed when two progressive waves of the same frequency (and speed, and ideally the same amplitude) travel in opposite directions and superpose. It stores energy rather than transferring it.
Node / antinode	A node is a point of zero amplitude. An antinode is a point of maximum amplitude. Adjacent nodes are $\lambda/2$ apart, and a node is $\lambda/4$ from the next antinode.

Equation	Symbols and units	Sheet
$\lambda = ax/D$	a slit separation (m); x fringe separation (m); D slit-to-screen distance (m). Needs a $\ll D$.	Learn
$d \sin \theta = n\lambda$	d grating spacing, i.e. $1 \div$ (lines per metre) (m); θ angle of the nth order maximum from the straight-through direction; n order (integer)	Learn

Often forgotten: in a stationary wave, all points between two adjacent nodes oscillate in phase, and points on either side of a node are in antiphase (180° apart). The highest observable order from a grating is the largest whole number n that is less than d/λ , because $\sin \theta$ must be less than 1 (an order at $\theta = 90^\circ$ would travel along the grating and could not be seen).

Electricity

Term	Definition
Electric current	The rate of flow of charge.
Coulomb (C)	The charge that passes a point when a current of 1 A flows for 1 s.
Potential difference	The energy transferred from electrical energy to other forms per unit charge passing between two points.
Volt (V)	One joule per coulomb.
Electromotive force (e.m.f.)	The energy transferred from other forms to electrical energy per unit charge moved round a complete circuit.
Resistance	The potential difference across a component divided by the current through it.
Ohm (Ω)	One volt per ampere.
Ohm's law	The current in a conductor is directly proportional to the potential difference across it, provided the temperature (and other physical conditions) stay constant.
Resistivity	A property of the material, defined by $\rho = RA/L$, where R is the resistance of a sample of length L and uniform cross-sectional area A. (Equivalently, the resistance of a sample of unit length and unit cross-sectional area.)
Quantisation of charge	Every charge is a whole-number multiple of the elementary charge e.

Characteristic behaviour	A filament lamp's resistance rises with p.d. because it gets hotter. A semiconductor diode conducts in one direction only, above a threshold p.d. An NTC thermistor's resistance falls as temperature rises. An LDR's resistance falls as light intensity rises.
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Equation	Symbols and units	Sheet
$Q = It$	Q charge (C); I current (A); t time (s)	Learn
$I = Anvq$	A cross-sectional area (m ²); n number density of charge carriers (m ⁻³); v drift speed (m s ⁻¹); q charge of each carrier (C)	Given
$V = W/Q$	V p.d. (V); W energy transferred (J)	Learn
$R = V/I$	R resistance (Ω)	Learn
$P = VI = I^2R = V^2/R$	P power (W)	Learn
$W = VIt$	W energy transferred (J)	Learn
$R = \rho L/A$	ρ resistivity (Ω m); L length (m); A cross-sectional area (m ²)	Learn

D.C. circuits

Term	Definition
Kirchhoff's first law	The sum of the currents entering a junction equals the sum of the currents leaving it. This follows from conservation of charge.
Kirchhoff's second law	Round any closed loop in a circuit, the sum of the e.m.f.s equals the sum of the p.d.s. This follows from conservation of energy.
Internal resistance	The resistance inside a source of e.m.f. Energy is transferred to thermal energy in it, so the terminal p.d. is less than the e.m.f. whenever a current flows.
Terminal p.d.	The p.d. across the terminals of a source. It equals the e.m.f. only when the current is zero.
Potential divider	Two (or more) resistors in series that split the supply p.d. in the ratio of their resistances.

Equation	Symbols and units	Sheet
$R = R_1 + R_2 + \dots$	resistors in series (Ω)	Given
$1/R = 1/R_1 + 1/R_2 + \dots$	resistors in parallel	Given
$E = I(R + r) = V + Ir$	E e.m.f. (V); r internal resistance (Ω); R external resistance; V terminal p.d.	Learn
$V_{\text{out}} = V_{\text{in}} \times R_2/(R_1 + R_2)$	V_{out} p.d. across R_2 (no load connected)	Learn

Often forgotten: a potentiometer is balanced when the galvanometer reads zero. At that point no current is drawn from the cell under test, so the balance gives its e.m.f., not its terminal p.d.

Particle physics

Term	Definition or fact
α -particle scattering result	Most α -particles pass straight through the foil, so most of the atom is empty space. A very small fraction are deflected through large angles, so the positive charge and most of the mass are concentrated in a tiny nucleus.
Proton number Z	The number of protons in a nucleus.
Nucleon number A	The total number of protons and neutrons in a nucleus.
Isotopes	Nuclei of the same element with the same proton number but different numbers of neutrons (different nucleon numbers).
Nuclide notation	A_ZX . Charge and nucleon number are conserved in every nuclear reaction.
α decay	A helium nucleus ${}^4_2\text{He}$ is emitted. A falls by 4 and Z falls by 2. α -particles all have the same (discrete) energy.
β^- decay	A neutron changes to a proton, and an electron and an electron antineutrino are emitted. Z rises by 1. β -particles have a continuous range of energies because the (anti)neutrino carries away some of the energy.
β^+ decay	A proton changes to a neutron, and a positron and an electron neutrino are emitted. Z falls by 1.
γ emission	A high-energy photon leaves an excited nucleus. A and Z do not change.
Antiparticle	A particle with the same mass as its partner but the opposite charge (and other opposite quantum numbers).
Quarks	Six flavours. Up ($+\frac{2}{3}e$), charm ($+\frac{2}{3}e$) and top ($+\frac{2}{3}e$); down ($-\frac{1}{3}e$), strange ($-\frac{1}{3}e$) and bottom ($-\frac{1}{3}e$). Antiquarks have the opposite charges.
Hadron	A particle made of quarks, which feels the strong force. Baryons contain three quarks (proton uud , neutron udd). Mesons contain a quark and an antiquark.
Lepton	A fundamental particle with no quark structure, which does not feel the strong force (e.g. electron, neutrino).
Quark changes in β decay	β^- : $d \rightarrow u + e^- + \bar{\nu}_e$ (electron antineutrino). β^+ : $u \rightarrow d + e^+ + \nu_e$ (electron neutrino). Both happen through the weak interaction.

Radiation	What it is	Mass	Charge
α	helium nucleus (2 protons + 2 neutrons)	4 u	+2e
β^-	electron	about $\frac{1}{2000}$ u	-e
β^+	positron	about $\frac{1}{2000}$ u	+e
γ	photon of electromagnetic radiation	0	0

A Level

Motion in a circle

Term	Definition
Radian	The angle subtended at the centre of a circle by an arc equal in length to the radius.
Angular displacement	The angle turned through about the centre (in radians).
Angular speed	The rate of change of angular displacement.
Centripetal force	The resultant force towards the centre that keeps an object moving in a circle. It is not an extra force. It is supplied by tension, gravity, friction and so on.

Equation	Symbols and units	Sheet
$\theta = s/r$	θ angle (rad); s arc length (m); r radius (m)	Learn
$\omega = \Delta\theta/\Delta t = 2\pi/T = 2\pi f$	ω angular speed (rad s ⁻¹); T period (s)	Learn
$v = r\omega$	v linear (tangential) speed (m s ⁻¹)	Learn
$a = r\omega^2 = v^2/r$	a centripetal acceleration (m s ⁻²), directed towards the centre	Learn
$F = mr\omega^2 = mv^2/r$	F centripetal force (N)	Learn

Gravitational fields

Term	Definition
Gravitational field	A region of space in which a mass experiences a force.
Gravitational field strength	The gravitational force per unit mass acting on a small test mass placed at that point.
Newton's law of gravitation	The gravitational force between two point masses is proportional to the product of their masses and inversely proportional to the square of their separation.
Gravitational potential	The work done per unit mass in bringing a small test mass from infinity to that point.
Geostationary orbit	An orbit above the equator, moving west to east (the same direction as Earth's rotation), with a period of 24 hours. The satellite stays above the same point on Earth.

Equation	Symbols and units	Sheet
$F = GMm/r^2$	G gravitational constant; M, m masses (kg); r separation of centres (m)	Learn
$g = F/m$	g field strength (N kg ⁻¹)	Learn
$g = GM/r^2$	field of a point (or spherical) mass M	Learn
$\phi = -GM/r$	ϕ gravitational potential (J kg ⁻¹)	Given
$E_p = -GMm/r$	E_p gravitational potential energy (J)	Given
$g = -\Delta\phi/\Delta r$	field strength = minus the potential gradient	Learn

$GMm/r^2 = mv^2/r$, which gives $T^2 = (4\pi^2/GM)r^3$	circular orbit: gravity supplies the centripetal force	Learn (derive)
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Often forgotten: potential is zero at infinity and negative everywhere else, because gravity is attractive and work is done *by* the field as a mass moves in. Near the Earth's surface, $g \approx$ constant, so $\Delta E_p = mg\Delta h$ works. Over large distances you must use $-GMm/r$.

Worked example 2: geostationary orbit radius

The mass of the Earth is 6.0×10^{24} kg. Calculate the radius of a geostationary orbit. [3]

Gravitational force provides the centripetal force: $GMm/r^2 = mr\omega^2$, so $r^3 = GM/\omega^2 = GMT^2/(4\pi^2)$ [1]

$$T = 24 \times 3600 = 86\,400 \text{ s}$$

$$r^3 = (6.67 \times 10^{-11} \times 6.0 \times 10^{24} \times 86\,400^2) \div (4\pi^2) \text{ [1]}$$

$$r^3 = (4.00 \times 10^{14} \times 7.46 \times 10^9) \div 39.5 = 7.57 \times 10^{22} \text{ m}^3$$

$$r = \sqrt[3]{(7.57 \times 10^{22})} = 4.2 \times 10^7 \text{ m, measured from the centre of the Earth. [1]}$$

Temperature

Term	Definition
Thermal equilibrium	Two objects are in thermal equilibrium when there is no net transfer of thermal energy between them, which means they are at the same temperature.
Thermodynamic (Kelvin) scale	An absolute temperature scale that does not depend on the property of any particular substance.
Absolute zero	The lowest possible temperature (0 K), at which a substance has minimum internal energy.
Specific heat capacity	The energy needed per unit mass to raise the temperature of a substance by one kelvin.
Specific latent heat of fusion	The energy needed per unit mass to change a substance from solid to liquid without a change in temperature.
Specific latent heat of vaporisation	The energy needed per unit mass to change a substance from liquid to gas without a change in temperature.
Thermometers	Any thermometer relies on a physical property that changes with temperature (e.g. the resistance of a thermistor, or the e.m.f. of a thermocouple).

Equation	Symbols and units	Sheet
$T/K = \theta/^{\circ}\text{C} + 273.15$	T thermodynamic temperature; θ Celsius temperature. A temperature <i>change</i> of 1 K is the same as a change of 1 $^{\circ}\text{C}$.	Learn
$E = mc\Delta\theta$	c specific heat capacity ($\text{J kg}^{-1} \text{K}^{-1}$); $\Delta\theta$ temperature change (K or $^{\circ}\text{C}$)	Learn
$E = mL$	L specific latent heat (J kg^{-1})	Learn

Often forgotten: the latent heat of vaporisation is much larger than that of fusion for the same substance. On boiling, the molecules must be separated completely and work must be done pushing back the atmosphere. On melting, the molecules only need to be separated slightly.

Ideal gases

Term	Definition
Mole	The amount of substance that contains N_A (6.02×10^{23}) particles.
Avogadro constant	The number of particles in one mole of substance.
Ideal gas	A gas that obeys $pV \propto T$ ($pV = nRT$) at all pressures, volumes and temperatures.
Kinetic theory assumptions	(1) The gas has a very large number of molecules moving randomly. (2) The volume of the molecules is negligible compared with the volume of the container. (3) There are no intermolecular forces except during collisions. (4) Collisions with each other and with the walls are elastic. (5) The time spent in a collision is negligible compared with the time between collisions.
Origin of gas pressure	Molecules change momentum as they hit a wall. By Newton's laws the wall exerts a force on them and they exert a force on the wall. Pressure is the total force per unit area.

Equation	Symbols and units	Sheet
$pV = nRT$	p pressure (Pa); V volume (m^3); n amount (mol); T temperature (K)	Learn
$pV = NkT$	N number of molecules; k Boltzmann constant ($J\ K^{-1}$)	Learn
$k = R/N_A$	links the two constants	Learn
$p = \frac{1}{3}(Nm/V)\langle c^2 \rangle$	m mass of one molecule (kg); $\langle c^2 \rangle$ mean square speed ($m^2\ s^{-2}$). Printed on the sheet as "pressure of an ideal gas"; it rearranges to $pV = \frac{1}{3}Nm\langle c^2 \rangle$.	Given
$p = \frac{1}{3}\rho\langle c^2 \rangle$	$\rho = Nm/V$ density of the gas	Learn (follows from the given equation)
$\frac{1}{2}m\langle c^2 \rangle = (3/2)kT$	mean translational kinetic energy of one molecule (J)	Learn (derive)
$c_{r.m.s.} = \sqrt{\langle c^2 \rangle}$	root-mean-square speed ($m\ s^{-1}$)	Learn

Worked example 3: mean kinetic energy of a molecule

Calculate the mean translational kinetic energy of a molecule of an ideal gas at $27\ ^\circ C$. [2]

$$T = 27 + 273 = 300\ K\ [1]$$

$$E_K = (3/2)kT = 1.5 \times 1.38 \times 10^{-23} \times 300$$

$$E_K = 6.2 \times 10^{-21}\ J\ [1].\ \text{This does not depend on which gas it is.}$$

Thermodynamics

Term	Definition
Internal energy	The sum of the random distribution of kinetic and potential energies of the molecules in a system.
First law of thermodynamics	The increase in internal energy of a system equals the energy supplied to it by heating plus the work done on it.
Internal energy of an ideal gas	Only kinetic, because an ideal gas has no intermolecular forces and therefore no potential energy. So its internal energy is proportional to T .
Temperature and internal energy	A rise in temperature raises the mean kinetic energy of the molecules. A change of state at constant temperature changes the potential energy instead.

Equation	Symbols and units	Sheet
$\Delta U = q + W$	ΔU increase in internal energy (J); q energy supplied to the system by heating (J); W work done <i>on</i> the system (J)	Learn
$W = p\Delta V$	work done when a gas changes volume at constant pressure p . ΔV is the volume change (m^3).	Learn

Sign convention: when a gas is compressed, work is done on it, so W is positive. When a gas expands, it does work on its surroundings, so W is negative. Energy lost by heating makes q negative. For a p - V graph, the work done equals the area under the line.

Oscillations

Term	Definition
Simple harmonic motion	Motion in which the acceleration is directly proportional to the displacement from a fixed point and always directed towards that point.
Displacement, amplitude, period, frequency	These mean the same as for waves. Displacement is measured from the equilibrium position.
Angular frequency	$\omega = 2\pi f$. It measures the rate of oscillation in rad s^{-1} .
Damping	The loss of energy from an oscillating system, usually because of a resistive force. The amplitude decreases over time.
Light damping	The system oscillates, and the amplitude decreases gradually (roughly exponentially).
Critical damping	The system returns to equilibrium in the shortest possible time without oscillating.
Heavy damping	The system returns to equilibrium slowly, without oscillating.
Free oscillation	Oscillation at the system's natural frequency with no external driving force.
Forced oscillation	Oscillation caused by a periodic driving force. The system oscillates at the driving frequency.

Resonance	The amplitude of a forced oscillation is at its maximum when the driving frequency equals the natural frequency of the system. More damping lowers and broadens the resonance peak, and moves it to a slightly lower frequency.
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Equation	Symbols and units	Sheet
$a = -\omega^2 x$	a acceleration (m s^{-2}); x displacement (m); ω angular frequency (rad s^{-1})	Given
$\omega = 2\pi f = 2\pi/T$	f frequency (Hz)	Learn
$x = x_0 \sin \omega t$	x_0 amplitude (m). Use $x = x_0 \cos \omega t$ if timing starts at maximum displacement.	Given (printed under alternating current/voltage; the same form applies to s.h.m.)
$v = v_0 \cos \omega t$	$v_0 = \omega x_0$ maximum speed	Given
$v = \pm \omega \sqrt{x_0^2 - x^2}$	speed at displacement x	Given
$v_{\max} = \omega x_0$; $a_{\max} = \omega^2 x_0$	maximum speed at $x = 0$; maximum acceleration at $x = \pm x_0$	Learn
$E = \frac{1}{2} m \omega^2 x_0^2$	E total energy (J); constant if undamped	Learn

Often forgotten: in s.h.m., displacement and acceleration are in antiphase. Velocity leads displacement by $\pi/2$. The period does not depend on the amplitude. Kinetic and potential energy each vary at twice the oscillation frequency.

Electric fields

Term	Definition
Electric field	A region of space in which a charge experiences a force.
Electric field strength	The force per unit positive charge acting on a small stationary test charge.
Field lines	These show the direction of the force on a positive charge. Where the lines are closer together, the field is stronger.
Coulomb's law	The electric force between two point charges is proportional to the product of the charges and inversely proportional to the square of their separation.
Electric potential	The work done per unit positive charge in bringing a small test charge from infinity to that point.

Equation	Symbols and units	Sheet
$E = F/q$	E field strength ($\text{N C}^{-1} = \text{V m}^{-1}$); F force (N); q charge (C)	Learn
$E = \Delta V/\Delta d$	uniform field between parallel plates. ΔV p.d. (V); Δd plate separation (m)	Learn
$F = Qq/(4\pi\epsilon_0 r^2)$	ϵ_0 permittivity of free space (F m^{-1}); r separation (m)	Learn
$E = Q/(4\pi\epsilon_0 r^2)$	field of a point charge	Learn

$V = Q/(4\pi\epsilon_0 r)$	V electric potential (V)	Given
$E_p = Qq/(4\pi\epsilon_0 r)$	E_p electric potential energy (J)	Given
$E = -\Delta V/\Delta r$	field strength = minus the potential gradient	Learn
$W = q\Delta V$	work done moving charge q through p.d. ΔV (J)	Learn

Gravitational vs electric: both obey an inverse-square law and both define potential with the zero at infinity. Gravity only attracts, so gravitational potential is always negative. Electric potential near a positive charge is positive and near a negative charge is negative. A charged particle entering a uniform field at right angles follows a parabola, like a projectile.

Capacitance

Term	Definition
Capacitance	The charge stored per unit potential difference. For a parallel-plate capacitor, the charge is the charge on one plate and the p.d. is between the plates. For an isolated conductor (such as a charged sphere), capacitance = charge $\div$ potential of the conductor, with the potential measured relative to zero at infinity.
Farad (F)	One coulomb per volt.
Time constant	$\tau = RC$. It is the time for the charge, p.d. or current of a discharging capacitor to fall to $1/e$ (about 37%) of its starting value.

Equation	Symbols and units	Sheet
$C = Q/V$	C capacitance (F); Q charge (C); V p.d. (V)	Learn
$C = 4\pi\epsilon_0 r$	capacitance of an isolated sphere of radius r (m)	Learn (derive from $V = Q/(4\pi\epsilon_0 r)$)
$C = C_1 + C_2 + \dots$	capacitors in parallel	Given
$1/C = 1/C_1 + 1/C_2 + \dots$	capacitors in series	Given
$W = \frac{1}{2}QV = \frac{1}{2}CV^2 = Q^2/(2C)$	W energy stored (J). It equals the area under a graph of V against Q.	Learn
$x = x_0 e^{-t/RC}$	x stands for Q, V or I during discharge; R resistance (Ω); RC time constant (s)	Given

Worked example 4: capacitor discharge

A 470 μF capacitor charged to 12 V discharges through a 22 k Ω resistor. Calculate the p.d. across the capacitor 5.0 s after the discharge begins. [3]

$$\tau = RC = 22 \times 10^3 \times 470 \times 10^{-6} = 10.3 \text{ s} \quad [1]$$

$$V = V_0 e^{-t/RC} = 12 \times e^{-5.0/10.3} \quad [1]$$

$$V = 12 \times e^{-0.484} = 12 \times 0.617$$

$$V = 7.4 \text{ V [1]}$$

Magnetic fields

Term	Definition
Magnetic field	A region of space in which a magnetic pole, a current-carrying conductor or a moving charge experiences a force.
Field of a long straight wire	Concentric circles centred on the wire, in planes perpendicular to it. The circles are further apart (the field is weaker) further from the wire. Right-hand grip rule: thumb along the conventional current, fingers curl in the direction of the field.
Field of a flat circular coil	The lines loop around each side of the wire. Near the centre of the coil they are nearly straight and pass through the coil perpendicular to its plane.
Field of a long solenoid	Inside: strong and nearly uniform, with parallel, equally spaced lines along the axis. Outside: like the field of a bar magnet. Right-hand grip rule: fingers curl with the current, and the thumb points to the north-pole end.
Ferrous core	Inserting a ferrous (iron) core into a solenoid greatly increases the magnetic flux density.
Forces between parallel conductors	Each conductor sits in the magnetic field of the other, so each feels a force $F = BIL$. Currents in the same direction attract; currents in opposite directions repel. The two forces are equal and opposite (Newton's third law).
Magnetic flux density	The force per unit current per unit length on a straight conductor placed at right angles to the magnetic field.
Tesla (T)	The flux density that produces a force of 1 N on each metre of a conductor carrying 1 A at right angles to the field ($1 \text{ T} = 1 \text{ N A}^{-1} \text{ m}^{-1}$).
Magnetic flux	The product of the magnetic flux density and the area normal to the field.
Weber (Wb)	$1 \text{ Wb} = 1 \text{ T m}^2$.
Magnetic flux linkage	The product of the magnetic flux and the number of turns of the coil.
Faraday's law	The magnitude of the induced e.m.f. is proportional to (equal to) the rate of change of magnetic flux linkage.
Lenz's law	The direction of the induced e.m.f. (or current) is such that it opposes the change that produces it. This is a consequence of conservation of energy.
Hall voltage	The p.d. that appears across a conductor carrying a current at right angles to a magnetic field. It forms because the charge carriers are pushed to one side.
Velocity selector	Crossed electric and magnetic fields. Only particles with speed $v = E/B$ pass through undeflected.

Equation	Symbols and units	Sheet
$F = BIL \sin \theta$	B flux density (T); I current (A); L length in field (m); θ angle between the conductor and B	Learn

$F = BQv \sin \theta$	force on a moving charge Q (C) with speed v (m s ⁻¹)	Learn
$V_H = BI/(ntq)$	V_H Hall voltage (V); n number density of carriers (m ⁻³); t thickness of the probe in the direction of B (m); q charge of each carrier (C)	Given
$r = mv/(BQ)$	radius of the circular path of a charge moving at right angles to B	Learn (derive from $BQv = mv^2/r$)
$v = E/B$	velocity selector (from $EQ = BQv$)	Learn
$\Phi = BA$	Φ flux (Wb); A area perpendicular to B (m ²)	Learn
$E = -\Delta(N\Phi)/\Delta t$	E induced e.m.f. (V); $N\Phi$ flux linkage (Wb); the minus sign expresses Lenz's law	Learn

Often forgotten: use Fleming's left-hand rule for the motor effect, with conventional current (for an electron, point your second finger opposite to its motion). A magnetic force on a moving charge is always perpendicular to the velocity. It therefore does no work and changes the direction of motion but not the speed.

Alternating currents

Term	Definition
Root-mean-square (r.m.s.) current	The value of the steady direct current that would dissipate energy at the same average rate (produce the same mean power) in a resistor as the alternating current.
Peak value	The maximum value (amplitude) of the alternating current or voltage.
Half-wave rectification	A single diode lets only one half of each cycle through.
Full-wave rectification	A bridge of four diodes makes current flow through the load in the same direction during both halves of each cycle.
Smoothing	A capacitor connected in parallel with the load discharges through the load between peaks, which reduces the ripple. A larger RC gives smoother output.

Equation	Symbols and units	Sheet
$x = x_0 \sin \omega t$	x instantaneous current or p.d.; x_0 peak value; $\omega = 2\pi f$ (rad s ⁻¹)	Given
$I_{r.m.s.} = I_0/\sqrt{2}$; $V_{r.m.s.} = V_0/\sqrt{2}$	sinusoidal a.c. only	Learn
$P_{mean} = \frac{1}{2}I_0V_0 = I_{r.m.s.}V_{r.m.s.}$	mean power in a resistive load (W). The peak power is I_0V_0 , twice the mean.	Learn

Quantum physics

Term	Definition
Photon	A quantum (discrete packet) of electromagnetic energy.

Electronvolt (eV)	The energy transferred to an electron when it moves through a potential difference of 1 V ($1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$).
Photoelectric effect	The emission of electrons from a metal surface when electromagnetic radiation of high enough frequency falls on it.
Work function	The minimum energy needed to remove an electron from the surface of a metal.
Threshold frequency	The minimum frequency of electromagnetic radiation that causes electrons to be emitted from the surface of a metal.
Evidence for particle nature	The photoelectric effect. One photon interacts with one electron and transfers all its energy (hf) to it. So emission is instantaneous, needs a minimum frequency whatever the intensity, and the maximum kinetic energy depends on frequency, not intensity. Intensity changes only the <i>rate</i> of emission.
Evidence for wave nature of particles	Electron diffraction by thin crystalline graphite gives rings, which shows electrons behave as waves.
de Broglie wavelength	The wavelength associated with a moving particle, $\lambda = h/p$.
Energy levels	Electrons in atoms can only have certain discrete energies. When an electron moves between levels, a photon of energy $hf = E_1 - E_2$ is emitted or absorbed. This produces emission and absorption line spectra.

Equation	Symbols and units	Sheet
$E = hf = hc/\lambda$	E photon energy (J); h Planck constant (J s); f frequency (Hz); λ wavelength (m)	Learn
$p = E/c$	p photon momentum (kg m s ⁻¹)	Learn
$hf = \Phi + \frac{1}{2}mv_{\text{max}}^2$	Φ work function (J); $\frac{1}{2}mv_{\text{max}}^2$ maximum kinetic energy of photoelectrons (J)	Learn
$\lambda = h/p = h/(mv)$	λ de Broglie wavelength (m)	Learn
$hf = E_1 - E_2$	E_1, E_2 the upper and lower energy levels (J)	Learn

Worked example 5: photoelectric effect

Light of wavelength 400 nm falls on a metal with work function 2.3 eV. Calculate the maximum kinetic energy of the emitted electrons. [3]

Photon energy $E = hc/\lambda = (6.63 \times 10^{-34} \times 3.00 \times 10^8) \div (400 \times 10^{-9}) = 4.97 \times 10^{-19} \text{ J}$ [1]

Work function $\Phi = 2.3 \times 1.60 \times 10^{-19} = 3.68 \times 10^{-19} \text{ J}$ [1]

$E_{K,\text{max}} = hf - \Phi = 4.97 \times 10^{-19} - 3.68 \times 10^{-19} = 1.3 \times 10^{-19} \text{ J}$ (about 0.81 eV) [1]

Nuclear physics

Term	Definition
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Mass defect	The difference between the total mass of the separate nucleons and the mass of the nucleus.
Binding energy	The minimum energy needed to separate a nucleus completely into its individual protons and neutrons.
Binding energy per nucleon	The binding energy divided by the nucleon number. It measures stability, with a peak near iron-56. Fusion of light nuclei and fission of heavy nuclei both raise the binding energy per nucleon, so both release energy.
Fission	A heavy nucleus splits into two smaller nuclei of similar mass, usually after absorbing a neutron, and releases energy and more neutrons.
Fusion	Two light nuclei join to form a heavier nucleus and release energy. It needs very high temperatures to overcome electrostatic repulsion.
Random decay	It is impossible to predict when a particular nucleus will decay, or which one will decay next.
Spontaneous decay	Decay is not affected by external factors such as temperature, pressure or chemical state.
Activity	The number of nuclei that decay per unit time.
Becquerel (Bq)	One decay per second.
Decay constant	The probability per unit time that a nucleus will decay.
Half-life	The time taken for half the undecayed nuclei of a particular isotope to decay (or for the activity to halve).

Equation	Symbols and units	Sheet
$E = mc^2$ ($\Delta E = \Delta m c^2$)	E energy (J); m mass (kg); c speed of light ($m s^{-1}$)	Learn
$A = \lambda N$	A activity (Bq); λ decay constant (s^{-1}); N number of undecayed nuclei	Learn
$x = x_0 e^{-\lambda t}$	x stands for N, A or count rate (after correcting for background)	Given
$\lambda = \ln 2 / t_{1/2} = 0.693 / t_{1/2}$	$t_{1/2}$ half-life (s)	Learn

Worked example 6: activity from half-life

A sample contains 3.0×10^{18} undecayed nuclei of an isotope with half-life 8.0 days. Calculate the activity of the sample. [3]

$$t_{1/2} = 8.0 \times 24 \times 3600 = 6.91 \times 10^5 \text{ s [1]}$$

$$\lambda = 0.693 \div 6.91 \times 10^5 = 1.00 \times 10^{-6} \text{ s}^{-1} \text{ [1]}$$

$$A = \lambda N = 1.00 \times 10^{-6} \times 3.0 \times 10^{18} = 3.0 \times 10^{12} \text{ Bq [1]}$$

Convert the half-life to seconds *before* you use $A = \lambda N$, so the activity comes out in Bq.

Medical physics

Term	Definition or fact
Piezoelectric transducer	A p.d. across a piezoelectric crystal changes its shape. An alternating p.d. makes it vibrate and emit ultrasound. Returning ultrasound deforms the crystal and produces a p.d., so the same crystal both emits and receives.
Specific acoustic impedance	The product of the density of a medium and the speed of sound in it ($Z = \rho c$).
Why a coupling gel is used	Air and skin have very different acoustic impedances, so almost all ultrasound would be reflected at the skin. Gel with an impedance close to skin's removes the air and lets most of the ultrasound enter the body.
Production of X-rays	Electrons are accelerated through a high p.d. and strike a metal target. As they decelerate they give a continuous (braking radiation) spectrum. The shortest wavelength is set by $eV = hc/\lambda_{\min}$. <i>Background, not required:</i> incident electrons also knock out inner-shell electrons; electrons from higher shells fall into the vacancies and emit characteristic line photons.
Attenuation	The decrease in intensity of a beam as it passes through matter. Absorption and scattering both contribute.
Contrast	The difference in brightness or blackening between neighbouring areas of an X-ray image. Contrast is good when neighbouring tissues have very different attenuation coefficients, and can be improved by using a contrast medium (e.g. barium or iodine).
CT scanning	Many X-ray images of one section (slice) are taken from different angles. A computer combines them into a 2-D image of the section. Repeating this for many sections along an axis and combining them builds a 3-D image, made of voxels (3-D volume elements).
PET scanning	A β^+ -emitting tracer is injected and collects in active tissue. Each positron annihilates with an electron to give two gamma photons that travel in opposite directions. Detectors record arrival times to locate the source.
Annihilation photon energy	Each photon carries the rest energy of one electron: $m_e c^2 = 9.11 \times 10^{-31} \times (3.00 \times 10^8)^2 = 8.2 \times 10^{-14} \text{ J}$ (0.511 MeV). Two photons are needed to conserve momentum.

Equation	Symbols and units	Sheet
$Z = \rho c$	Z acoustic impedance ($\text{kg m}^{-2} \text{ s}^{-1}$); ρ density (kg m^{-3}); c speed of sound (m s^{-1})	Learn
$I_R/I_0 = (Z_1 - Z_2)^2 / (Z_1 + Z_2)^2$	I_R/I_0 intensity reflection coefficient (no unit)	Given
$I = I_0 e^{-\mu x}$	μ linear attenuation (absorption) coefficient (m^{-1}); x thickness (m). Applies to both ultrasound and X-rays.	Learn
$\lambda_{\min} = hc/(eV)$	V accelerating p.d. of the X-ray tube (V)	Learn

Astronomy and cosmology

Term	Definition
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Luminosity	The total power of electromagnetic radiation emitted by a star.
Radiant flux intensity	The radiant power passing through unit area normal to the direction of travel (the power received per unit area at the observer).
Standard candle	An astronomical object of known luminosity (e.g. a Cepheid variable star or a type Ia supernova). Measuring its radiant flux intensity gives its distance.
Wien's displacement law	The wavelength at which a black body emits maximum power per unit wavelength is inversely proportional to its thermodynamic temperature ($\lambda_{\max} \propto 1/T$).
Redshift	An increase in the observed wavelength (a decrease in frequency) of radiation from a source moving away from the observer.
Hubble's law	The recession speed of a distant galaxy is proportional to its distance from us.
Big Bang evidence	Redshift of distant galaxies increases with distance, which shows the Universe is expanding. Traced backwards, this suggests the Universe was once extremely small, hot and dense (the Big Bang theory).

Equation	Symbols and units	Sheet
$F = L/(4\pi d^2)$	F radiant flux intensity (W m^{-2}); L luminosity (W); d distance (m)	Learn
$L = 4\pi r^2 \sigma T^4$	σ Stefan–Boltzmann constant; r radius of the star (m); T surface temperature (K)	Given
$\lambda_{\max} \propto 1/T$	$\lambda_{\max}$ peak wavelength (m); T thermodynamic temperature (K). Use it as a ratio: $\lambda_1 T_1 = \lambda_2 T_2$.	Learn
$\Delta\lambda/\lambda \approx \Delta f/f \approx v/c$	$\Delta\lambda$ change in wavelength; v speed of the source along the line of sight ($v \ll c$)	Given
$v = H_0 d$	H_0 Hubble constant (s^{-1}); d distance (m)	Learn

Often forgotten: $1/H_0$ gives an estimate of the age of the Universe, so convert H_0 to s^{-1} first. Hubble's law needs the *recession speed*, so find it from the redshift first.

Common mistakes

- Leaving out "per unit" or the reference condition in a definition. Examples: "force on a charge" instead of "force per unit positive charge", and "work done bringing a mass from infinity" without "per unit mass".
- Defining potential difference as "energy per charge" without the direction of transfer. Keep p.d. (electrical $\rightarrow$ other forms) and e.m.f. (other forms $\rightarrow$ electrical) apart.
- Defining the spring constant or Young modulus without "within the limit of proportionality".
- Writing "acceleration proportional to displacement" for s.h.m. and forgetting "and directed towards the fixed point (equilibrium position)".
- Defining the r.m.s. current as "the average current". The mean of a sinusoidal current over a cycle is zero. The r.m.s. value is defined by equal *power* in a resistor.
- Using Celsius temperatures in $pV = nRT$, $E_K = (3/2)kT$ or the Stefan–Boltzmann law. Always convert to kelvin.

- Getting the sign in $\Delta U = q + W$ wrong. W is the work done *on* the gas, so it is negative when the gas expands.
- Measuring r from the surface instead of the centre in gravitational and electric field equations (for an orbit, $r = \text{planet radius} + \text{height}$).
- Stating that weight or centripetal force is "the same as mass" or is an extra force in a free-body diagram. Mass is a property of the object, and centripetal force is the resultant force.
- Forgetting to convert eV to J ($\times 1.60 \times 10^{-19}$), MeV to J ($\times 1.60 \times 10^{-13}$), days or years to seconds before using $A = \lambda N$, and nm, μF or $\text{k}\Omega$ to base units.
- Squaring the amplitude incorrectly. Intensity $\propto \text{amplitude}^2$, so halving the amplitude quarters the intensity.
- Using d in $d \sin \theta = n\lambda$ as "lines per mm". It must be the spacing in metres, $1 \div (\text{lines per metre})$.
- Quoting the photoelectric equation with the *typical* kinetic energy instead of the *maximum* kinetic energy.
- Claiming that increasing light intensity increases the kinetic energy of photoelectrons. It increases only the number emitted per second.
- Describing binding energy as "energy stored in the nucleus" or "energy released when the nucleus forms" without the idea of separating it into its individual nucleons.
- Giving the half-life as "time for the mass to halve". The mass of the sample hardly changes. It is the number of *undecayed nuclei*, or the activity, that halves.
- Quoting final answers to too many significant figures. Match the least precise data in the question, usually 2 or 3 s.f., and always include the unit.