Diploma Programme

Physics data booklet

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Physics data booklet

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Contents

Fundamental constants

Quantity	Symbol	Approximate value
Acceleration of free fall (Earth's surface)	g	$9.81\ \mathrm{m\,s^{-2}}$
Gravitational constant	G	$6.67 \times 10^{-11}\ \mathrm{N\,m^2\,kg^{-2}}$
Avogadro's constant	N_A	$6.02 \times 10^{23}\ \mathrm{mol^{-1}}$
Gas constant	R	$8.31\ \mathrm{J\,K^{-1}\,mol^{-1}}$
Boltzmann's 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's 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	$1.20 \times 10^{-15}\ \mathrm{m}$

Metric （SI） multipliers

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

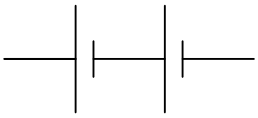
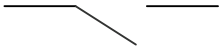
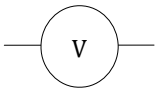
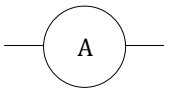
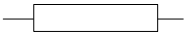
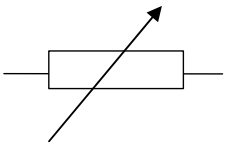
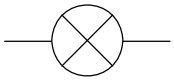
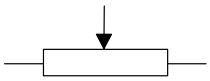
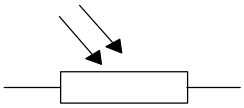
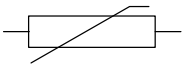
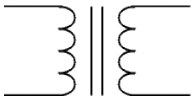
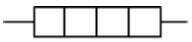
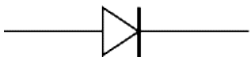
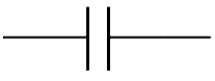
1 parsec (pc) = 3.26 ly

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

1 kilowatt-hour (kWh) = 3.60×10^{6} J

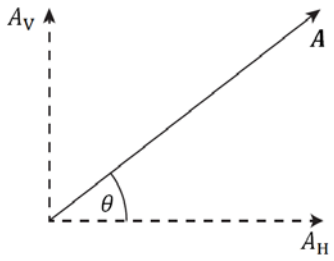
$hc = 1.99 \times 10^{-25}$ J m = 1.24×10^{-6} eV m

Electrical circuit symbols

cell		battery	
ac supply		switch	
voltmeter		ammeter	
resistor		variable resistor	
lamp		potentiometer	
light-dependent resistor (LDR)		thermistor	
transformer		heating element	
diode		capacitor	

Equations—Core

Note: All equations relate to the magnitude of the quantities only. Vector notation has not been used.

Sub-topic 1.2 – Uncertainties and errors	Sub-topic 1.3 – Vectors and scalars
If: $y = a \pm b$ then: $\Delta y = \Delta a + \Delta b$ If: $y = \frac{ab}{c}$ then: $\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c}$ If: $y = a^n$ then: $\frac{\Delta y}{y} = \left\lvert n\frac{\Delta a}{a} \right\rvert$	 $A_H = A\cos\theta$ $A_V = A\sin\theta$

Sub-topic 2.1 – Motion	Sub-topic 2.2 – Forces
$v = u + at$ $s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$ $s = \frac{(v+u)t}{2}$	$F = ma$ $F_f \leq \mu_s R$ $F_f = \mu_d R$
Sub-topic 2.3 – Work, energy and power	**Sub-topic 2.4 – Momentum and impulse**
$W = Fs\cos\theta$ $E_K = \frac{1}{2}mv^2$ $E_P = \frac{1}{2}k\Delta x^2$ $\Delta E_P = mg\Delta h$ power $= Fv$ Efficiency $= \frac{\text{useful work out}}{\text{total work in}}$ $= \frac{\text{useful power out}}{\text{total power in}}$	$p = mv$ $F = \frac{\Delta p}{\Delta t}$ $E_K = \frac{p^2}{2m}$ Impulse $= F\Delta t = \Delta p$

Sub-topic 3.1 – Thermal concepts	Sub-topic 3.2 – Modelling a gas
$Q = mc\Delta T$ $Q = mL$	$p = \frac{F}{A}$ $n = \frac{N}{N_A}$ $pV = nRT$ $\bar{E}_K = \frac{3}{2}k_B T = \frac{3}{2}\frac{R}{N_A}T$

Sub-topic 4.1 – Oscillations	Sub-topic 4.4 – Wave behaviour
$T = \frac{1}{f}$	$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$ $s = \frac{\lambda D}{d}$ Constructive interference: path difference $= n\lambda$ Destructive interference: path difference $= (n + \frac{1}{2})\lambda$
Sub-topic 4.2 – Travelling waves	
$c = f\lambda$	
Sub-topic 4.3 – Wave characteristics	
$I \propto A^2$ $I \propto x^{-2}$ $I = I_0 cos^2\theta$	

Sub-topic 5.1 – Electric fields	Sub-topic 5.2 – Heating effect of electric currents
$I = \frac{\Delta q}{\Delta t}$ $F = k\frac{q_1 q_2}{r^2}$ $k = \frac{1}{4\pi\varepsilon_0}$ $V = \frac{W}{q}$ $E = \frac{F}{q}$ $I = nAvq$	Kirchhoff's circuit laws: $\Sigma V = 0$ (loop) $\Sigma I = 0$ (junction) $R = \frac{V}{I}$ $P = VI = I^2R = \frac{V^2}{R}$ $R_{total} = R_1 + R_2 + \cdots$ $\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$ $\rho = \frac{RA}{L}$
Sub-topic 5.3 – Electric cells	**Sub-topic 5.4 – Magnetic effects of electric currents**
$\varepsilon = I(R + r)$	$F = qvB\sin\theta$ $F = BIL\sin\theta$

Sub-topic 6.1 – Circular motion	Sub-topic 6.2 – Newton's law of gravitation
$v = \omega r$ $a = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2}$ $F = \frac{mv^2}{r} = m\omega^2 r$	$F = G\frac{Mm}{r^2}$ $g = \frac{F}{m}$ $g = G\frac{M}{r^2}$

Sub-topic 7.1 – Discrete energy and radioactivity	Sub-topic 7.2 – Nuclear reactions
$E = hf$ $\lambda = \frac{hc}{E}$	$\Delta E = \Delta m\, c^2$

Sub-topic 7.3 – The structure of matter

Charge	Quarks			Baryon number
$\frac{2}{3}e$	u	c	t	$\frac{1}{3}$
$-\frac{1}{3}e$	d	s	b	$\frac{1}{3}$
All quarks have a strangeness number of 0 except the strange quark that has a strangeness number of –1				

Charge	Leptons		
–1	e	μ	τ
0	υ_e	υ_μ	υ_τ
All leptons have a lepton number of 1 and antileptons have a lepton number of –1			

	Gravitational	Weak	Electromagnetic	Strong
Particles experiencing	All	Quarks, leptons	Charged	Quarks, gluons
Particles mediating	Graviton	W^+, W^-, Z^0	γ	Gluons

Sub-topic 8.1 – Energy sources	Sub-topic 8.2 – Thermal energy transfer
$\text{Power} = \frac{\text{energy}}{\text{time}}$ $\text{Power} = \frac{1}{2}A\rho v^3$	$P = e\sigma AT^4$ $\lambda_{\max}(\text{metres}) = \frac{2.90 \times 10^{-3}}{T(\text{kelvin})}$ $I = \frac{\text{power}}{A}$ $\text{albedo} = \frac{\text{total scattered power}}{\text{total incident power}}$

Equations—AHL

Sub-topic 9.1 – Simple harmonic motion

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

$a = -\omega^2 x$

$x = x_0 \sin \omega t$; $x = x_0 \cos \omega t$

$v = \omega x_0 \cos \omega t$; $v = -\omega x_0 \sin \omega t$

$v = \pm\omega\sqrt{({x_0}^2 - x^2)}$

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

$E_{\mathrm{T}} = \frac{1}{2} m\omega^2 {x_0}^2$

Pendulum: $T = 2\pi\sqrt{\frac{l}{g}}$

Mass–spring: $T = 2\pi\sqrt{\frac{m}{k}}$

Sub-topic 9.2 – Single-slit diffraction

$\theta = \frac{\lambda}{b}$

Sub-topic 9.3 – Interference

$n\lambda = d \sin\theta$

Constructive interference: $2dn = (m + \frac{1}{2})\,\lambda$

Destructive interference: $2dn = m\lambda$

Sub-topic 9.4 – Resolution

$\theta = 1.22\,\frac{\lambda}{b}$

$R = \frac{\lambda}{\Delta\lambda} = mN$

Sub-topic 9.5 – Doppler effect

Moving source: $f' = f\left(\frac{v}{v \pm u_{\mathrm{s}}}\right)$

Moving observer: $f' = f\left(\frac{v \pm u_0}{v}\right)$

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

Sub-topic 10.1 – Describing fields

$W = q\Delta V_e$

$W = m\Delta V_g$

Sub-topic 10.2 – Fields at work

$V_g = -\frac{GM}{r}$	$V_e = \frac{kq}{r}$
$g = -\frac{\Delta V_g}{\Delta r}$	$E = -\frac{\Delta V_e}{\Delta r}$
$E_{\mathrm{P}} = mV_g = -\frac{GMm}{r}$	$E_{\mathrm{P}} = qV_{\mathrm{e}} = \frac{kq_1q_2}{r}$
$F_{\mathrm{G}} = G\frac{m_1m_2}{r^2}$	$F_{\mathrm{E}} = k\frac{q_1q_2}{r^2}$

$v_{\mathrm{esc}} = \sqrt{\frac{2GM}{r}}$

$v_{\mathrm{orbit}} = \sqrt{\frac{GM}{r}}$

Sub-topic 11.1 – Electromagnetic induction

$\Phi = BA\cos\theta$

$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$

$\varepsilon = Bvl$

$\varepsilon = BvlN$

Sub-topic 11.2 – Power generation and transmission

$I_{\text{rms}} = \frac{I_0}{\sqrt{2}}$

$V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$

$R = \frac{V_0}{I_0} = \frac{V_{\text{rms}}}{I_{\text{rms}}}$

$P_{\max} = I_0 V_0$

$\bar{P} = \frac{1}{2} I_0 V_0$

$\frac{\varepsilon_{\text{p}}}{\varepsilon_{\text{s}}} = \frac{N_{\text{p}}}{N_{\text{s}}} = \frac{I_{\text{s}}}{I_{\text{p}}}$

Sub-topic 11.3 – Capacitance

$C = \frac{q}{V}$

$C_{\text{parallel}} = C_1 + C_2 + \cdots$

$\frac{1}{C_{\text{series}}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots$

$C = \varepsilon\frac{A}{d}$

$E = \frac{1}{2}CV^2$

$\tau = RC$

$q = q_0 e^{-\frac{t}{\tau}}$

$I = I_0 e^{-\frac{t}{\tau}}$

$V = V_0 e^{-\frac{t}{\tau}}$

Sub-topic 12.1 – The interaction of matter with radiation

$E = hf$

$E_{\max} = hf - \Phi$

$E = -\frac{13.6}{n^2} eV$

$mvr = \frac{nh}{2\pi}$

$P(r) = |\psi|^2 \Delta V$

$\Delta x \Delta p \geq \frac{h}{4\pi}$

$\Delta E \Delta t \geq \frac{h}{4\pi}$

Sub-topic 12.2 – Nuclear physics

$R = R_0 A^{1/3}$

$N = N_0 e^{-\lambda t}$

$A = \lambda N_0 e^{-\lambda t}$

$\sin\theta \approx \frac{\lambda}{D}$

Equations—Options

Sub-topic A.1 – The beginnings of relativity	Sub-topic A.2 – Lorentz transformations
$x' = x - vt$ $u' = u - v$	$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$ $x' = \gamma(x - vt)\ ;\ \Delta x' = \gamma(\Delta x - v\Delta t)$ $t' = \gamma(t - \frac{vx}{c^2})\ ;\ \Delta t' = \gamma(\Delta t - \frac{v\Delta x}{c^2})$ $u' = \frac{u - v}{1 - \frac{uv}{c^2}}$ $\Delta t = \gamma \Delta t_0$ $L = \frac{L_0}{\gamma}$ $(ct')^2 - (x')^2 = (ct)^2 - (x)^2$
Sub-topic A.3 – Spacetime diagrams	
$\theta = \tan^{-1}\left(\frac{v}{c}\right)$	
Sub-topic A.4 – Relativistic mechanics (HL only)	**Sub-topic A.5 – General relativity (HL only)**
$E = \gamma m_0 c^2$ $E_0 = m_0 c^2$ $E_\mathrm{K} = (\gamma - 1) m_0 c^2$ $p = \gamma m_0 v$ $E^2 = p^2 c^2 + {m_0}^2 c^4$ $qV = \Delta E_\mathrm{K}$	$\frac{\Delta f}{f} = \frac{g \Delta h}{c^2}$ $R_\mathrm{s} = \frac{2GM}{c^2}$ $\Delta t = \frac{\Delta t_0}{\sqrt{1 - \frac{R_\mathrm{s}}{r}}}$

Sub-topic B.1 – Rigid bodies and rotational dynamics	Sub-topic B.2 – Thermodynamics
$\Gamma = Fr\sin\theta$ $I = \sum mr^2$ $\Gamma = I\alpha$ $\omega = 2\pi f$ $\omega_\mathrm{f} = \omega_\mathrm{i} + \alpha t$ $\omega_\mathrm{f}^2 = \omega_\mathrm{i}^2 + 2\alpha\theta$ $\theta = \omega_\mathrm{i} t + \frac{1}{2}\alpha t^2$ $L = I\omega$ $E_{\mathrm{K_{rot}}} = \frac{1}{2} I\omega^2$	$Q = \Delta U + W$ $U = \frac{3}{2} nRT$ $\Delta S = \frac{\Delta Q}{T}$ $pV^{\frac{5}{3}} =$ constant (for monatomic gases) $W = p\Delta V$ $\eta = \frac{\text{useful work done}}{\text{energy input}}$ $\eta_\mathrm{Carnot} = 1 - \frac{T_\mathrm{cold}}{T_\mathrm{hot}}$
Sub-topic B.3 – Fluids and fluid dynamics (HL only)	**Sub-topic B.4 – Forced vibrations and resonance (HL only)**
$B = \rho_\mathrm{f} V_\mathrm{f} g$ $P = P_0 + \rho_\mathrm{f} g d$ $Av =$ constant $\frac{1}{2}\rho v^2 + \rho g z + p =$ constant $F_\mathrm{D} = 6\pi\eta r v$ $R = \frac{vr\rho}{\eta}$	$Q = 2\pi \frac{\text{energy stored}}{\text{energy dissipated per cycle}}$ $Q = 2\pi \times \text{resonant frequency} \times \frac{\text{energy stored}}{\text{power loss}}$

Sub-topic C.1 – Introduction to imaging	Sub-topic C.2 – Imaging instrumentation
$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$ $P = \frac{1}{f}$ $m = \frac{h_\mathrm{i}}{h_\mathrm{o}} = -\frac{v}{u}$ $M = \frac{\theta_\mathrm{i}}{\theta_\mathrm{o}}$ $M_{\text{near point}} = \frac{D}{f} + 1\ ;\ M_{\text{infinity}} = \frac{D}{f}$	$M = \frac{f_\mathrm{o}}{f_\mathrm{e}}$
	Sub-topic C.3 – Fibre optics
	$n = \frac{1}{\sin c}$ $\text{attenuation} = 10\log\frac{I}{I_0}$
	Sub-topic C.4 – Medical imaging (HL only)
	$L_\mathrm{I} = 10\log\frac{I_1}{I_0}$ $I = I_0 e^{-\mu x}$ $\mu x_{\frac{1}{2}} = \ln 2$ $Z = \rho c$

Sub-topic D.1 – Stellar quantities	Sub-topic D.2 – Stellar characteristics and stellar evolution
$d\ (\text{parsec}) = \frac{1}{p\ (\text{arc–second})}$ $L = \sigma A T^4$ $b = \frac{L}{4\pi d^2}$	$\lambda_{\max} T = 2.9 \times 10^{-3}\ \text{m K}$ $L \propto M^{3.5}$
Sub-topic D.3 – Cosmology	**Sub-topic D.5 – Further cosmology (HL only)**
$z = \frac{\Delta\lambda}{\lambda_0} \approx \frac{v}{c}$ $z = \frac{R}{R_0} - 1$ $v = H_0 d$ $T \approx \frac{1}{H_0}$	$v = \sqrt{\frac{4\pi G\rho}{3}}\, r$ $\rho_c = \frac{3H^2}{8\pi G}$