

# Physics data booklet

First assessment 2016



## **Diploma Programme Physics data booklet**

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Cardiff, Wales CF23 8GL  
United Kingdom  
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## Fundamental constants

Quantity	Symbol	Approximate value
Acceleration of free fall (Earth's surface)	$g$	$9.81 \text{ m s}^{-2}$
Gravitational constant	$G$	$6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
Avogadro's constant	$N_A$	$6.02 \times 10^{23} \text{ mol}^{-1}$
Gas constant	$R$	$8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Boltzmann's constant	$k_B$	$1.38 \times 10^{-23} \text{ J K}^{-1}$
Stefan-Boltzmann constant	$\sigma$	$5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$
Coulomb constant	$k$	$8.99 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$
Permittivity of free space	$\epsilon_0$	$8.85 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$
Permeability of free space	$\mu_0$	$4\pi \times 10^{-7} \text{ T m A}^{-1}$
Speed of light in vacuum	$c$	$3.00 \times 10^8 \text{ m s}^{-1}$
Planck's 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	$m_n$	$1.675 \times 10^{-27} \text{ kg} = 1.008665 \text{ u} = 940 \text{ MeV } c^{-2}$
Unified 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	$R_0$	$1.20 \times 10^{-15} \text{ m}$

## 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	$\mu$	$10^{-6}$
nano	n	$10^{-9}$
pico	p	$10^{-12}$
femto	f	$10^{-15}$

## Unit conversions

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

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

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


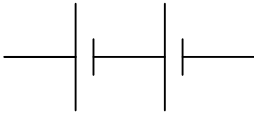

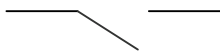
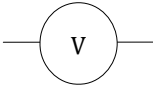
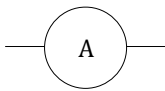
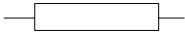
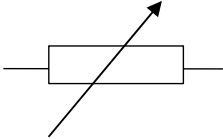
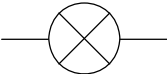
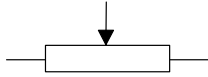
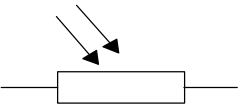
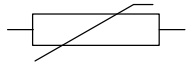

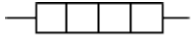
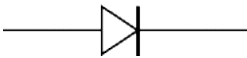
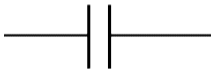
$$1 \text{ parsec (pc)} = 3.26 \text{ ly}$$

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

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

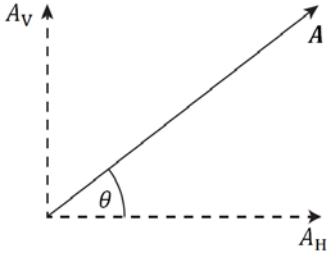
$$hc = 1.99 \times 10^{-25} \text{ J m} = 1.24 \times 10^{-6} \text{ eV m}$$

# 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
<p>If: <math>y = a \pm b</math>  then: <math>\Delta y = \Delta a + \Delta b</math></p> <p>If: <math>y = \frac{ab}{c}</math>  then: <math>\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c}</math></p> <p>If: <math>y = a^n</math>  then: <math>\frac{\Delta y}{y} = \left  n \frac{\Delta a}{a} \right </math></p>	 <p><math>A_H = A \cos \theta</math>  <math>A_V = A \sin \theta</math></p>
Sub-topic 2.1 – Motion	Sub-topic 2.2 – Forces
<p><math>v = u + at</math>  <math>s = ut + \frac{1}{2}at^2</math>  <math>v^2 = u^2 + 2as</math>  <math>s = \frac{(v + u)t}{2}</math></p>	<p><math>F = ma</math>  <math>F_f \leq \mu_s R</math>  <math>F_f = \mu_d R</math></p>
Sub-topic 2.3 – Work, energy and power	Sub-topic 2.4 – Momentum and impulse
<p><math>W = Fs \cos \theta</math>  <math>E_K = \frac{1}{2}mv^2</math>  <math>E_P = \frac{1}{2}k\Delta x^2</math>  <math>\Delta E_P = mg\Delta h</math>  power = <math>Fv</math></p> <p>Efficiency = <math>\frac{\text{useful work out}}{\text{total work in}}</math>  = <math>\frac{\text{useful power out}}{\text{total power in}}</math></p>	<p><math>p = mv</math>  <math>F = \frac{\Delta p}{\Delta t}</math>  <math>E_K = \frac{p^2}{2m}</math>  Impulse = <math>F\Delta t = \Delta p</math></p>



<b>Sub-topic 3.1 – Thermal concepts</b>	<b>Sub-topic 3.2 – Modelling a gas</b>
$Q = mc\Delta T$ $Q = mL$	$p = \frac{F}{A}$ $n = \frac{N}{N_A}$ $pV = nRT$ $\bar{E}_K = \frac{3}{2} k_B T = \frac{3}{2} \frac{R}{N_A} T$
<b>Sub-topic 4.1 – Oscillations</b>	<b>Sub-topic 4.4 – Wave behaviour</b>
$T = \frac{1}{f}$	$\frac{n_1}{n_2} = \frac{\sin \theta_2}{\sin \theta_1} = \frac{v_2}{v_1}$ $s = \frac{\lambda D}{d}$
<b>Sub-topic 4.2 – Travelling waves</b>	Constructive interference: path difference = $n\lambda$ Destructive interference: path difference = $(n + \frac{1}{2})\lambda$
$c = f\lambda$	
<b>Sub-topic 4.3 – Wave characteristics</b>	
$I \propto A^2$ $I \propto x^{-2}$ $I = I_0 \cos^2 \theta$	
<b>Sub-topic 5.1 – Electric fields</b>	<b>Sub-topic 5.2 – Heating effect of electric currents</b>
$I = \frac{\Delta q}{\Delta t}$ $F = k \frac{q_1 q_2}{r^2}$ $k = \frac{1}{4\pi\epsilon_0}$ $V = \frac{W}{q}$ $E = \frac{F}{q}$ $I = nAvq$	Kirchoff's circuit laws: $\Sigma V = 0$ (loop) $\Sigma I = 0$ (junction) $R = \frac{V}{I}$ $P = VI = I^2 R = \frac{V^2}{R}$ $R_{\text{total}} = R_1 + R_2 + \dots$ $\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$ $\rho = \frac{RA}{L}$
<b>Sub-topic 5.3 – Electric cells</b>	<b>Sub-topic 5.4 – Magnetic effects of electric currents</b>
$\varepsilon = I(R + r)$	$F = qvB \sin \theta$ $F = BIL \sin \theta$

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	$\mu$	$\tau$
0	$\nu_e$	$\nu_\mu$	$\nu_\tau$
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	$W^+, W^-, Z^0$	$\gamma$	Gluons

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

# Equations—AHL

Sub-topic 9.1 – Simple harmonic motion	Sub-topic 9.2 – Single-slit diffraction								
$\omega = \frac{2\pi}{T}$ $a = -\omega^2 x$ $x = x_0 \sin \omega t ; x = x_0 \cos \omega t$ $v = \omega x_0 \cos \omega t ; v = -\omega x_0 \sin \omega t$ $v = \pm \omega \sqrt{(x_0^2 - x^2)}$ $E_K = \frac{1}{2} m \omega^2 (x_0^2 - x^2)$ $E_T = \frac{1}{2} m \omega^2 x_0^2$ Pendulum: $T = 2\pi \sqrt{\frac{l}{g}}$ Mass-spring: $T = 2\pi \sqrt{\frac{m}{k}}$	$\theta = \frac{\lambda}{b}$								
	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	Sub-topic 9.5 – Doppler effect								
$\theta = 1.22 \frac{\lambda}{b}$ $R = \frac{\lambda}{\Delta\lambda} = mN$	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								
$W = q\Delta V_e$ $W = m\Delta V_g$	<table border="1"> <tbody> <tr> <td><math display="block">V_g = -\frac{GM}{r}</math></td> <td><math display="block">V_e = \frac{kq}{r}</math></td> </tr> <tr> <td><math display="block">g = -\frac{\Delta V_g}{\Delta r}</math></td> <td><math display="block">E = -\frac{\Delta V_e}{\Delta r}</math></td> </tr> <tr> <td><math display="block">E_P = mV_g = -\frac{GMm}{r}</math></td> <td><math display="block">E_P = qV_e = \frac{kq_1q_2}{r}</math></td> </tr> <tr> <td><math display="block">F_G = G \frac{m_1m_2}{r^2}</math></td> <td><math display="block">F_E = k \frac{q_1q_2}{r^2}</math></td> </tr> </tbody> </table> $v_{\text{esc}} = \sqrt{\frac{2GM}{r}}$ $v_{\text{orbit}} = \sqrt{\frac{GM}{r}}$	$V_g = -\frac{GM}{r}$	$V_e = \frac{kq}{r}$	$g = -\frac{\Delta V_g}{\Delta r}$	$E = -\frac{\Delta V_e}{\Delta r}$	$E_P = mV_g = -\frac{GMm}{r}$	$E_P = qV_e = \frac{kq_1q_2}{r}$	$F_G = G \frac{m_1m_2}{r^2}$	$F_E = k \frac{q_1q_2}{r^2}$
$V_g = -\frac{GM}{r}$	$V_e = \frac{kq}{r}$								
$g = -\frac{\Delta V_g}{\Delta r}$	$E = -\frac{\Delta V_e}{\Delta r}$								
$E_P = mV_g = -\frac{GMm}{r}$	$E_P = qV_e = \frac{kq_1q_2}{r}$								
$F_G = G \frac{m_1m_2}{r^2}$	$F_E = k \frac{q_1q_2}{r^2}$								

Sub-topic 11.1 – Electromagnetic induction	Sub-topic 11.3 – Capacitance
$\Phi = BA \cos \theta$ $\varepsilon = -N \frac{\Delta\Phi}{\Delta t}$ $\varepsilon = Bvl$ $\varepsilon = BvlN$	$C = \frac{q}{V}$ $C_{\text{parallel}} = C_1 + C_2 + \dots$ $\frac{1}{C_{\text{series}}} = \frac{1}{C_1} + \frac{1}{C_2} + \dots$
Sub-topic 11.2 – Power generation and transmission	
$I_{\text{rms}} = \frac{I_0}{\sqrt{2}}$ $V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$ $R = \frac{V_0}{I_0} = \frac{V_{\text{rms}}}{I_{\text{rms}}}$ $P_{\text{max}} = I_0 V_0$ $\bar{P} = \frac{1}{2} I_0 V_0$ $\frac{\varepsilon_p}{\varepsilon_s} = \frac{N_p}{N_s} = \frac{I_s}{I_p}$	$C = \varepsilon \frac{A}{d}$ $E = \frac{1}{2} CV^2$ $\tau = RC$ $q = q_0 e^{-\frac{t}{\tau}}$ $I = I_0 e^{-\frac{t}{\tau}}$ $V = V_0 e^{-\frac{t}{\tau}}$

Sub-topic 12.1 – The interaction of matter with radiation	Sub-topic 12.2 – Nuclear physics
$E = hf$ $E_{\text{max}} = hf - \Phi$ $E = -\frac{13.6}{n^2} eV$ $mvr = \frac{nh}{2\pi}$ $P(r) =  \psi ^2 \Delta V$ $\Delta x \Delta p \geq \frac{h}{4\pi}$ $\Delta E \Delta t \geq \frac{h}{4\pi}$	$R = R_0 A^{1/3}$ $N = N_0 e^{-\lambda t}$ $A = \lambda N_0 e^{-\lambda t}$ $\sin \theta \approx \frac{\lambda}{D}$

# Equations—Options

Sub-topic A.1 – The beginnings of relativity	Sub-topic A.2 – Lorentz transformations
$x' = x - vt$ $u' = u - v$	$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$
Sub-topic A.3 – Spacetime diagrams	$x' = \gamma(x - vt) ; \Delta x' = \gamma(\Delta x - v\Delta t)$ $t' = \gamma\left(t - \frac{vx}{c^2}\right) ; \Delta t' = \gamma\left(\Delta t - \frac{v\Delta x}{c^2}\right)$ $u' = \frac{u - v}{1 - \frac{uv}{c^2}}$ $\Delta t = \gamma\Delta t_0$ $L = \frac{L_0}{\gamma}$ $(ct')^2 - (x')^2 = (ct)^2 - (x)^2$
$\theta = \tan^{-1}\left(\frac{v}{c}\right)$	
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
$\Gamma = Fr \sin \theta$ $I = \sum mr^2$ $\Gamma = I\alpha$ $\omega = 2\pi f$ $\omega_f = \omega_i + \alpha t$ $\omega_f^2 = \omega_i^2 + 2\alpha\theta$ $\theta = \omega_i t + \frac{1}{2}\alpha t^2$ $L = I\omega$ $E_{Krot} = \frac{1}{2}I\omega^2$	$Q = \Delta U + W$ $U = \frac{3}{2}nRT$ $\Delta S = \frac{\Delta Q}{T}$ $pV^{\frac{5}{3}} = \text{constant (for monatomic gases)}$ $W = p\Delta V$ $\eta = \frac{\text{useful work done}}{\text{energy input}}$ $\eta_{Carnot} = 1 - \frac{T_{cold}}{T_{hot}}$
Sub-topic B.3 – Fluids and fluid dynamics (HL only)	Sub-topic B.4 – Forced vibrations and resonance (HL only)
$B = \rho_f V_f g$ $P = P_0 + \rho_f g d$ $Av = \text{constant}$ $\frac{1}{2}\rho v^2 + \rho g z + p = \text{constant}$ $F_D = 6\pi\eta r v$ $R = \frac{vr\rho}{\eta}$	$Q = 2\pi \frac{\text{energy stored}}{\text{energy dissipated per cycle}}$ $Q = 2\pi \times \text{resonant frequency} \times \frac{\text{energy stored}}{\text{power loss}}$
Sub-topic C.1 – Introduction to imaging	Sub-topic C.2 – Imaging instrumentation
$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$ $P = \frac{1}{f}$ $m = \frac{h_i}{h_o} = -\frac{v}{u}$ $M = \frac{\theta_i}{\theta_o}$ $M_{\text{near point}} = \frac{D}{f} + 1; M_{\text{infinity}} = \frac{D}{f}$	$M = \frac{f_o}{f_e}$
	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)
	$L_1 = 10 \log \frac{I_1}{I_0}$ $I = I_0 e^{-\mu x}$ $\mu x_{\frac{1}{2}} = \ln 2$ $Z = \rho c$

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