IB Physics HL *one-page formula sheet*

HL higher level only   pietromeloni.com

Mathematical equations

Triangle; circle
$A = \frac{1}{2}(bh)$ (b base, h height) $A = \pi r^2$ (r radius) $C = 2\pi r$

Cuboid; prism
$V = lwh$ (l length, w width, h height) $V = Ah$ (A area of cross-section)

Sphere; cylinder $V = \frac{4}{3}\pi r^3$ $V = \pi r^2 h$ $A = 2\pi r h$

Vector components $A_H = A\cos\theta$ $A_V = A\sin\theta$

Trigonometry $\tan\theta = \frac{\sin\theta}{\cos\theta}$ $\sin^2\theta + \cos^2\theta = 1$

Uncertainties

Sum or difference: If $y = a \pm b$, then $\Delta y = \Delta a + \Delta b$

Product or quotient: If $y = \frac{ab}{c}$, then $\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c}$

Power: If $y = a^n$, then $\frac{\Delta y}{y} = \left|n\frac{\Delta a}{a}\right|$

Metric (SI) multipliers

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

Unit conversions

1 radian (rad) $\equiv \frac{180°}{\pi}$

Temperature (K) = temperature (°C) + 273

1 light year (ly) = 9.46×10^{15} m   1 parsec (pc) = 3.26 ly

1 astronomical unit (AU) = 1.50×10^{11} m

1 kilowatt-hour (kWh) = 3.60×10^{6} J

$hc = 1.99 \times 10^{-25}$ J m $= 1.24 \times 10^{-6}$ eV m

Fundamental constants

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

A. Space, time and motion

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

A.1 KINEMATICS

SUVAT $s = \frac{u+v}{2}t$ $v = u + at$ $s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$

A.2 FORCES AND MOMENTUM

Static friction $F_f \le \mu_s F_N$
Dynamic friction $F_f = \mu_d F_N$
Hooke's law $F_H = -kx$
Stokes' drag $F_d = 6\pi\eta r v$
Buoyancy $F_b = \rho V g$
Weight $F_g = mg$
Momentum $p = mv$
Impulse $J = F\Delta t$
Newton's second law $F = ma = \frac{\Delta p}{\Delta t}$
Circular motion $a = \frac{v^2}{r} = \omega^2 r = \frac{4\pi^2 r}{T^2}$ $v = \frac{2\pi r}{T} = \omega r$

A.3 WORK, ENERGY AND POWER

Work $W = Fs\cos\theta$
Power $P = \frac{\Delta W}{\Delta t} = Fv$
Kinetic energy $E_k = \frac{1}{2}mv^2 = \frac{p^2}{2m}$
Change in GPE $\Delta E_p = mg\Delta h$
Elastic PE $E_H = \frac{1}{2}k\Delta x^2$
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 Moment of inertia $I = \Sigma m r^2$
HL Rotational SUVAT $\Delta\theta = \frac{\omega_f + \omega_i}{2}t$ $\omega_f = \omega_i + \alpha t$
$\Delta\theta = \omega_i t + \frac{1}{2}\alpha t^2$ $\omega_f^2 = \omega_i^2 + 2\alpha\Delta\theta$
HL Newton II (rotation) $\tau = I\alpha$
HL Angular momentum $L = I\omega$
HL Angular impulse $\Delta L = \tau\Delta t$ $\Delta L = \Delta(I\omega)$
HL Rotational KE $E_k = \frac{1}{2}I\omega^2 = \frac{L^2}{2I}$

A.5 GALILEAN AND SPECIAL RELATIVITY

HL Galilean transformation $x' = x - vt$ $t' = t$ $u' = u - v$
HL Lorentz transformation
$x' = \gamma(x - vt)$ where $\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$ $t' = \gamma\left(t - \frac{vx}{c^2}\right)$
HL Relativistic velocity $u' = \frac{u - v}{1 - \frac{uv}{c^2}}$
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 axes angle $\tan\theta = \frac{v}{c}$

B. The particulate nature of matter

B.1 THERMAL ENERGY TRANSFERS

Density $\rho = \frac{m}{V}$
Mean particle KE $\overline{E_k} = \frac{3}{2}k_B T$
Specific heat $Q = mc\Delta T$
Latent heat $Q = mL$
Conduction $\frac{\Delta Q}{\Delta t} = -kA\frac{\Delta T}{\Delta x}$
Luminosity $L = \sigma A T^4$
Apparent brightness $b = \frac{L}{4\pi d^2}$
Wien's law $\lambda_{max} T = 2.9 \times 10^{-3}$ 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 $P = \frac{F}{A}$
Moles $n = \frac{N}{N_A}$
Fixed amount of gas $\frac{PV}{T} = \text{constant}$
Ideal gas $PV = nRT = Nk_B T$
Kinetic theory $P = \frac{1}{3}\rho v^2$
Internal energy (monatomic) $U = \frac{3}{2}nRT = \frac{3}{2}Nk_B T$

B.4 THERMODYNAMICS

HL First law $Q = \Delta U + W$
HL Work, constant P $W = P\Delta V$
HL Change in internal energy (monatomic) $\Delta U = \frac{3}{2}nR\Delta T = \frac{3}{2}Nk_B\Delta T$
HL Entropy change $\Delta S = \frac{\Delta Q}{T}$
HL Entropy $S = k_B \ln\Omega$
HL Adiabatic (monatomic) $PV^{5/3} = \text{constant}$
HL Carnot $\eta_{Carnot} = 1 - \frac{T_c}{T_h}$
HL Heat engine efficiency $\eta = \frac{\text{useful work}}{\text{input energy}}$

B.5 CURRENT AND CIRCUITS

Current $I = \frac{\Delta q}{\Delta t}$
Potential difference $V = \frac{W}{q}$
Resistance $R = \frac{V}{I}$
Resistivity $\rho = \frac{RA}{L}$
Power $P = IV = I^2 R = \frac{V^2}{R}$
EMF $\varepsilon = I(R + r)$
Series
$I = I_1 = I_2 = \ldots$ $V = V_1 + V_2 + \ldots$ $R_s = R_1 + R_2 + \ldots$
Parallel
$I = I_1 + I_2 + \ldots$ $V = V_1 = V_2 = \ldots$ $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$

C. Wave behaviour

C.1 SIMPLE HARMONIC MOTION

SHM $a = -\omega^2 x$
Period $T = \frac{1}{f} = \frac{2\pi}{\omega}$
Mass on spring $T = 2\pi\sqrt{\frac{m}{k}}$
Pendulum $T = 2\pi\sqrt{\frac{l}{g}}$
HL SHM x and v $x = x_0\sin(\omega t + \phi)$ $v = \omega x_0\cos(\omega t + \phi)$
HL SHM speed at x $v = \pm\omega\sqrt{x_0^2 - x^2}$
HL Total energy $E_T = \frac{1}{2}m\omega^2 x_0^2$
HL Potential energy $E_p = \frac{1}{2}m\omega^2 x^2$

C.2 WAVE MODEL C.3 WAVE PHENOMENA

Wave equation $v = f\lambda = \frac{\lambda}{T}$
Double-slit $s = \frac{\lambda D}{d}$
Snell's law $\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$
Constructive; destructive
path difference $= n\lambda$ path difference $= \left(n + \frac{1}{2}\right)\lambda$
HL Single slit, first min. $\theta = \frac{\lambda}{b}$
HL Grating $n\lambda = d\sin\theta$

C.5 DOPPLER EFFECT

Light ($v \ll c$) $\frac{\Delta f}{f} = \frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}$
HL Moving source $f' = f\left(\frac{v}{v \pm u_s}\right)$
HL Moving observer $f' = f\left(\frac{v \pm u_o}{v}\right)$

D. Fields

D.1 GRAVITATIONAL FIELDS

Gravitation $F = G\frac{m_1 m_2}{r^2}$
Field strength $g = \frac{F}{m} = G\frac{M}{r^2}$
HL Potential energy $E_p = -G\frac{m_1 m_2}{r}$
HL Potential $V_g = -G\frac{M}{r}$
HL Potential gradient $g = -\frac{\Delta V_g}{\Delta r}$
HL Work done $W = m\Delta V_g$
HL Escape speed $v_{esc} = \sqrt{\frac{2GM}{r}}$
HL Orbital speed $v_{orbital} = \sqrt{\frac{GM}{r}}$

D.2 ELECTRIC AND MAGNETIC FIELDS

Coulomb's law $F = k\frac{q_1 q_2}{r^2}$ where $k = \frac{1}{4\pi\varepsilon_0}$
Field strength $E = \frac{F}{q}$
Parallel plates $E = \frac{V}{d}$
HL Potential energy $E_p = k\frac{q_1 q_2}{r}$
HL Potential $V_e = \frac{kQ}{r}$
HL Potential gradient $E = -\frac{\Delta V_e}{\Delta r}$
HL Work done $W = q\Delta V_e$

D.3 MOTION IN ELECTROMAGNETIC FIELDS

On a charge $F = qvB\sin\theta$
On a wire $F = BIL\sin\theta$
Parallel wires $\frac{F}{L} = \mu_0\frac{I_1 I_2}{2\pi r}$

D.4 INDUCTION

HL Magnetic flux $\Phi = BA\cos\theta$
HL Faraday, Lenz $\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$
HL Moving 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 Hydrogen levels $E = -\frac{13.6}{n^2}$ eV
HL Bohr condition $mvr = \frac{nh}{2\pi}$

E.2 QUANTUM PHYSICS

HL Photo-electric $E_{max} = hf - \Phi$
HL de Broglie $\lambda = \frac{h}{p}$
HL Compton scattering $\lambda_f - \lambda_i = \Delta\lambda = \frac{h}{m_e c}(1 - \cos\theta)$

E.3 RADIOACTIVE DECAY E.5 FUSION AND STARS

Mass-energy $E = mc^2$
HL Decay law $N = N_0 e^{-\lambda t}$
HL Activity $A = \lambda N = \lambda N_0 e^{-\lambda t}$
HL Half-life $T_{1/2} = \frac{\ln 2}{\lambda}$
Stellar parallax $d\,(\text{parsec}) = \frac{1}{p\,(\text{arc-second})}$