Diploma Programme

Physics data booklet

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Physics data booklet

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Mathematical equations

Area of a circle	$A = \pi r^2$, where r is the radius
Circumference of a circle	$C = 2\pi r$, where r is the radius
Surface area of a sphere	$A = 4\pi r^2$, where r is the radius
Volume of a sphere	$V = \frac{4}{3}\pi r^3$, where r is the radius

Fundamental constants

Quantity	Symbol	Approximate value
Acceleration of free fall (Earth's surface)	g	$9.81\,\text{m}\,\text{s}^{-2}$
Gravitational constant	G	$6.67\times10^{-11}\,\text{N}\,\text{m}^2\,\text{kg}^{-2}$
Avogadro's constant	N_A	$6.02\times10^{23}\,\text{mol}^{-1}$
Gas constant	R	$8.31\,\text{J}\,\text{K}^{-1}\,\text{mol}^{-1}$
Boltzmann's constant	k_B	$1.38\times10^{-23}\,\text{J}\,\text{K}^{-1}$
Stefan–Boltzmann constant	σ	$5.67\times10^{-8}\,\text{W}\,\text{m}^{-2}\,\text{K}^{-4}$
Coulomb constant	k	$8.99\times10^{9}\,\text{N}\,\text{m}^2\,\text{C}^{-2}$
Permittivity of free space	ε_0	$8.85\times10^{-12}\,\text{C}^2\,\text{N}^{-1}\,\text{m}^{-2}$
Permeability of free space	μ_0	$4\pi\times10^{-7}\,\text{T}\,\text{m}\,\text{A}^{-1}$
Speed of light in vacuum	c	$3.00\times10^{8}\,\text{m}\,\text{s}^{-1}$
Planck's constant	h	$6.63\times10^{-34}\,\text{J}\,\text{s}$
Elementary charge	e	$1.60\times10^{-19}\,\text{C}$
Electron rest mass	m_e	$9.110\times10^{-31}\,\text{kg} = 0.000549\,\text{u} = 0.511\,\text{MeV}\,\text{c}^{-2}$
Proton rest mass	m_p	$1.673\times10^{-27}\,\text{kg} = 1.007276\,\text{u} = 938\,\text{MeV}\,\text{c}^{-2}$
Neutron rest mass	m_n	$1.675\times10^{-27}\,\text{kg} = 1.008665\,\text{u} = 940\,\text{MeV}\,\text{c}^{-2}$
Unified atomic mass unit	u	$1.661\times10^{-27}\,\text{kg} = 931.5\,\text{MeV}\,\text{c}^{-2}$
Solar constant	S	$1.36\times10^{3}\,\text{W}\,\text{m}^{-2}$
Fermi radius	R_0	$1.20\times10^{-15}\,\text{m}$

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

$$1 \text{ radian (rad)} \equiv \frac{180^\circ}{\pi}$$

$$\text{Temperature (K)} = \text{temperature (°C)} + 273$$

$$1 \text{ light year (ly)} = 9.46 \times 10^{15} \text{ m}$$

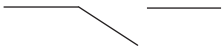
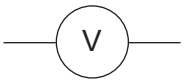
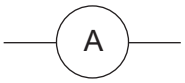
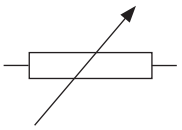
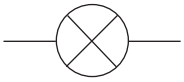
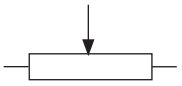
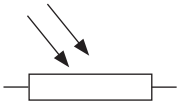
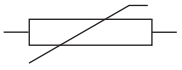
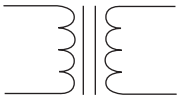
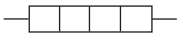
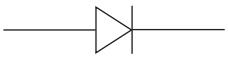
$$1 \text{ parsec (pc)} = 3.26 \text{ ly}$$

$$1 \text{ astronomical unit (AU)} = 1.50 \times 10^{11} \text{ m}$$

$$1 \text{ kilowatt-hour (kWh)} = 3.60 \times 10^{6} \text{ J}$$

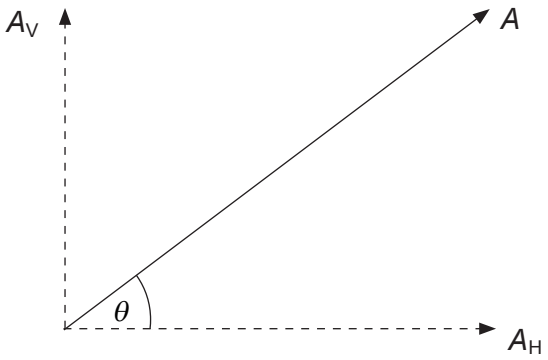
$$hc = 1.99 \times 10^{-25} \text{ Jm} = 1.24 \times 10^{-6} \text{ eV m}$$

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 $= \left(n + \frac{1}{2}\right)\lambda$
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) $R = \frac{V}{I}$ $P = VI = I^2R = \frac{V^2}{R}$ $R_{\text{total}} = R_1 + R_2 + \ldots$ $\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$ $\rho = \frac{RA}{L}$
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

$$E = hf$$

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

Sub-topic 7.2 – Nuclear reactions

$$\Delta E = \Delta mc^2$$

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	ν_e	ν_μ	ν_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

$$\text{power} = \frac{\text{energy}}{\text{time}}$$

$$\text{power} = \frac{1}{2}A\rho v^3$$

Sub-topic 8.2 – Thermal energy transfer

$$P = e\sigma AT^4$$

$$\lambda_{\text{max}}(\text{metres}) = \frac{2.90 \times 10^{-3}}{T(\text{kelvin})}$$

$$I = \frac{\text{power}}{A}$$

$$\text{albedo} = \frac{\text{total scattered power}}{\text{total incident power}}$$

Equations—AHL

Sub-topic 9.1 – Simple harmonic motion

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

$a = -\omega^2 x$

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

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

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

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

$E_T = \frac{1}{2} m\omega^2 x_0{}^2$

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: $2dn = \left(m + \frac{1}{2}\right)\lambda$

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: $f' = f\left(\frac{v}{v \pm u_s}\right)$

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

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

Sub-topic 10.1 – Describing fields	Sub-topic 10.2 – Fields at work
$W = q\Delta V_e$ $W = m\Delta V_g$	$V_g = -\frac{GM}{r}$ | $V_e = \frac{kQ}{r}$ $g = -\frac{\Delta V_g}{\Delta r}$ | $E = -\frac{\Delta V_e}{\Delta r}$ $E_p = mV_g = -\frac{GMm}{r}$ | $E_p = qV_e = \frac{kQq}{r}$ $F_g = \frac{GMm}{r^2}$ | $F_e = \frac{kQq}{r^2}$ $v_{esc} = \sqrt{\frac{2GM}{r}}$ $v_{orbit} = \sqrt{\frac{GM}{r}}$

Sub-topic 11.1 – Electromagnetic induction

$$\Phi = BA\cos\theta$$

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

$$\varepsilon = Blv$$

$$\varepsilon = BlvN$$

Sub-topic 11.2 – Power generation and transmission

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

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

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

$$P_{\text{max}} = I_0 V_0$$

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

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

Sub-topic 11.3 – Capacitance

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

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

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

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

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

$$\tau = RC$$

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

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

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

Sub-topic 12.1 – The interaction of matter with radiation

$$E = hf$$

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

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

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

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

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

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

Sub-topic 12.2 – Nuclear physics

$$R = R_0 A^{\frac{1}{3}}$$

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

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

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

Equations—Options

Sub-topic A.1 – The beginnings of relativity	Sub-topic A.2 – Lorentz transformations
$x' = x - vt$ $u' = u - v$	$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$ $x' = \gamma(x - vt); \Delta x' = \gamma(\Delta x - v\Delta t)$ $t' = \gamma\left(t - \frac{vx}{c^2}\right); \Delta t' = \gamma\left(\Delta t - \frac{v\Delta x}{c^2}\right)$ $u' = \frac{u - v}{1 - \frac{uv}{c^2}}$ $\Delta t = \gamma \Delta t_0$ $L = \frac{L_0}{\gamma}$ $(ct')^2 - (x')^2 = (ct)^2 - (x)^2$
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)**
$E = \gamma m_0 c^2$ $E_0 = m_0 c^2$ $E_K = (\gamma - 1) m_0 c^2$ $p = \gamma m_0 v$ $E^2 = p^2 c^2 + m_0{}^2 c^4$ $qV = \Delta E_K$	$\frac{\Delta f}{f} = \frac{g\Delta h}{c^2}$ $R_s = \frac{2GM}{c^2}$ $\Delta t = \frac{\Delta t_0}{\sqrt{1 - \frac{R_s}{r}}}$

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

Sub-topic C.1 – Introduction to imaging	Sub-topic C.2 – Imaging instrumentation
$\frac{1}{f}=\frac{1}{v}+\frac{1}{u}$ $P=\frac{1}{f}$ $m=\frac{h_i}{h_o}=-\frac{v}{u}$ $M=\frac{\theta_i}{\theta_o}$ $M_{\text{near point}}=\frac{D}{f}+1;\ M_{\text{infinity}}=\frac{D}{f}$	$M=\frac{f_o}{f_e}$
	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)
	$L_I=10\log\frac{I_1}{I_0}$ $I=I_0e^{-\mu x}$ $\mu x_{\frac{1}{2}}=\ln 2$ $Z=\rho c$

Sub-topic D.1 – Stellar quantities	Sub-topic D.2 – Stellar characteristics and stellar evolution
$d\,(\text{parsec})=\frac{1}{p\,(\text{arc-second})}$ $L=\sigma AT^4$ $b=\frac{L}{4\pi d^2}$	$\lambda_{\max}T=2.9\times10^{-3}\ \text{mK}$ $L\propto M^{3.5}$
Sub-topic D.3 – Cosmology	**Sub-topic D.5 – Further cosmology (HL only)**
$z=\frac{\Delta\lambda}{\lambda_0}\approx\frac{v}{c}$ $z=\frac{R}{R_0}-1$ $v=H_0d$ $T\approx\frac{1}{H_0}$	$v=\sqrt{\frac{4\pi G\rho}{3}}r$ $\rho_c=\frac{3H^2}{8\pi G}$