Diploma Programme

Physics data booklet

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Diploma Programme
Physics data booklet

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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	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 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	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}

Unit conversions

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

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

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

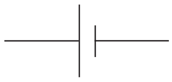
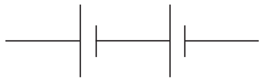
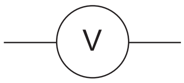
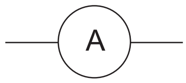
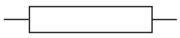
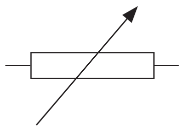
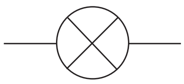
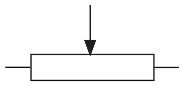
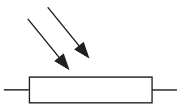
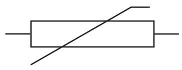
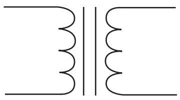
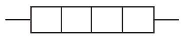
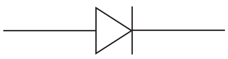
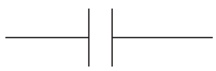
$1 \text{ parsec (pc)} = 3.26 \text{ ly}$

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

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

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

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.

y = Result.

a, b, c = Quantities.

Δ = Uncertainty.

Sub-topic 1.2 – Uncertainties and errors

If: $y = a \pm b$

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

Adding/subtracting quantities: uncertainty in result will be sum of uncertainties of quantities.

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

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

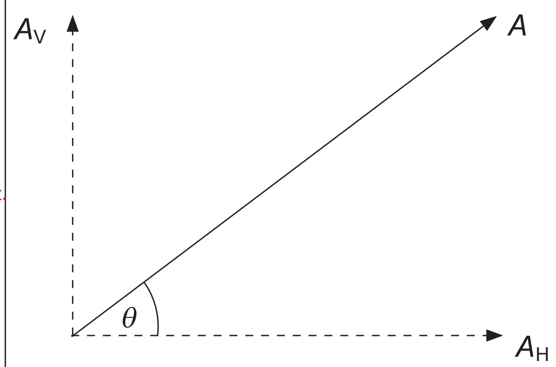
Multiplying/dividing quantities: % uncertainties of quantities are added together to obtain % uncertainty in result.

If: $y = a^n$

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

Powers of quantities: % uncertainty of quantity is multiplied by power to obtain % uncertainty in result.

Sub-topic 1.3 – Vectors and scalars



$A_H = A \cos\theta$

$A_V = A \sin\theta$

Trigonometric rules of triangles are applied when taking components of vector quantities.

AH = Horizontal component.

AV = Vertical component.

Sub-topic 2.1 – Motion

v = Final velocity.

u = Initial velocity.

a = Acceleration ('g' for gravitational).

s = Displacement.

t = Time elapsed.

$v = u + at$

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

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

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

Equations applied to uniform motion (known as 'suvat' equations).

Sub-topic 2.2 – Forces

F = Resultant force.

m = Mass.

a = Acceleration.

μs = Coefficient of static friction.

μd = " dynamic ".

Ff = Frictional force.

R = Normal reaction force.

$F = ma$ Acceleration due to resultant force (Newton's 2nd law of motion).

$F_f \le \mu_s R$ Frictional force on a static object.

$F_f = \mu_d R$ Frictional force on a dynamic object.

Sub-topic 2.3 – Work, energy and power

W = Work done.

F = Force.

s = Displacement.

EK = Kinetic energy.

m = Mass.

v = Velocity.

EP = Potential energy.

k = Spring constant

x = Extension.

g = Earth's gravity.

h = Height.

$W = Fs\cos\theta$ Work done.

$E_K = \frac{1}{2}mv^2$ Kinetic energy.

$E_p = \frac{1}{2}k\Delta x^2$ Elastic potential energy (in a spring).

$\Delta E_p = mg\Delta h$ Gravitational potential energy.

$\text{power} = Fv$ Power.

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

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

Sub-topic 2.4 – Momentum and impulse

p = Momentum.

m = Mass.

v = Velocity.

F = Force.

t = Time.

EK = Kinetic energy.

$p = mv$ Momentum.

$F = \frac{\Delta p}{\Delta t}$ Resultant force due to momentum.

$E_K = \frac{p^2}{2m}$ Kinetic energy.

$\text{impulse} = F\Delta t = \Delta p$

p = Pressure.

F = Force.

A = Area.

n = Number of moles.

N = Number of atoms.

NA = Avogadro's constant.

V = Volume.

R = Gas constant.

T = Temperature.

EK = Kinetic energy.

kb = Boltzmann's constant.

Q = Energy/heat.

m = Mass.

c = Specific heat capacity.

T = Temperature.

L = Specific latent heat.

Sub-topic 3.1 – Thermal concepts

$Q = mc\Delta T$ Energy/heat given/received in changing an object's temperature.

$Q = mL$ Energy/heat given/received in changing an object's phase.

Sub-topic 3.2 – Modelling a gas

$p = \frac{F}{A}$ Pressure.

$n = \frac{N}{N_A}$ Number of moles of a substance.

$pV = nRT$ Ideal gas law.

$\bar{E}_K = \frac{3}{2}k_B T = \frac{3}{2}\frac{R}{N_A}T$ Average kinetic energy per molecule of a gas.

T = Period.

f = Frequency.

c = Velocity.

f = Frequency.

λ = Wavelength.

I = Intensity.

A = Amplitude.

x = Distance from source.

I0 = Original intensity.

θ = Angle of polarizer.

Sub-topic 4.1 – Oscillations

$T = \frac{1}{f}$ Period (time taken to complete 1 oscillation).

Sub-topic 4.2 – Travelling waves

$c = f\lambda$ Speed of a wave.

Sub-topic 4.3 – Wave characteristics

$I \propto A^2$ Intensity of a wave vs. amplitude.

$I \propto x^{-2}$ Intensity of a wave's radiation at a certain distance from the source.

$I = I_0 \cos^2 \theta$ Transmitted intensity of light incident on a polariser (Malus's law).

Sub-topic 4.4 – Wave behaviour

$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$ Refraction when a wave crosses a boundary between 2 media (Snell's law).

$s = \frac{\lambda D}{d}$ Fringe spacing in double slit diffraction.

Constructive interference:
path difference $= n\lambda$

Destructive interference:
path difference $= \left(n + \frac{1}{2}\right)\lambda$

Maxima/minima on screen in double slit diffraction.

n1/n2 = Index of refraction.

θ = Angle of incidence/refraction.

v = Wave velocity.

s = Fringe spacing.

λ = Wavelength.

D = Distance to screen.

d = Slit spacing.

n = Any integer (order of minimum/ maximum).

I = Current.

q = Charge.

t = Time.

F = Force.

k = Coulomb constant.

r = Separation distance.

ε0 = Permittivity of free space.

V = Potential.

W = Work done.

E = Electric field strength.

n = Number of charges per unit volume.

A = X-sectional area.

v = Drift velocity.

Sub-topic 5.1 – Electric fields	Sub-topic 5.2 – Heating effect of electric currents
$I = \frac{\Delta q}{\Delta t}$ Current.	Kirchhoff's circuit laws: $\Sigma V = 0$ (loop) $\Sigma I = 0$ (junction)
$F = k\frac{q_1 q_2}{r^2}$ Force experienced by 2 charges (Coulomb's law).	$R = \frac{V}{I}$ Resistance.
$k = \frac{1}{4\pi\varepsilon_0}$ Coulomb constant.	$P = VI = I^2 R = \frac{V^2}{R}$ Power supplied/dissipated.
$V = \frac{W}{q}$ Potential difference.	$R_{\text{total}} = R_1 + R_2 + \ldots$ Total resistance of resistors in series.
$E = \frac{F}{q}$ Electric field strength.	$\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$ Total resistance of resistors in parallel.
$I = nAvq$ Current in a wire.	$\rho = \frac{RA}{L}$ Resistivity of material of a wire.

V = Potential.

I = Current.

R = Resistance.

P = Power.

ρ = Resistivity.

A = X-sectional area.

L = Length.

ε = Emf.

I = Current.

R = Resistance.

r = Internal resistance.

Sub-topic 5.3 – Electric cells	Sub-topic 5.4 – Magnetic effects of electric currents
$\varepsilon = I(R + r)$ Emf of a cell.	$F = qvB\sin\theta$ Force on a charge moving through a magnetic field.
	$F = BIL\sin\theta$ Force on a current-carrying wire in a magnetic field.

F = Force.

q = Charge.

v = Velocity of charge.

B = Magnitude of magnetic field.

θ = Angle with field.

v = Velocity.

ω = Angular velocity.

r = Radius of circle.

a = Acceleration.

T = Period of rotation.

F = Force.

m = Mass.

Sub-topic 6.1 – Circular motion	Sub-topic 6.2 – Newton's law of gravitation
$v = \omega r$ Velocity of body travelling in circle.	$F = G\frac{Mm}{r^2}$ Force experienced by 2 masses (Newton's law of gravitation).
$a = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2}$ Centripetal acceleration.	$g = \frac{F}{m}$ Field strength as experienced by a mass in the field.
$F = \frac{mv^2}{r} = m\omega^2 r$ Centripetal force.	$g = G\frac{M}{r^2}$ Field strength at a certain distance from body.

F = Force.

G = Gravitational constant.

M = Mass of body.

m = Mass of body (in a field).

r = Separation distance of bodies.

g = Gravitational field strength

E = Energy.

h = Planck's constant.

f = Frequency.

λ = Wavelength.

c = Speed of light.

Sub-topic 7.1 – Discrete energy and radioactivity

$E = hf$ Energy of a photon.

$\lambda = \frac{hc}{E}$ Wavelength of a photon.

Sub-topic 7.2 – Nuclear reactions

$\Delta E = \Delta mc^2$ Energy released when nucleons are assembled into nucleus.

E = Energy.

m = Mass.

c = Speed of light.

Sub-topic 7.3 – The structure of matter

e = Elementary charge.

u = Up.

d = Down.

c = Charm.

s = Strange.

t = Top.

b = Bottom.

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

e = Electron.

μ = Muon.

τ = Tau.

ν = Neutrino.

	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

A = Area swept out by turbine blades.

ρ = Air density.

v = Wind speed.

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

$\text{power} = \frac{1}{2}A\rho v^3$ Power available from a wind turbine.

Sub-topic 8.2 – Thermal energy transfer

$P = e\sigma AT^4$ Power radiated by a body.

$\lambda_{max}(\text{metres}) = \frac{2.90 \times 10^{-3}}{T(\text{kelvin})}$ Wavelength at which intensity of radiation is at a maximum.

$I = \frac{\text{power}}{A}$ Intensity of radiation.

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

P = Power.

e = Emissivity.

σ = Stefan-Boltzmann constant.

A = Area.

T = Temperature.

λ = Wavelength.

I = Intensity.

Equations—AHL

ω = Angular frequency.

T = Period.

a = Acceleration.

x = Displacement from equilibrium.

x0 = Maximum displacement.

t = Time elapsed.

EK = Kinetic energy.

ET = Total energy.

l = Length of pendulum.

g = Gravitational field strength.

k = Spring constant.

Sub-topic 9.1 – Simple harmonic motion	Sub-topic 9.2 – Single-slit diffraction
$\omega = \frac{2\pi}{T}$ Angular frequency of oscillation.	$\theta = \frac{\lambda}{b}$ Angle at which first minimum occurs in single-slit diffraction.
$a = -\omega^2 x$ Acceleration of object in SHM.	**Sub-topic 9.3 – Interference**
$x = x_0 \sin \omega t; x = x_0 \cos \omega t$ Displacement of object in SHM.	$n\lambda = d \sin \theta$ Path difference between slits for a diffraction grating (constructive/destructive interference).
$v = \omega x_0 \cos \omega t; v = -\omega x_0 \sin \omega t$ Velocity of object in SHM.	Constructive interference: $2dn = \left(m + \frac{1}{2}\right)\lambda$
$v = \pm\omega\sqrt{(x_0^2 - x^2)}$ Velocity of object in SHM.	Destructive interference: $2dn = m\lambda$
$E_K = \frac{1}{2}m\omega^2(x_0^2 - x^2)$ Kinetic energy of object in SHM.	Interference patterns for thin-film interference.
$E_T = \frac{1}{2}m\omega^2 x_0^2$ Total energy of object in SHM.	
pendulum: $T = 2\pi\sqrt{\frac{l}{g}}$ Period of oscillation of a pendulum in SHM.	
mass-spring: $T = 2\pi\sqrt{\frac{m}{k}}$ Period of oscillation of a mass on a spring in SHM.	

θ = Angle.

λ = Wavelength.

b = Slit width.

n = Any integer (for diffraction grating).

λ = Wavelength.

d = Slit spacing (for diffraction grating).

θ = Angle.

d = Thickness of medium (for TFI).

n = Refractive index of medium (for TFI).

m = Any integer (for TFI).

θ = Angle.

λ = Wavelength.

b = Slit width/ diameter.

R = Resolvance

Δλ = Smallest possible resolvable wavelength difference.

m = Diffraction order.

N = Number of slits illuminated.

Sub-topic 9.4 – Resolution	Sub-topic 9.5 – Doppler effect
$\theta = 1.22\frac{\lambda}{b}$ First minimum for diffraction in a circular aperture.	Moving source: $f' = f\left(\frac{v}{v \pm u_s}\right)$
$R = \frac{\lambda}{\Delta\lambda} = mN$ Resolvance of a diffraction grating.	Moving observer: $f' = f\left(\frac{v \pm u_o}{v}\right)$
	$\frac{\Delta f}{f} = \frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}$ Doppler effect for light.

f' = Perceived frequency.

f = Actual frequency.

v = Wave speed.

us = Velocity of source.

uo = Velocity of observer.

λ = Wavelength.

v = Relative speed of observer and source.

c = Speed of light.

W = Work done.

q = Charge.

Ve = Electric potential.

m = Mass.

Vg = Gravitational potential.

Sub-topic 10.1 – Describing fields	Sub-topic 10.2 – Fields at work	
$W = q\Delta V_e$ Work done moving a charge between 2 points in a field. Potential.	$V_g = -\frac{GM}{r}$	$V_e = \frac{kQ}{r}$
$W = m\Delta V_g$ Work done moving a mass between 2 points in a field. Field strength.	$g = -\frac{\Delta V_g}{\Delta r}$	$E = -\frac{\Delta V_e}{\Delta r}$
Potential energy.	$E_p = mV_g = -\frac{GMm}{r}$	$E_p = qV_e = \frac{kQq}{r}$
Force.	$F_g = \frac{GMm}{r^2}$	$F_e = \frac{kQq}{r^2}$
	$v_{esc} = \sqrt{\frac{2GM}{r}}$ Escape velocity of a planet.	
	$v_{orbit} = \sqrt{\frac{GM}{r}}$ Velocity of a body in circular orbit around another body.	

Vg = Gravitational potential.

Ve = Electric potential.

G = Gravitational constant.

k = Coulomb constant.

M = Mass.

Q = Charge.

r = Separation distance.

g = Gravitational field strength.

E = Electric field strength.

Ep = Potential energy.

m = Mass.

q = Charge.

Fg = Gravitational force.

Fe = Electric force.

V(esc) = Escape velocity.

V(orbit) = velocity of orbit.

Φ = Magnetic flux.

B = B = Magnitude of magnetic field.

A = Area of coil.

N = Number of turns.

t = Time elapsed.

v = Speed of wire.

l = Length of wire.

I(rms) = Effective current.

I0 = Maximum current.

V(rms) = Effective pd.

V0 = Maximum pd.

R = Resistance

P(max) = Maximum power dissipated.

P = Power dissipated.

ε = Emf.

N = Number of turns.

p/s = Primary/ secondary.

Sub-topic 11.1 – Electromagnetic induction	
$\Phi = BA\cos\theta$	Magnetic flux.
$\varepsilon = -N\dfrac{\Delta\Phi}{\Delta t}$	Induced emf in a coil.
$\varepsilon = Bvl$	Induced emf in a conductor moving through a field.
$\varepsilon = BvlN$	Induced emf in a coiled wire moving through a field.

Sub-topic 11.2 – Power generation and transmission	
$I_{rms} = \dfrac{I_0}{\sqrt{2}}$	Effective (root mean square) current in an AC generator.
$V_{rms} = \dfrac{V_0}{\sqrt{2}}$	Effective (root mean square) potential difference in an AC generator.
$R = \dfrac{V_0}{I_0} = \dfrac{V_{rms}}{I_{rms}}$	Resistance.
$P_{max} = I_0 V_0$	Maximum power dissipated.
$\bar{P} = \dfrac{1}{2} I_0 V_0$	Average power dissipated.
$\dfrac{\varepsilon_p}{\varepsilon_s} = \dfrac{N_p}{N_s} = \dfrac{I_s}{I_p}$	Ratios of emf, turns and current in a transformer.

Sub-topic 11.3 – Capacitance	
$C = \dfrac{q}{V}$	Capacitance of a capacitor.
$C_{parallel} = C_1 + C_2 + \ldots$	Capacitance of capacitors in parallel.
$\dfrac{1}{C_{series}} = \dfrac{1}{C_1} + \dfrac{1}{C_2} + \ldots$	Capacitance of capacitors in series.
$C = \varepsilon\dfrac{A}{d}$	Capacitance of a capacitor.
$E = \dfrac{1}{2}CV^2$	Energy stored in a capacitor.
$\tau = RC$	Time constant for a circuit.
$q = q_0 e^{-\frac{t}{\tau}}$	Exponential decrease of charge stored for a discharging capacitor.
$I = I_0 e^{-\frac{t}{\tau}}$	Exponential decrease of current for a discharging capacitor.
$V = V_0 e^{-\frac{t}{\tau}}$	Exponential decrease of potential difference for a discharging capacitor.

C = Capacitance.

q = Charge.

V = Potential (difference).

ε = Permittivity of dielectric material.

A = Area of plates.

d = Separation of plates.

E = Energy stored.

τ = Time constant.

R = Resistance.

q0 = Original charge.

t = Time elapsed.

I = Current.

I0 = Initial maximum current.

V0 = Initial maximum potential difference.

E = Energy.

h = Planck's constant.

f = Frequency.

Φ = Work function.

n = State of atom.

m = Mass.

v = Velocity.

r = Radius.

Ψ = Wave function.

V = Volume.

x = Position.

p = Momentum.

t = Time.

Sub-topic 12.1 – The interaction of matter with radiation	
$E = hf$	Energy of a photon.
$E_{max} = hf - \Phi$	Kinetic energy of freed electron (photoelectric effect) (= e × stopping voltage).
$E = -\dfrac{13.6}{n^2}eV$	Quantised energy of electron in the hydrogen atom.
$mvr = \dfrac{nh}{2\pi}$	Angular momentum of the orbiting electron in the hydrogen atom.
$P(r) = \lvert\psi\rvert^2 \Delta V$	Probability that an electron will be found within a small volume ΔV.
$\Delta x \Delta p \geq \dfrac{h}{4\pi}$	Uncertainty in momentum and position of a particle (Heisenberg).
$\Delta E \Delta t \geq \dfrac{h}{4\pi}$	Uncertainty in energy and lifetime of the state of a particle (Heisenberg).

Sub-topic 12.2 – Nuclear physics	
$R = R_0 A^{\frac{1}{3}}$	Nuclear radius of an element.
$N = N_0 e^{-\lambda t}$	Number of nuclei left in a radioactive sample.
$A = \lambda N_0 e^{-\lambda t}$	Activity of a radioactive sample.
$\sin\theta \approx \dfrac{\lambda}{D}$	First minimum of an electron diffraction pattern around a circular object.

R = Nuclear radius.

R0 = Fermi radius (constant).

A = Atomic mass number.

N = Number of nuclei.

N0 = Original number of nuclei.

A = Activity.

λ = Decay constant.

θ = Angle of first minimum.

λ = De Broglie wavelength.

D = Diameter of circular object.

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

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

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

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

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

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

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)

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

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

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

$$Z = \rho c$$

d = Distance from Earth to a star.

p = Parallax angle.

L = Luminosity.

σ = Stefan-Boltzmann constant.

A = Area.

T = Temperature.

b = Apparent brightness.

d = Distance to star.

Sub-topic D.1 – Stellar quantities

$$d\,(\text{parsec}) = \frac{1}{p\,(\text{arc-second})}$$

Distance to a star in parsec.

$$L = \sigma A T^4$$

Luminosity of a star.

$$b = \frac{L}{4\pi d^2}$$

Apparent brightness of a star.

Sub-topic D.2 – Stellar characteristics and stellar evolution

$$\lambda_{\max} T = 2.9 \times 10^{-3}\ \text{mK}$$

Relation between wavelength of maximum intensity radiation of a star and its temperature.

$$L \propto M^{3.5}$$

Mass-luminosity relation for main sequence stars.

λ = Wavelength.

T = Temperature.

L = Luminosity.

M = Mass.

z = Red shift.

λ(0) =Emitted wavelength.

v = Relative velocity of light source.

c = Speed of light.

R = Cosmic scale factor.

R(0) =

H(0) = Hubble constant.

d = Distance from Earth.

Sub-topic D.3 – Cosmology

$$z = \frac{\Delta\lambda}{\lambda_0} \approx \frac{v}{c}$$

Red shift of a star/galaxy moving away from us.

$$z = \frac{R}{R_0} - 1$$

Red shift depending on cosmic scale factor.

$$v = H_0 d$$

$$T \approx \frac{1}{H_0}$$

Sub-topic D.5 – Further cosmology (HL only)

$$v = \sqrt{\frac{4\pi G\rho}{3}}\,r$$

$$\rho_c = \frac{3H^2}{8\pi G}$$