

EXAMINERPREP · FORMULA HANDOUT · IB PHYSICS SL & HL

Equations Not in the Data Booklet

For IB Diploma Physics SL and HL (syllabus first assessed 2025)

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Every equation below is one you must know or be able to derive yourself, because it is not printed in the data booklet you get in Papers 1 and 2.

How to use this sheet

Learn these until you can write them from memory, and know where each one comes from: most are two lines of algebra away from a booklet equation, and a derivation is worth knowing in case the question asks you to show it.

- **SL+HL** = everyone needs it. **HL** = Additional Higher Level only.
- **Derived** = not printed, but follows from a booklet equation. Practise the derivation once.
- **Exam tip** and **Common error** boxes flag where marks are usually gained or lost.
- Equations are magnitudes unless a sign is shown. Use SI units throughout unless told otherwise.
- The data booklet can be revised between sessions. Check this sheet against the current version before your exams.

CONTENTS

1. Tools: uncertainties, maths and graphs
2. A. Space, time and motion A.1–A.5
3. B. The particulate nature of matter B.1–B.5

- 4. C. Wave behaviour C.1–C.5
- 5. D. Fields D.1–D.4
- 6. E. Nuclear and quantum physics E.1–E.5

Tools: uncertainties, maths and graphs

Uncertainties SL+HL

The booklet gives the propagation rules (sums, products/quotients, powers). These are not given:

Fractional and percentage uncertainty

$$\text{fractional} = \frac{\Delta x}{x} \quad \text{percentage} = \frac{\Delta x}{x} \times 100\%$$

Uncertainty from repeated readings (half the range)

$$\Delta x \approx \frac{x_{\max} - x_{\min}}{2}$$

Multiplying by an exact constant

$$y = kx \Rightarrow \Delta y = |k| \Delta x$$

Uncertainty in a gradient (from the steepest and shallowest lines through all error bars)

$$\Delta m \approx \frac{m_{\max} - m_{\min}}{2}$$

Percentage difference from an accepted value

$$\% \text{ difference} = \frac{|x_{\text{exp}} - x_{\text{accepted}}|}{x_{\text{accepted}}} \times 100\%$$

EXAM TIP

Quote the absolute uncertainty to 1 significant figure (2 is acceptable if the first digit is 1), then round the value to the same decimal place.

Maths not in the booklet **SL+HL**

The booklet gives the volume of a sphere but not its surface area. You need it for stars (E.5) and for radiation from spheres (B.1).

$$A_{\text{sphere}} = 4\pi r^2$$

Small-angle approximation (θ in radians, roughly $\theta < 0.1$ rad; behind $s = \lambda D/d$ and $\theta = \lambda/b$)

$$\sin \theta \approx \tan \theta \approx \theta$$

Arc length and angle

$$s = r\theta \quad \omega = \frac{\Delta\theta}{\Delta t} = \frac{2\pi}{T} = 2\pi f$$

Linearising for graphs

$$y = kx^n : \text{plot } \ln y \text{ against } \ln x, \text{ gradient} = n$$

$$y = Ae^{-\lambda x} : \text{plot } \ln y \text{ against } x, \text{ gradient} = -\lambda$$

Graph relationships SL+HL

GRAPH	GRADIENT GIVES	AREA UNDER IT GIVES
displacement–time	velocity	—
velocity–time	acceleration	displacement
acceleration–time	—	change in velocity
force–time	rate of change of momentum	impulse (Δp)
force–extension	spring constant k	work done / elastic energy
pressure–volume	—	work done by or on the gas
power–time	—	energy transferred
current–time	—	charge

COMMON ERROR

Reading the gradient of a curve from one point. Draw a tangent at the point asked for and use a large triangle.

A. Space, time and motion

A.1 Kinematics SL+HL

Definitions of average velocity and acceleration (the booklet gives only the four suvat equations)

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

Projectile components (launch speed u at angle θ above the horizontal)

$$u_x = u \cos \theta \quad u_y = u \sin \theta \quad a_x = 0 \quad a_y = -g$$

Derived

Level ground, no air resistance: time of flight, maximum height, range

$$T = \frac{2u \sin \theta}{g} \quad H = \frac{u^2 \sin^2 \theta}{2g} \quad R = \frac{u^2 \sin 2\theta}{g}$$

EXAM TIP

These three only hold for launch and landing at the same height. In any other case, apply suvat separately to the horizontal and vertical motion.

A.2 Forces and momentum

SL+HL

Equilibrium (Newton's first law)

$$\Sigma F = 0 \iff a = 0$$

Conservation of momentum (isolated system)

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

Elastic collision: kinetic energy is also conserved. Explosion from rest: total momentum after is zero.

Weight components on a slope (angle θ to the horizontal)

$$F_{\parallel} = mg \sin \theta \quad F_{\perp} = mg \cos \theta$$

Derived

Centripetal force (from $F = ma$ and $a = v^2/r$)

$$F = \frac{mv^2}{r} = m\omega^2 r \quad \omega = \frac{2\pi}{T}$$

COMMON ERROR

Drawing a separate "centripetal force" on a free-body diagram. It is the resultant of the real forces (tension, gravity, friction, normal force).

Normal force in a lift (upward acceleration a positive)

$$N = m(g + a)$$

Derived **Terminal velocity of a sphere** (weight = drag + buoyancy, using Stokes' law)

$$mg = 6\pi\eta r v_t + \rho_f V g \Rightarrow v_t = \frac{2r^2 g (\rho_s - \rho_f)}{9\eta}$$

A.3 Work, energy and power **SL+HL**

Conservation of energy (no dissipative forces)

$$E_k + E_p = \text{constant} \qquad \frac{1}{2}mv^2 = mg\Delta h$$

Work–energy theorem

$$W_{\text{net}} = \Delta E_k$$

Power as rate of energy transfer

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

EXAM TIP

With friction, energy lost = friction force $\times$ distance along the path, not the vertical height.

A.4 Rigid body mechanics **HL**

Rolling without slipping

$$v = \omega r \qquad a = \alpha r$$

Total kinetic energy of a rolling object

$$E_k = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$$

Derived Rolling down a height h from rest

$$mgh = \frac{1}{2}mv^2 \left(1 + \frac{I}{mr^2} \right)$$

Rotational work and power

$$W = \tau\Delta\theta \quad P = \tau\omega$$

Rotational equilibrium (both conditions together)

$$\Sigma F = 0 \text{ and } \Sigma \tau = 0$$

Conservation of angular momentum (no external torque) and angular momentum of a point mass

$$I_1\omega_1 = I_2\omega_2 \quad L = mvr$$

COMMON ERROR

Assuming rotational kinetic energy is conserved when I changes. Angular momentum is conserved; kinetic energy usually is not.

A.5 Galilean and special relativity HL

Inverse Lorentz transformations (from S' back to S)

$$x = \gamma(x' + vt')$$
$$t = \gamma\left(t' + \frac{vx'}{c^2}\right)$$

Interval forms (use these for two events)

$$\Delta x' = \gamma(\Delta x - v\Delta t) \quad \Delta t' = \gamma\left(\Delta t - \frac{v\Delta x}{c^2}\right)$$

Derived **Relativity of simultaneity** (events simultaneous in S, $\Delta t = 0$)

$$\Delta t' = -\frac{\gamma v \Delta x}{c^2}$$

EXAM TIP

Proper time Δt_0 is measured by the observer who sees both events at the same place; proper length L_0 is measured in the frame where the object is at rest. Identify them before using the booklet equations.

B. The particulate nature of matter

B.1 Thermal energy transfers **SL+HL**

Heating with a known power (e.g. an electric heater, $P = IV$)

$$Pt = mc\Delta T \quad Pt = mL$$

Mixing: energy lost by the hot body = energy gained by the cold body (no losses)

$$m_1 c_1 (T_1 - T_f) = m_2 c_2 (T_f - T_2)$$

Derived **Power radiated per unit area by a black body**

$$\frac{P}{A} = \sigma T^4$$

EXAM TIP

A temperature change is the same in K and $^{\circ}\text{C}$, but σT^4 and Wien's law need absolute temperature in K.

B.2 Greenhouse effect SL+HL

Intensity

$$I = \frac{P}{A}$$

Mean incoming solar intensity on the whole Earth (disc area πR^2 intercepts, sphere area $4\pi R^2$ shares)

$$I_{\text{mean}} = \frac{S}{4}$$

Derived **Energy balance for an equilibrium planet** (albedo α , emissivity e)

$$(1 - \alpha) \frac{S}{4} = e\sigma T^4$$

COMMON ERROR

Forgetting the factor 4, or using α instead of $(1 - \alpha)$ for the absorbed fraction.

B.3 Gas laws SL+HL

Amount of substance from mass (M = molar mass in kg mol^{-1})

$$n = \frac{m}{M}$$

Derived **Single-change gas laws** (fixed amount of ideal gas)

$$p_1 V_1 = p_2 V_2 \quad (T \text{ const}) \qquad \frac{V_1}{T_1} = \frac{V_2}{T_2} \quad (p \text{ const}) \qquad \frac{p_1}{T_1} = \frac{p_2}{T_2} \quad (V \text{ const})$$

Link between the constants

$$R = N_A k_B$$

Derived **rms speed of gas molecules** (from $p = \frac{1}{3}\rho v^2$ and $pV = nRT$)

$$v_{\text{rms}} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{m_{\text{molecule}}}}$$

COMMON ERROR

Using grams per mole for M . Convert to kg mol^{-1} first.

B.4 Thermodynamics **HL**

Sign convention with $Q = \Delta U + W$: W is work done **by** the gas (positive on expansion).

Special processes

PROCESS	CONDITION	FIRST LAW BECOMES
Isovolumetric (isochoric)	$W = 0$	$Q = \Delta U$
Isobaric	p constant	$W = p\Delta V$
Isothermal	$\Delta U = 0$	$Q = W$, and $pV = \text{constant}$
Adiabatic	$Q = 0$	$W = -\Delta U$
Complete cycle	$\Delta U = 0$	$Q_{\text{net}} = W_{\text{net}} = \text{enclosed area on } p\text{-}V$

Derived **Adiabatic change for a monatomic ideal gas, in terms of T**

$$TV^{2/3} = \text{constant}$$

Heat engines: energy in, work out and energy rejected

$$Q_H = W + Q_C \quad \eta = \frac{W}{Q_H} = 1 - \frac{Q_C}{Q_H}$$

Second law (isolated system)

$$\Delta S \geq 0$$

EXAM TIP

No real engine can beat the Carnot efficiency between the same two temperatures. Use it as a check on your answer.

B.5 Current and circuits **SL+HL**

Kirchhoff's laws

$$\text{junction: } \Sigma I_{\text{in}} = \Sigma I_{\text{out}} \quad \text{loop: } \Sigma \varepsilon = \Sigma IR$$

Potential divider

$$V_{\text{out}} = V_{\text{in}} \frac{R_2}{R_1 + R_2}$$

Derived**Terminal potential difference** (lost volts = Ir)

$$V = \varepsilon - Ir$$

Charge and energy

$$q = It \quad E = VIt = Pt \quad q = Ne$$

EXAM TIP

Treat an ideal ammeter as zero resistance and an ideal voltmeter as infinite resistance unless the question says otherwise.

C. Wave behaviour

C.1 Simple harmonic motion SL+HL

Angular frequency

$$\omega = 2\pi f = \frac{2\pi}{T}$$

Derived ω for the two standard oscillators

$$\omega^2 = \frac{k}{m} \quad (\text{mass-spring}) \qquad \omega^2 = \frac{g}{l} \quad (\text{pendulum})$$

Maximum speed and acceleration

$$v_{\max} = \omega x_0 \qquad a_{\max} = \omega^2 x_0$$

Phase difference from a time difference

$$\Delta\phi = \frac{2\pi \Delta t}{T}$$

HL Derived **Kinetic energy at displacement x** (the booklet gives E_T and E_p only)

$$E_k = \frac{1}{2} m \omega^2 (x_0^2 - x^2)$$

EXAM TIP

The pendulum period is independent of mass and (for small angles) of amplitude.
The spring period is independent of g .

C.2 Wave model SL+HL

Phase difference between two points on a wave

$$\Delta\phi = \frac{2\pi \Delta x}{\lambda}$$

Intensity and amplitude

$$I \propto A^2$$

Inverse-square law for a point source

$$I = \frac{P}{4\pi r^2}$$

COMMON ERROR

Thinking that doubling the amplitude doubles the intensity. It quadruples it.

C.3 Wave phenomena SL+HL

Absolute refractive index

$$n = \frac{c}{v}$$

Critical angle (light going from medium n_1 into a less dense medium n_2)

$$\sin \theta_c = \frac{n_2}{n_1} \quad \text{into air: } \sin \theta_c = \frac{1}{n}$$

HL Grating spacing and highest order visible (N lines per metre)

$$d = \frac{1}{N} \quad n_{\max} \leq \frac{d}{\lambda} \quad (\text{round down})$$

HL Single slit: width of the central maximum (screen at distance D)

$$\text{angular width} = \frac{2\lambda}{b} \quad \text{linear width} \approx \frac{2\lambda D}{b}$$

COMMON ERROR

Forgetting to convert lines per mm into lines per metre before finding d .

C.4 Standing waves and resonance **SL+HL**

The booklet gives no equations for this topic.

String fixed at both ends, or pipe open at both ends ($n = 1, 2, 3, \dots$)

$$\lambda_n = \frac{2L}{n} \quad f_n = \frac{nv}{2L}$$

Pipe closed at one end (odd harmonics only, $n = 1, 2, 3, \dots$)

$$\lambda = \frac{4L}{2n-1} \quad f = \frac{(2n-1)v}{4L}$$

Spacings

$$\text{node to node} = \frac{\lambda}{2} \quad \text{node to adjacent antinode} = \frac{\lambda}{4}$$

EXAM TIP

Sketch the pattern first (nodes at fixed or closed ends, antinodes at open ends) and read λ off the sketch. This avoids errors in numbering harmonics.

C.5 Doppler effect

SL+HL Redshift for light ($v \ll c$)

$$z = \frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}$$

SL+HL

Derived

Reflection from a moving object (radar, ultrasound; $v \ll \text{wave speed } c$)

$$\Delta f \approx \frac{2v}{c} f$$

HL

Source and observer both moving (upper signs when they approach each other)

$$f' = f \frac{v \pm u_o}{v \mp u_s}$$

COMMON ERROR

Getting the sign wrong. Check your answer: approaching means a higher received frequency.

D. Fields

D.1 Gravitational fields

SL+HL

Orbital radius from the planet's centre

$$r = R_{\text{planet}} + h$$

SL+HL

Derived

Circular orbit (gravity provides the centripetal force)

$$\frac{GMm}{r^2} = \frac{mv^2}{r} \Rightarrow v = \sqrt{\frac{GM}{r}}$$

SL+HL

Derived

Kepler's third law

$$T^2 = \frac{4\pi^2}{GM} r^3$$

HL

Derived

Energies of a satellite in circular orbit

$$E_k = \frac{GMm}{2r} \quad E_{\text{total}} = -\frac{GMm}{2r}$$

HL

Derived

Energy needed to move to a higher circular orbit

$$\Delta E = \frac{GMm}{2} \left(\frac{1}{r_1} - \frac{1}{r_2} \right)$$

COMMON ERROR

Using the height above the surface as r . Always measure r from the centre of the planet.

EXAM TIP

A geostationary satellite has $T = 24$ h and orbits above the equator.

D.2 Electric and magnetic fields**SL+HL**

Derived

Field of a point charge (from $F = kq_1q_2/r^2$ and $E = F/q$)

$$E = \frac{kQ}{r^2}$$

SL+HL**Quantisation of charge and the electronvolt**

$$q = ne \quad 1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$$

SL+HL

Derived

Magnetic field of a long straight wire (from the force per unit length between two wires)

$$B = \frac{\mu_0 I}{2\pi r}$$

EXAM TIP

Field lines meet equipotentials at right angles, and no work is done moving a charge along an equipotential.

D.3 Motion in electromagnetic fields SL+HL

Force on a charge in an electric field

$$F = qE \quad a = \frac{qE}{m}$$

Acceleration through a potential difference V (from rest)

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

Derived

Circular motion in a uniform magnetic field ($qvB = mv^2/r$)

$$r = \frac{mv}{qB} \quad T = \frac{2\pi m}{qB}$$

Derived

Velocity selector (crossed fields, undeflected particle: $qE = qvB$)

$$v = \frac{E}{B}$$

EXAM TIP

The magnetic force is always perpendicular to the velocity, so it does no work and the speed stays constant. Between parallel plates, treat the motion like a projectile: constant velocity along the plates, constant acceleration across them.

D.4 Induction HL

Flux linkage and induced current

$$\text{flux linkage} = N\Phi \qquad I = \frac{\varepsilon}{R}$$

Coil of N turns, area A , rotating at ω in a uniform field B

$$\varepsilon = NBA\omega \sin \omega t \qquad \varepsilon_{\max} = NBA\omega$$

EXAM TIP

Doubling the rotation speed doubles both the peak emf and the frequency of the output.

COMMON ERROR

Dropping the minus sign without explanation. State Lenz's law: the induced current opposes the change in flux that causes it.

E. Nuclear and quantum physics

E.1 Structure of the atom

SL+HL Photon energy from wavelength (hc is given as a constant)

$$E = \frac{hc}{\lambda}$$

SL+HL Photon emitted or absorbed in a transition

$$\Delta E = E_{\text{upper}} - E_{\text{lower}} = hf = \frac{hc}{\lambda}$$

SL+HL

Derived

Distance of closest approach (head-on alpha scattering, all E_k becomes E_p)

$$E_k = \frac{kQq}{d}$$

HL

Derived

Hydrogen transition wavelength (from $E = -13.6/n^2$ eV)

$$\frac{hc}{\lambda} = 13.6 \text{ eV} \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$$

HL

Derived

Nuclear density is about the same for all nuclei (from $R = R_0 A^{1/3}$)

$$\rho \approx \frac{3m_u}{4\pi R_0^3}$$

COMMON ERROR

Leaving ΔE in eV when using it with h in J s. Convert, or use $hc = 1.24 \times 10^{-6}$ eV m.

E.2 Quantum physics HL**Threshold frequency and stopping potential**

$$f_0 = \frac{\Phi}{h} \quad eV_s = E_{\max}$$

Momentum of a photon

$$p = \frac{h}{\lambda} = \frac{E}{c}$$

Derived

de Broglie wavelength from kinetic energy (non-relativistic; second form for a charge accelerated through V)

$$\lambda = \frac{h}{\sqrt{2mE_k}} = \frac{h}{\sqrt{2meV}}$$

EXAM TIP

Intensity changes the number of photoelectrons, not their maximum kinetic energy.
Frequency changes $E_{\max}$.

E.3 Radioactive decay

SL+HL Mass defect and binding energy

$$\Delta m = Zm_p + (A - Z)m_n - M_{\text{nucleus}} \quad E_B = \Delta m c^2$$

SL+HL Binding energy per nucleon

$$\frac{E_B}{A}$$

SL+HL Unit shortcut (mass in u, energy in MeV)

$$E \text{ (MeV)} = \Delta m \text{ (u)} \times 931.5$$

SL+HL Remaining fraction after n half-lives ($n = t / T_{1/2}$)

$$N = N_0 \left(\frac{1}{2} \right)^n$$

In every decay or reaction equation, nucleon number A and charge (proton) number Z are each conserved.

HL Mass and count rate decay the same way

$$m = m_0 e^{-\lambda t} \quad C = C_0 e^{-\lambda t}$$

HL Linear form for graphs (gradient = $-\lambda$)

$$\ln N = \ln N_0 - \lambda t$$

COMMON ERROR

Using atomic mass instead of nuclear mass without accounting for the electrons.
Check which one the question gives.

E.4 Fission SL+HL

Energy released in a reaction

$$Q = (\Sigma m_{\text{before}} - \Sigma m_{\text{after}})c^2$$

Power output of a reactor or power station

$$P_{\text{out}} = \eta \times (\text{fissions per second}) \times (\text{energy per fission})$$

E.5 Fusion and stars SL+HL

Derived Comparing two stars (from $L = \sigma AT^4$ with $A = 4\pi R^2$)

$$\frac{L_1}{L_2} = \left(\frac{R_1}{R_2} \right)^2 \left(\frac{T_1}{T_2} \right)^4$$

Derived Radius of a star

$$R = \sqrt{\frac{L}{4\pi\sigma T^4}}$$

Derived Distance from apparent brightness

$$d = \sqrt{\frac{L}{4\pi b}}$$

EXAM TIP

In ratio questions the constants cancel. Write the ratio first and substitute last.

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