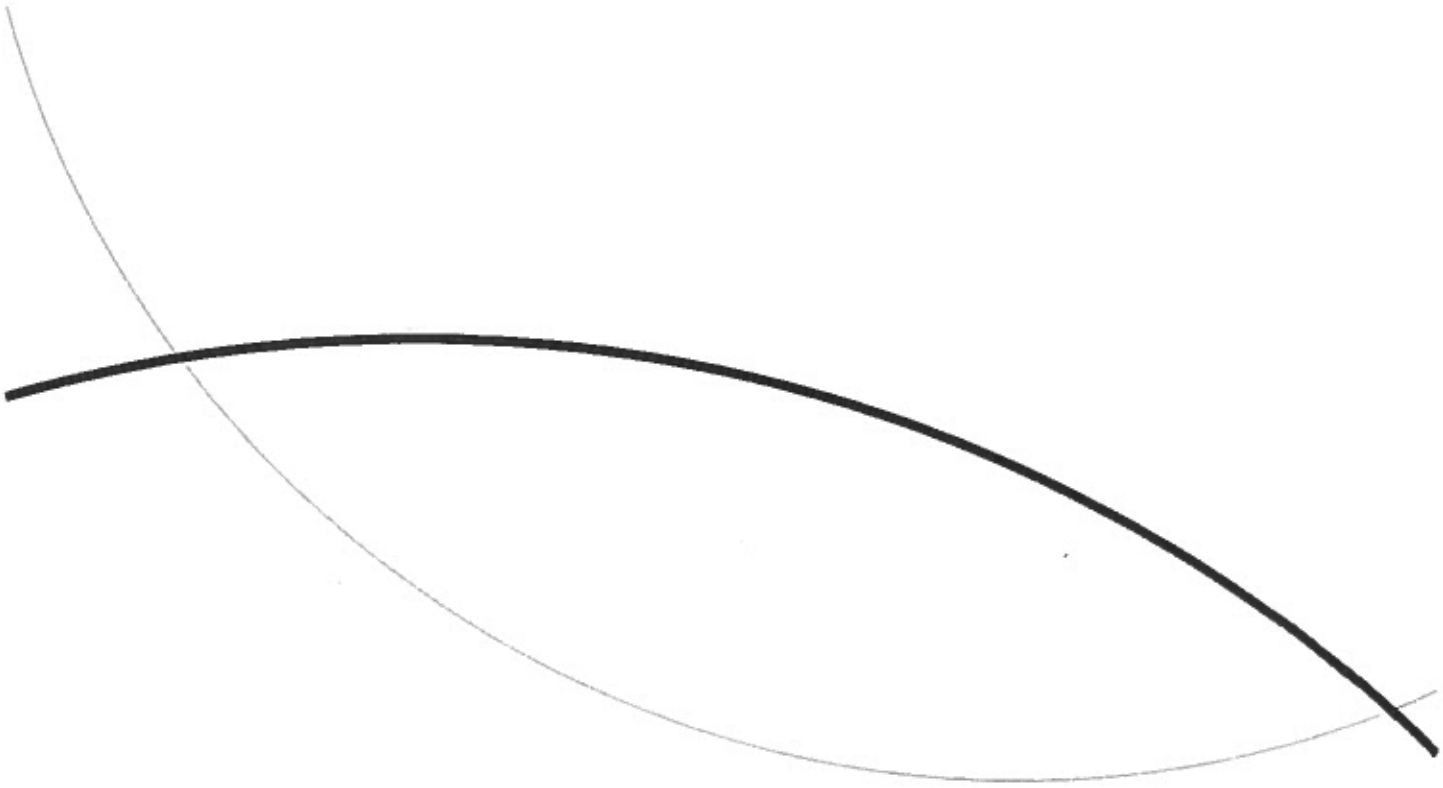
Diploma Programme

Physics data booklet

First assessment 2016



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Diploma Programme
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

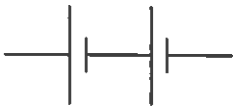
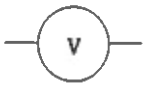
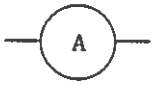
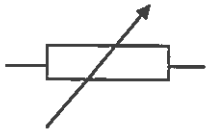
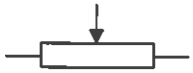
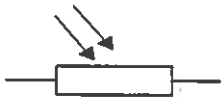
1 parsec (pc) = 3.26 ly

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

If: $y = a \pm b$

then: $\Delta y = \Delta a + \Delta b$

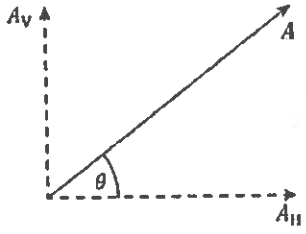
If: $y = \frac{ab}{c}$

then: $\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c}$

If: $y = a^n$

then: $\frac{\Delta y}{y} = \left| n\frac{\Delta a}{a} \right|$

Sub-topic 1.3 – Vectors and scalars



$A_H = A\cos\theta$

$A_V = A\sin\theta$

Sub-topic 2.1 – Motion

$v = u + at$

$s = ut + \frac{1}{2}at^2$

$v^2 = u^2 + 2as$

$s = \frac{(v+u)t}{2}$

V = final velocity
u = initial velocity
s = displacement

Sub-topic 2.2 – Forces

$F = ma$

$F_f \leq \mu_s R$

$F_f = \mu_d R$

R = normal force

Sub-topic 2.3 – Work, energy and power

$W = Fs\cos\theta$

$E_K = \frac{1}{2}mv^2$

$E_P = \frac{1}{2}k\Delta x^2$

$\Delta E_P = mg\Delta h$

power $= Fv$

Efficiency $= \frac{\text{useful work out}}{\text{total work in}}$

$= \frac{\text{useful power out}}{\text{total power in}}$

Sub-topic 2.4 – Momentum and impulse

$p = mv$

$F = \frac{\Delta p}{\Delta t}$

$E_K = \frac{p^2}{2m}$

Impulse $= F\Delta t = \Delta p$

Sub-topic 3.1 – Thermal concepts

$Q = mc\Delta T$ c = specific heat

$Q = mL$ L = specific latent heat

Sub-topic 3.2 – Modelling a gas

$p = \frac{F}{A}$ ← equation for pressure

$n = \frac{N}{N_A}$ n = moles of gas, N = atoms of gas | R = ideal gas constant

$pV = nRT$ N_A = Avogadro's Number

$\bar{E}_K = \frac{3}{2}k_BT = \frac{3}{2}\frac{R}{N_A}T$ ← avg. kinetic energy of a gas

Sub-topic 4.1 – Oscillations

$T = \frac{1}{f}$ T = period (s), f = frequency (Hz)

Sub-topic 4.2 – Travelling waves

$c = f\lambda$ c = wave velocity

Sub-topic 4.3 – Wave characteristics

$I \propto A^2$

$I \propto x^{-2}$

$I = I_0 \cos^2\theta$ I - intensity, A - amplitude, θ = ∠ btwn. polarizers (°)

Sub-topic 4.4 – Wave behaviour

$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$

$s = \frac{\lambda D}{d}$

Constructive interference: path difference = $n\lambda$ ← order of the maximum (n=0 is central maximum)

Destructive interference: path difference = $(n + \frac{1}{2})\lambda$ ← order of the minimum (n=0 is first order minimum)

Sub-topic 5.1 – Electric fields

$I = \frac{\Delta q}{\Delta t}$ I = current (A)

$F = k\frac{q_1q_2}{r^2}$ q = charge (C)

$k = \frac{1}{4\pi\varepsilon_0}$ k = look it up

ε_0 = look it up

$V = \frac{W}{q}$ r = dist. btwn. (m)

$E = \frac{F}{q}$ V = pot. difference (V)

$I = nAvq$ E = elec. field stength (N/C)

Sub-topic 5.2 – Heating effect of electric currents

Kirchhoff's circuit laws:

$\Sigma V = 0$ (loop)

$\Sigma I = 0$ (junction)

$R = \frac{V}{I}$

$P = VI = I^2R = \frac{V^2}{R}$

$R_{total} = R_1 + R_2 + \cdots$

$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$

$\rho = \frac{RA}{L}$

R - resistance (Ω), I - current (A), V - potential difference (V), ρ - resistivity (Ω m), A - cross-sec. area (m^2), L - wire length (m)

Sub-topic 5.3 – Electric cells

$\varepsilon = I(R + r)$

ε - emf (aka potential diff), I - current through battery, R - equivalent resistance of circuit, r - internal resistance of battery

Sub-topic 5.4 – Magnetic effects of electric currents

$F = qvB\sin\theta$

$F = BIL\sin\theta$

F = magnetic force (N), q = charge (C), v = charge velocity (m/s), B = mag. field stength (T), θ = angle in degrees, I = current (A), L = length (m)

Sub-topic 6.1 – Circular motion

$v = \omega r$

$a = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2}$

$F = \frac{mv^2}{r} = m\omega^2 r$

v - linear velocity (m/s)
ω - angular velocity (rad/s)
r - radius (m)
T - period (s)

Sub-topic 6.2 – Newton's law of gravitation

$F = G\frac{Mm}{r^2}$

$g = \frac{F}{m}$

$g = G\frac{M}{r^2}$

Sub-topic 7.1 – Discrete energy and radioactivity

$E = hf$

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

E - energy (J)
f - frequency (Hz)
λ - wavelength (m)
c - speed of light
h - constant

Sub-topic 7.2 – Nuclear reactions

$\Delta E = \Delta m\, c^2$

E - energy (J)
m - mass (kg)
c - speed of light (m/s)

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

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

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

A - cross-sectional area (m^2)
ρ - fluid density (kg/m^2)
v - speed of fluid

Sub-topic 8.2 – Thermal energy transfer

$P = e\sigma AT^4$

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

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

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

P - power (W)
e - emissivity
σ - Stefan-Boltzmann constant
A - area of emitting surface (m^2)
T - temp. of emitting surface (K)
I - intensity

Equations—AHL

Sub-topic 9.1 – Simple harmonic motion

$\omega = \frac{2\pi}{T}$ ω - angular frequency (rad/s) T - period (s)

$a = -\omega^2 x$ a - acceleration (m/s²)

$x = x_0 \sin \omega t \; ; x = x_0 \cos \omega t$ x - displacement from equilibrium (m)

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

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

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

$E_T = \frac{1}{2} m\omega^2 x_0^2$ v_0 - max velocity

Pendulum: $T = 2\pi\sqrt{\frac{l}{g}}$ l - length (m), g - acc. grav.

Mass–spring: $T = 2\pi\sqrt{\frac{m}{k}}$ m - mass (kg), k - sp. const.

Sub-topic 9.2 – Single-slit diffraction

$\theta = \frac{\lambda}{b}$ b - slit width (m) λ - wavelength (m) θ - angle to first minimum (IN RADIANS!)

Sub-topic 9.3 – Interference

$n\lambda = d \sin\theta$ - equation for diffraction grating maxima locations

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

Destructive interference: $2dn = m\lambda$

n - order of maxima (n=0 is central max)

λ - wavelength (m)

d - distance b/w lines on grating

θ - angle (IN DEGREES!)

Sub-topic 9.4 – Resolution

$\theta = 1.22 \frac{\lambda}{b}$ θ - angle (IN RADIANS!) λ - wavelength (m) b - diameter of opening

$R = \frac{\lambda}{\Delta\lambda} = mN$ R - resolvance of diff. grating m - order of diffraction N - total # of slits illuminated

Rayleigh criterion for circular apertures

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

$W = q\Delta V_e$

$W = m\Delta V_g$

W - work/energy (J)

q - charge (C)

ΔV_e - change in electrical pot. difference (V)

m - mass (kg)

ΔV_g - change in gravitational pot. difference (J/kg)

Sub-topic 10.2 – Fields at work

$V_g = -\frac{GM}{r}$	$V_e = \frac{kq}{r}$
$g = -\frac{\Delta V_g}{\Delta r}$	$E = -\frac{\Delta V_e}{\Delta r}$
$E_P = mV_g = -\frac{GMm}{r}$	$E_P = qV_e = \frac{kq_1q_2}{r}$
$F_G = G\frac{m_1m_2}{r^2}$	$F_E = k\frac{q_1q_2}{r^2}$

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

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

Φ - magnetic flux (Wb)

B - magnetic field strength (T)

A - cross sectional area (m^2)

θ - angle between NORMAL of surface + B-field (°)

Sub-topic 11.1 – Electromagnetic induction

$\Phi = BA\cos\theta$

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

$\varepsilon = Blv$

$\varepsilon = BvlN$

ε - emf / pot. diff. (V)

N - number of loops/turns

v - velocity of conductor (m/s)

l - length of conductor (m)

Sub-topic 11.2 – Power generation and transmission

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

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

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

$P_{max} = I_0V_0$

$\bar{P} = \frac{1}{2}I_0V_0$

$\frac{\varepsilon_p}{\varepsilon_s} = \frac{N_p}{N_s} = \frac{I_s}{I_p}$

rms - root mean square

$\bar{P}$ - average power

Sub-topic 11.3 – Capacitance

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

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

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

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

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

$\tau = RC$

$q = q_0e^{-\frac{t}{\tau}}$

$I = I_0e^{-\frac{t}{\tau}}$

$V = V_0e^{-\frac{t}{\tau}}$

C - capacitance (F)

q - charge (C)

V - pot. diff. (V)

ε - permittivity of material between plates (if air or vacuum use ε_0)

E - electric field strength

τ - time constant of RC circuit

R - resistance (Ω)

t - time (s)

equations for charge/current/pot. diff. left in an RC circuit after a set time has elapsed.

Sub-topic 12.1 – The interaction of matter with radiation

$E = hf$

$E_{max} = hf - \Phi$

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

$mvr = \frac{nh}{2\pi}$ → hydrogen radius equation

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

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

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

E - energy (J)

h - constant

f - frequency (Hz)

Φ - work function (J)

m - mass of electron (kg)

v - speed of electron (m/s)

r - radius of orbit (m)

n - energy level of orbit

h - constant

P(r) - probability of particle location

ψ - wave function

ΔV - change in potential

Δx - uncertainty in position

Δp - uncertainty in momentum

ΔE - uncertainty in energy

Δt - uncertainty in time

h - constant

Sub-topic 12.2 – Nuclear physics

$R = R_0A^{1/3}$

$N = N_0e^{-\lambda t}$

$A = \lambda N_0e^{-\lambda t}$

$\sin\theta \approx \frac{\lambda}{D}$ → Nuclear Scattering (nucleus acts like a single slit)

R - nuclear radius (m)

R_0 - Fermi radius

A - atomic mass (ex. - Helium = 4)

θ - angle (°)

λ - wavelength

D - nuclear diameter

N - current population/activity

N_0 - original population/activity

λ - decay constant → $T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$

t - time (s)

Memorize this !!!

Equations—Options

Sub-topic A.1 – The beginnings of relativity

$$x' = x - vt$$

$$u' = u - v$$

Sub-topic A.2 – Lorentz transformations

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$x' = \gamma(x - vt)\ ;\ \Delta x' = \gamma(\Delta x - v\Delta t)$$

$$t' = \gamma\left(t - \frac{vx}{c^2}\right)\ ;\ \Delta t' = \gamma\left(\Delta t - \frac{v\Delta x}{c^2}\right)$$

$$u' = \frac{u - v}{1 - \frac{uv}{c^2}}$$

$$\Delta t = \gamma \Delta t_0$$

$$L = \frac{L_0}{\gamma}$$

$$(ct')^2 - (x')^2 = (ct)^2 - (x)^2$$

Sub-topic A.3 – Spacetime diagrams

$$\theta = \tan^{-1}\left(\frac{v}{c}\right)$$

Sub-topic A.4 – Relativistic mechanics (HL only)

$$E = \gamma m_0 c^2$$

$$E_0 = m_0 c^2$$

$$E_K = (\gamma - 1) m_0 c^2$$

$$p = \gamma m_0 v$$

$$E^2 = p^2 c^2 + {m_0}^2 c^4$$

$$qV = \Delta E_K$$

Sub-topic A.5 – General relativity (HL only)

$$\frac{\Delta f}{f} = \frac{g\Delta h}{c^2}$$

$$R_s = \frac{2GM}{c^2}$$

$$\Delta t = \frac{\Delta t_0}{\sqrt{1 - \frac{R_s}{r}}}$$

Sub-topic B.1 – Rigid bodies and rotational dynamics

$\Gamma = Fr\sin\theta$ Γ - torque (Nm)

$I = \sum mr^2$ F - force (N)

$\Gamma = I\alpha$ r - length of moment arm (m)

$\omega = 2\pi f$ I - moment of inertia (kgm^2)

$\omega_f = \omega_i + \alpha t$ α - angular acc. (rad/s^2)

$\omega_f^2 = \omega_i^2 + 2\alpha\theta$ ω - angular velocity (rad/s)

$\theta = \omega_i t + \frac{1}{2}\alpha t^2$ L - angular momentum (kgm^2/s)

$L = I\omega$ E - energy (J)

$E_{K_{rot}} = \frac{1}{2}I\omega^2$

Sub-topic B.2 – Thermodynamics

$Q = \Delta U + W$ Q - thermal energy in/out (J)

$U = \frac{3}{2}nRT$ ΔU - internal energy (J)

$\Delta S = \frac{\Delta Q}{T}$ W - work done on/by gas (J)

$pV^{\frac{5}{3}} = \text{constant}$ (for monatomic gases)

$W = p\Delta V$ p - pressure ΔV - change in volume

$\eta = \frac{\text{useful work done}}{\text{energy input}}$ η - efficiency

$\eta_{Carnot} = 1 - \frac{T_{cold}}{T_{hot}}$

Sub-topic B.3 – Fluids and fluid dynamics (HL only)

$B = \rho_f V_f g$ B - buoyant force (N)

$P = P_0 + \rho_f g d$ ρ - density (kg/m^3)

$Av = \text{constant}$ V_f - volume displaced (m^3)

$\frac{1}{2}\rho v^2 + \rho g z + p = \text{constant}$ P - pressure

$F_D = 6\pi\eta r v$ F_D - drag force (N)

$R = \frac{vr\rho}{\eta}$ η - viscosity

R - Reynolds' number r - radius v - velocity

Sub-topic B.4 – Forced vibrations and resonance (HL only)

$Q = 2\pi \frac{\text{energy stored}}{\text{energy dissipated per cycle}}$

$Q = 2\pi \times \text{resonant frequency} \times \frac{\text{energy stored}}{\text{power loss}}$

Q - Q - Factor

Sub-topic C.1 – Introduction to imaging

$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$

$P = \frac{1}{f}$

$m = \frac{h_i}{h_o} = -\frac{v}{u}$

$M = \frac{\theta_i}{\theta_o}$

$M_{\text{near point}} = \frac{D}{f} + 1$; $M_{\text{infinity}} = \frac{D}{f}$

Sub-topic C.2 – Imaging instrumentation

$M = \frac{f_o}{f_e}$

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)

$L_I = 10\log\frac{I_1}{I_0}$

$I = I_0 e^{-\mu x}$

$\mu x_{\frac{1}{2}} = \ln 2$

$Z = \rho c$

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)**
$z = \frac{\Delta\lambda}{\lambda_0} \approx \frac{v}{c}$ $z = \frac{R}{R_0} - 1$ $v = H_0 d$ $T \approx \frac{1}{H_0}$	$v = \sqrt{\frac{4\pi G\rho}{3}} r$ $\rho_c = \frac{3H^2}{8\pi G}$