INTERNATIONAL BACCALAUREATE · DIPLOMA

IB Physics

HL formula booklet

The complete IB Physics data booklet, SL and HL content

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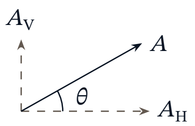
Mathematical equations

Area of a triangle	$A = \frac{1}{2}(bh)$ (b base, h height)
Area and circumference of a circle	$A = \pi r^2$ (r radius) $\quad C = 2\pi r$
Volume of a cuboid	$V = lwh$ (l length, w width, h height)
Volume of a prism	$V = Ah$ (A area of cross-section)
Volume of a sphere	$V = \frac{4}{3}\pi r^3$
Volume and area of the curved surface of a cylinder	$V = \pi r^2 h \quad A = 2\pi rh$
Vectors: resolving into horizontal and vertical components	 $A_\mathrm{H} = A\cos\theta$ $A_\mathrm{V} = A\sin\theta$
Trigonometric relationships	$\tan\theta = \frac{\sin\theta}{\cos\theta} \quad \sin^2\theta + \cos^2\theta = 1$

Uncertainties

Sum or difference: add absolute uncertainties	If $y = a \pm b$, then $\Delta y = \Delta a + \Delta b$
Product or quotient: add fractional uncertainties	If $y = \frac{ab}{c}$, then $\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c}$
Power: multiply the fractional uncertainty by the power	If $y = a^n$, then $\frac{\Delta y}{y} = \left\lvert n\frac{\Delta a}{a} \right\rvert$

Metric (SI) multipliers

PREFIX	peta	tera	giga	mega	kilo	hecto	deca	deci	centi	milli	micro	nano	pico	femto
SYMBOL	P	T	G	M	k	h	da	d	c	m	µ	n	p	f
VALUE	10^{15}	10^{12}	10^{9}	10^{6}	10^{3}	10^{2}	10^{1}	10^{-1}	10^{-2}	10^{-3}	10^{-6}	10^{-9}	10^{-12}	10^{-15}

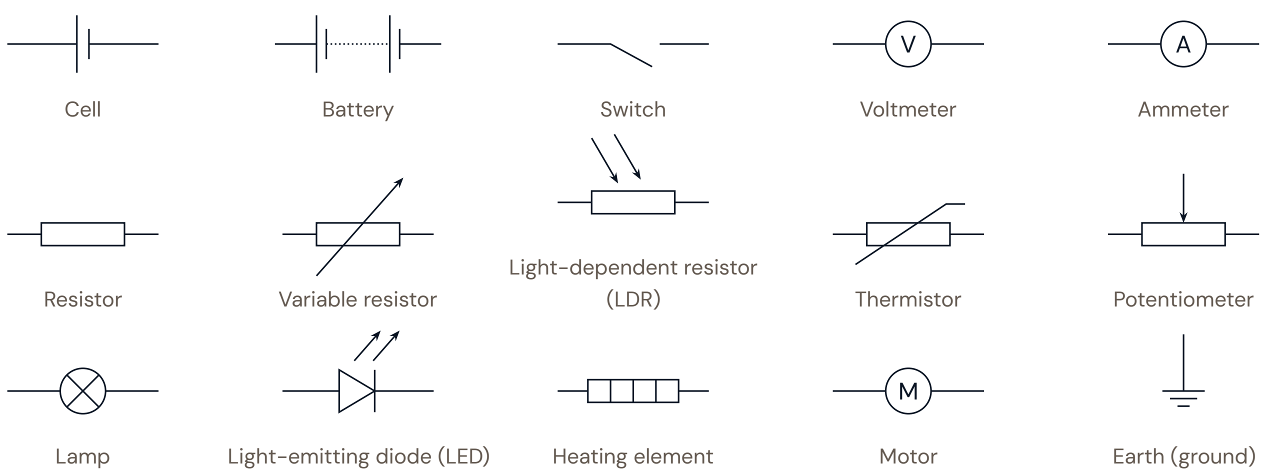
Unit conversions

Radian in degrees	$1 \text{ radian (rad)} \equiv \frac{180^\circ}{\pi}$
Kelvin from degrees Celsius	Temperature (K) = temperature (°C) + 273
Light year	$1 \text{ light year (ly)} = 9.46 \times 10^{15}$ m
Parsec	1 parsec (pc) = 3.26 ly
Astronomical unit	$1 \text{ astronomical unit (AU)} = 1.50 \times 10^{11}$ m
Kilowatt-hour	$1 \text{ kilowatt-hour (kWh)} = 3.60 \times 10^{6}$ J
Planck constant times speed of light	$hc = 1.99 \times 10^{-25}\ \mathrm{J\,m} = 1.24 \times 10^{-6}\ \mathrm{eV\,m}$

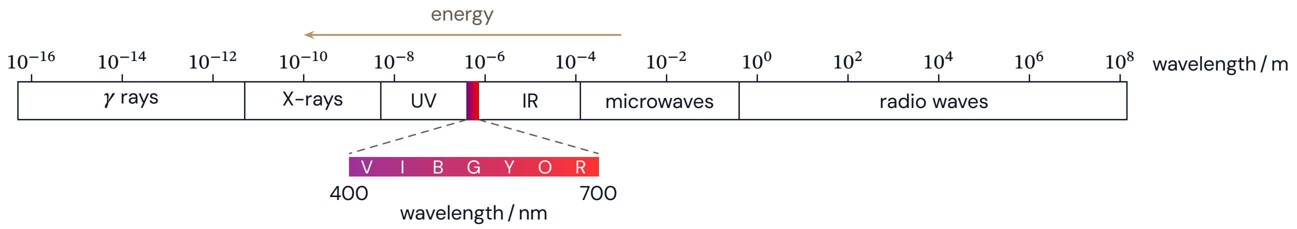
Fundamental constants

QUANTITY	SYMBOL	APPROXIMATE VALUE
Acceleration of free fall	g	$9.8\ \mathrm{m\,s^{-2}}$ (Earth's surface)
Gravitational constant	G	$6.67 \times 10^{-11}\ \mathrm{N\,m^2\,kg^{-2}}$
Avogadro constant	N_A	$6.02 \times 10^{23}\ \mathrm{mol^{-1}}$
Gas constant	R	$8.31\ \mathrm{J\,K^{-1}\,mol^{-1}}$
Boltzmann constant	k_B	$1.38 \times 10^{-23}\ \mathrm{J\,K^{-1}}$
Stefan–Boltzmann constant	σ	$5.67 \times 10^{-8}\ \mathrm{W\,m^{-2}\,K^{-4}}$
Coulomb constant	k	$8.99 \times 10^{9}\ \mathrm{N\,m^2\,C^{-2}}$
Permittivity of free space	ε_0	$8.85 \times 10^{-12}\ \mathrm{C^2\,N^{-1}\,m^{-2}}$
Permeability of free space	μ_0	$4\pi \times 10^{-7}\ \mathrm{T\,m\,A^{-1}}$
Speed of light in vacuum	c	$3.00 \times 10^{8}\ \mathrm{m\,s^{-1}}$
Planck constant	h	$6.63 \times 10^{-34}\ \mathrm{J\,s}$
Elementary charge	e	$1.60 \times 10^{-19}\ \mathrm{C}$
Electron rest mass	m_e	$9.110 \times 10^{-31}\ \mathrm{kg} = 0.000549\ \mathrm{u} = 0.511\ \mathrm{MeV}\,c^{-2}$
Proton rest mass	m_p	$1.673 \times 10^{-27}\ \mathrm{kg} = 1.007276\ \mathrm{u} = 938\ \mathrm{MeV}\,c^{-2}$
Neutron rest mass	m_n	$1.675 \times 10^{-27}\ \mathrm{kg} = 1.008665\ \mathrm{u} = 940\ \mathrm{MeV}\,c^{-2}$
(Unified) atomic mass unit	u	$1.661 \times 10^{-27}\ \mathrm{kg} = 931.5\ \mathrm{MeV}\,c^{-2}$
Solar constant	S	$1.36 \times 10^{3}\ \mathrm{W\,m^{-2}}$
Fermi radius	R_0	$1.20 \times 10^{-15}\ \mathrm{m}$

Electrical circuit symbols



Electromagnetic spectrum



A. Space, time and motion

All equations give magnitudes only: vector notation is not used.

A.1 KINEMATICS

	SUVAT: displacement from average velocity	$s = \frac{u+v}{2}t$
	SUVAT: final velocity	$v = u + at$
	SUVAT: displacement from initial velocity	$s = ut + \frac{1}{2}at^2$
	SUVAT: velocity and displacement (no time)	$v^2 = u^2 + 2as$

A.2 FORCES AND MOMENTUM

	Static friction (up to a maximum)	$F_\mathrm{f} \leq \mu_\mathrm{s} F_\mathrm{N}$
	Dynamic (kinetic) friction	$F_\mathrm{f} = \mu_\mathrm{d} F_\mathrm{N}$
	Hooke's law	$F_\mathrm{H} = -kx$
	Stokes' drag on a sphere	$F_\mathrm{d} = 6\pi\eta rv$
	Buoyancy force (Archimedes' principle)	$F_\mathrm{b} = \rho Vg$
	Weight	$F_\mathrm{g} = mg$
	Linear momentum	$p = mv$
	Impulse	$J = F\Delta t$
	Newton's second law	$F = ma = \frac{\Delta p}{\Delta t}$
	Centripetal acceleration	$a = \frac{v^2}{r} = \omega^2 r = \frac{4\pi^2 r}{T^2}$
	Speed in circular motion	$v = \frac{2\pi r}{T} = \omega r$

A.3 WORK, ENERGY AND POWER

	Work done by a constant force	$W = Fs\cos\theta$
	Kinetic energy	$E_\mathrm{k} = \frac{1}{2}mv^2 = \frac{p^2}{2m}$
	Change in gravitational potential energy	$\Delta E_\mathrm{p} = mg\Delta h$
	Elastic potential energy	$E_\mathrm{H} = \frac{1}{2}k\Delta x^2$
	Power	$P = \frac{\Delta W}{\Delta t} = Fv$
	Efficiency	$\eta = \frac{\text{useful work out}}{\text{total work in}} = \frac{\text{useful power out}}{\text{total power in}}$

A.4 RIGID BODY MECHANICS

HL	Torque	$\tau = Fr\sin\theta$
HL	Rotational SUVAT: angle from average angular velocity	$\Delta\theta = \frac{\omega_\mathrm{f} + \omega_\mathrm{i}}{2}t$
HL	Rotational SUVAT: final angular velocity	$\omega_\mathrm{f} = \omega_\mathrm{i} + \alpha t$
HL	Rotational SUVAT: angle from initial angular velocity	$\Delta\theta = \omega_\mathrm{i} t + \frac{1}{2}\alpha t^2$
HL	Rotational SUVAT: angular velocity and angle (no time)	$\omega_\mathrm{f}^2 = \omega_\mathrm{i}^2 + 2\alpha\Delta\theta$

HL	Moment of inertia	$I = \Sigma m r^2$
HL	Newton's second law for rotation	$\tau = I\alpha$
HL	Angular momentum	$L = I\omega$
HL	Angular impulse and change in angular momentum	$\Delta L = \tau \Delta t \qquad \Delta L = \Delta(I\omega)$
HL	Rotational kinetic energy	$E_\mathrm{k} = \frac{1}{2} I\omega^2 = \frac{L^2}{2I}$

A.5 GALILEAN AND SPECIAL RELATIVITY

HL	Galilean transformation: position	$x' = x - vt$
HL	Galilean transformation: time	$t' = t$
HL	Galilean velocity transformation	$u' = u - v$
HL	Lorentz transformation: position; Lorentz factor	$x' = \gamma(x - vt) \quad \text{where } \gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$
HL	Lorentz transformation: time	$t' = \gamma\left(t - \frac{vx}{c^2}\right)$
HL	Relativistic velocity transformation	$u' = \frac{u - v}{1 - \frac{uv}{c^2}}$
HL	Spacetime interval	$(\Delta s)^2 = (c\Delta t)^2 - \Delta x^2$
HL	Time dilation	$\Delta t = \gamma \Delta t_0$
HL	Length contraction	$L = \frac{L_0}{\gamma}$
HL	Spacetime diagram: angle of the moving frame's axes	$\tan\theta = \frac{v}{c}$

B. The particulate nature of matter

B.1 THERMAL ENERGY TRANSFERS

Density	$\rho = \frac{m}{V}$
Mean kinetic energy of a gas particle	$\overline{E_\mathrm{k}} = \frac{3}{2} k_\mathrm{B} T$
Specific heat capacity	$Q = mc\Delta T$
Specific latent heat	$Q = mL$
Rate of thermal conduction	$\frac{\Delta Q}{\Delta t} = -kA\frac{\Delta T}{\Delta x}$
Stefan–Boltzmann law (luminosity)	$L = \sigma A T^4$
Apparent brightness	$b = \frac{L}{4\pi d^2}$
Wien's displacement law	$\lambda_{\mathrm{max}} T = 2.9 \times 10^{-3}\ \mathrm{m\,K}$

B.2 GREENHOUSE EFFECT

Emissivity	$\text{emissivity} = \frac{\text{power radiated per unit area}}{\sigma T^4}$
Albedo	$\text{albedo} = \frac{\text{total scattered power}}{\text{total incident power}}$

B.3 GAS LAWS

	Pressure	$P = \frac{F}{A}$
	Amount of substance (moles)	$n = \frac{N}{N_A}$
	Combined gas law (fixed amount of gas)	$\frac{PV}{T} = \text{constant}$
	Ideal gas equation	$PV = nRT = Nk_BT$
	Kinetic theory: pressure of an ideal gas	$P = \frac{1}{3}\rho v^2$
	Internal energy of an ideal monatomic gas	$U = \frac{3}{2}nRT = \frac{3}{2}Nk_BT$

B.4 THERMODYNAMICS

HL	First law of thermodynamics	$Q = \Delta U + W$
HL	Work done by a gas at constant pressure	$W = P\Delta V$
HL	Change in internal energy of an ideal monatomic gas	$\Delta U = \frac{3}{2}nR\Delta T = \frac{3}{2}Nk_B\Delta T$
HL	Change in entropy	$\Delta S = \frac{\Delta Q}{T}$
HL	Entropy (statistical definition)	$S = k_B \ln \Omega$
HL	Adiabatic process (ideal monatomic gas)	$PV^{5/3} = \text{constant}$
HL	Efficiency of a heat engine	$\eta = \frac{\text{useful work}}{\text{input energy}}$
HL	Carnot efficiency	$\eta_{\text{Carnot}} = 1 - \frac{T_c}{T_h}$

B.5 CURRENT AND CIRCUITS

	Electric current	$I = \frac{\Delta q}{\Delta t}$	
	Potential difference	$V = \frac{W}{q}$	
	Resistance	$R = \frac{V}{I}$	
	Resistivity	$\rho = \frac{RA}{L}$	
	Electrical power	$P = IV = I^2R = \frac{V^2}{R}$	
	Series and parallel circuits: current, potential difference, resistance	SERIES CIRCUITS $I = I_1 = I_2 = \ldots$ $V = V_1 + V_2 + \ldots$ $R_s = R_1 + R_2 + \ldots$	PARALLEL CIRCUITS $I = I_1 + I_2 + \ldots$ $V = V_1 = V_2 = \ldots$ $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$
	EMF and internal resistance	$\varepsilon = I(R + r)$	

C. Wave behaviour

C.1 SIMPLE HARMONIC MOTION

	Defining equation of SHM	$a = -\omega^2 x$
	Period, frequency and angular frequency	$T = \frac{1}{f} = \frac{2\pi}{\omega}$
	Period of a mass on a spring	$T = 2\pi\sqrt{\frac{m}{k}}$
	Period of a simple pendulum	$T = 2\pi\sqrt{\frac{l}{g}}$
HL	SHM: displacement	$x = x_0 \sin(\omega t + \phi)$
HL	SHM: velocity	$v = \omega x_0 \cos(\omega t + \phi)$
HL	SHM: speed at displacement x	$v = \pm\omega\sqrt{x_0^2 - x^2}$
HL	SHM: total energy	$E_\mathrm{T} = \frac{1}{2}m\omega^2 x_0^2$
HL	SHM: potential energy	$E_\mathrm{p} = \frac{1}{2}m\omega^2 x^2$

C.2 WAVE MODEL

	Wave equation	$v = f\lambda = \frac{\lambda}{T}$

C.3 WAVE PHENOMENA

	Snell's law (refraction)	$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$
	Constructive interference	$\text{path difference} = n\lambda$
	Destructive interference	$\text{path difference} = \left(n + \frac{1}{2}\right)\lambda$
	Double-slit fringe spacing	$s = \frac{\lambda D}{d}$
HL	Single-slit diffraction: angle of first minimum	$\theta = \frac{\lambda}{b}$
HL	Diffraction grating	$n\lambda = d\sin\theta$

C.5 DOPPLER EFFECT

	Doppler effect for light ($v \ll c$)	$\frac{\Delta f}{f} = \frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}$
HL	Doppler effect: moving source	$f' = f\left(\frac{v}{v \pm u_\mathrm{s}}\right)$
HL	Doppler effect: moving observer	$f' = f\left(\frac{v \pm u_\mathrm{o}}{v}\right)$

D. Fields

D.1 GRAVITATIONAL FIELDS

	Newton's law of gravitation	$F = G\frac{m_1 m_2}{r^2}$
	Gravitational field strength	$g = \frac{F}{m} = G\frac{M}{r^2}$
HL	Gravitational potential energy	$E_\mathrm{p} = -G\frac{m_1 m_2}{r}$
HL	Gravitational potential	$V_\mathrm{g} = -G\frac{M}{r}$
HL	Field strength as potential gradient	$g = -\frac{\Delta V_\mathrm{g}}{\Delta r}$
HL	Work done moving a mass in a gravitational field	$W = m\Delta V_\mathrm{g}$

HL	Escape speed	$v_{\mathrm{esc}} = \sqrt{\dfrac{2GM}{r}}$
HL	Orbital speed	$v_{\mathrm{orbital}} = \sqrt{\dfrac{GM}{r}}$

D.2 ELECTRIC AND MAGNETIC FIELDS

	Coulomb's law	$F = k\dfrac{q_1 q_2}{r^2}$ where $k = \dfrac{1}{4\pi\varepsilon_0}$
	Electric field strength	$E = \dfrac{F}{q}$
	Uniform field between parallel plates	$E = \dfrac{V}{d}$
HL	Electric potential energy	$E_{\mathrm{p}} = k\dfrac{q_1 q_2}{r}$
HL	Electric potential of a point charge	$V_{\mathrm{e}} = \dfrac{kQ}{r}$
HL	Field strength as potential gradient	$E = -\dfrac{\Delta V_{\mathrm{e}}}{\Delta r}$
HL	Work done moving a charge in an electric field	$W = q\Delta V_{\mathrm{e}}$

D.3 MOTION IN ELECTROMAGNETIC FIELDS

	Magnetic force on a moving charge	$F = qvB\sin\theta$
	Magnetic force on a current-carrying wire	$F = BIL\sin\theta$
	Force per unit length between parallel wires	$\dfrac{F}{L} = \mu_0\dfrac{I_1 I_2}{2\pi r}$

D.4 INDUCTION

HL	Magnetic flux	$\Phi = BA\cos\theta$
HL	Faraday's law with Lenz's law	$\varepsilon = -N\dfrac{\Delta\Phi}{\Delta t}$
HL	EMF induced in a moving straight conductor	$\varepsilon = BvL$

E. Nuclear and quantum physics

E.1 STRUCTURE OF THE ATOM

	Photon energy	$E = hf$
HL	Nuclear radius	$R = R_0 A^{1/3}$
HL	Energy levels of hydrogen (Bohr model)	$E = -\dfrac{13.6}{n^2}\ \mathrm{eV}$
HL	Bohr condition: quantised angular momentum	$mvr = \dfrac{nh}{2\pi}$

E.2 QUANTUM PHYSICS

HL	Photoelectric equation	$E_{\max} = hf - \Phi$
HL	de Broglie wavelength	$\lambda = \dfrac{h}{p}$
HL	Compton scattering	$\lambda_{\mathrm{f}} - \lambda_{\mathrm{i}} = \Delta\lambda = \dfrac{h}{m_{\mathrm{e}}c}(1-\cos\theta)$

E.3 RADIOACTIVE DECAY

	Mass–energy equivalence	$E = mc^2$
HL	Radioactive decay law	$N = N_0 e^{-\lambda t}$
HL	Activity	$A = \lambda N = \lambda N_0 e^{-\lambda t}$
HL	Half-life and decay constant	$T_{1/2} = \dfrac{\ln 2}{\lambda}$

E.5 FUSION AND STARS

	Distance from stellar parallax	$d\,(\text{parsec}) = \dfrac{1}{p\,(\text{arc-second})}$