



Physics A

PHYA4

Unit 4 Fields and Further Mechanics

Data and Formulae Booklet

DATA

FUNDAMENTAL CONSTANTS AND VALUES

<i>Quantity</i>	<i>Symbol</i>	<i>Value</i>	<i>Units</i>
speed of light in vacuo	c	3.00×10^8	m s^{-1}
permeability of free space	μ_0	$4\pi \times 10^{-7}$	H m^{-1}
permittivity of free space	ϵ_0	8.85×10^{-12}	F m^{-1}
magnitude of the charge of electron	e	1.60×10^{-19}	C
the Planck constant	h	6.63×10^{-34}	J s
gravitational constant	G	6.67×10^{-11}	$\text{N m}^2 \text{kg}^{-2}$
the Avogadro constant	N_A	6.02×10^{23}	mol^{-1}
molar gas constant	R	8.31	$\text{J K}^{-1} \text{mol}^{-1}$
the Boltzmann constant	k	1.38×10^{-23}	J K^{-1}
the Stefan constant	σ	5.67×10^{-8}	$\text{W m}^{-2} \text{K}^{-4}$
the Wien constant	α	2.90×10^{-3}	m K
electron rest mass (equivalent to 5.5×10^{-4} u)	m_e	9.11×10^{-31}	kg
electron charge/mass ratio	e/m_e	1.76×10^{11}	C kg^{-1}
proton rest mass (equivalent to 1.00728 u)	m_p	$1.67(3) \times 10^{-27}$	kg
proton charge/mass ratio	e/m_p	9.58×10^7	C kg^{-1}
neutron rest mass (equivalent to 1.00867 u)	m_n	$1.67(5) \times 10^{-27}$	kg
gravitational field strength	g	9.81	N kg^{-1}
acceleration due to gravity	g	9.81	m s^{-2}
atomic mass unit (1u is equivalent to 931.3 MeV)	u	1.661×10^{-27}	kg

GEOMETRICAL EQUATIONS

<i>arc length</i>	$= r\theta$
<i>circumference of circle</i>	$= 2\pi r$
<i>area of circle</i>	$= \pi r^2$
<i>surface area of cylinder</i>	$= 2\pi rh$
<i>volume of cylinder</i>	$= \pi r^2 h$
<i>area of sphere</i>	$= 4\pi r^2$
<i>volume of sphere</i>	$= \frac{4}{3} \pi r^3$

ASTRONOMICAL DATA

<i>Body</i>	<i>Mass/kg</i>	<i>Mean radius/m</i>
Sun	1.99×10^{30}	6.96×10^8
Earth	5.98×10^{24}	6.37×10^6

AS FORMULAE

PARTICLE PHYSICS

Rest energy values

class	name	symbol	rest energy /MeV
photon	photon	γ	0
lepton	neutrino	ν_e	0
		ν_μ	0
	electron	$e^\pm$	0.510999
	muon	$\mu^\pm$	105.659
mesons	π meson	$\pi^\pm$	139.576
		π^0	134.972
	K meson	$K^\pm$	493.821
		K^0	497.762
baryons	proton	p	938.257
	neutron	n	939.551

Properties of quarks

antiquarks have opposite signs

type	charge	baryon number	strangeness
u	$+\frac{2}{3}e$	$+\frac{1}{3}$	0
d	$-\frac{1}{3}e$	$+\frac{1}{3}$	0
s	$-\frac{1}{3}e$	$+\frac{1}{3}$	-1

Properties of Leptons

	lepton number
particles: $e^-, \nu_e; \mu^-, \nu_\mu$	+1
antiparticles: $e^+, \bar{\nu}_e; \mu^+, \bar{\nu}_\mu$	-1

Photons and Energy Levels

photon energy	$E = hf = hc/\lambda$
photoelectricity	$hf = \phi + E_{K(\max)}$
energy levels	$hf = E_1 - E_2$
de Broglie wavelength	$\lambda = \frac{h}{p} = \frac{h}{mv}$

ELECTRICITY

$$\text{current and pd} \quad I = \frac{\Delta Q}{\Delta t} \quad V = \frac{W}{Q} \quad R = \frac{V}{I}$$

$$\text{emf} \quad \varepsilon = \frac{E}{Q} \quad \varepsilon = I(R + r)$$

$$\text{resistors in series} \quad R = R_1 + R_2 + R_3 + \dots$$

$$\text{resistors in parallel} \quad \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$$

$$\text{resistivity} \quad \rho = \frac{RA}{L}$$

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

$$\text{alternating current} \quad I_{\text{rms}} = \frac{I_0}{\sqrt{2}} \quad V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$$

MECHANICS

$$\text{moments} \quad \text{moment} = Fd$$

$$\text{velocity and acceleration} \quad v = \frac{\Delta s}{\Delta t} \quad a = \frac{\Delta v}{\Delta t}$$

$$\text{equations of motion} \quad v = u + at \quad s = \frac{(u+v)t}{2}$$

$$v^2 = u^2 + 2as \quad s = ut + \frac{at^2}{2}$$

$$\text{force} \quad F = ma$$

$$\begin{aligned} \text{work, energy and power} \quad W &= Fs \cos \theta \\ E_K &= \frac{1}{2} m v^2 \quad \Delta E_P = mg\Delta h \\ P &= \frac{\Delta W}{\Delta t}, P = Fv \end{aligned}$$

$$\text{efficiency} = \frac{\text{useful output power}}{\text{input power}}$$

MATERIALS

$$\text{density} \quad \rho = \frac{m}{V} \quad \text{Hooke's law} \quad F = k \Delta L$$

$$\begin{aligned} \text{Young modulus} &= \frac{\text{tensile stress}}{\text{tensile strain}} \quad \text{tensile stress} = \frac{F}{A} \\ \text{tensile strain} &= \frac{\Delta L}{L} \end{aligned}$$

$$\text{energy stored} \quad E = \frac{1}{2} F \Delta L$$

WAVES

$$\text{wave speed} \quad c = f\lambda \quad \text{period} \quad T = \frac{1}{f}$$

$$\text{fringe spacing} \quad w = \frac{\lambda D}{s} \quad \text{diffraction grating} \quad d \sin \theta = n\lambda$$

$$\text{refractive index of a substance } s, \quad n = \frac{c}{c_s}$$

for two different substances of refractive indices n_1 and n_2 ,

$$\text{law of refraction} \quad n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\text{critical angle} \quad \sin \theta_c = \frac{n_2}{n_1} \text{ for } n_1 > n_2$$

A2 FORMULAE**MOMENTUM**

$$\text{force} \quad F = \frac{\Delta(mv)}{\Delta t}$$

$$\text{impulse} \quad F \Delta t = \Delta(mv)$$

CIRCULAR MOTION

$$\text{angular velocity} \quad \omega = \frac{v}{r}$$

$$\omega = 2\pi f$$

$$\text{centripetal acceleration} \quad a = \frac{v^2}{r} = \omega^2 r$$

$$\text{centripetal force} \quad F = \frac{mv^2}{r} = m\omega^2 r$$

OSCILLATIONS

$$\text{acceleration} \quad a = -(2\pi f)^2 x$$

$$\text{displacement} \quad x = A \cos(2\pi f t)$$

$$\text{speed} \quad v = \pm 2\pi f \sqrt{A^2 - x^2}$$

$$\text{maximum speed} \quad v_{\max} = 2\pi f A$$

$$\text{maximum acceleration} \quad a_{\max} = (2\pi f)^2 A$$

$$\text{for a mass-spring system} \quad T = 2\pi \sqrt{\frac{m}{k}}$$

$$\text{for a simple pendulum} \quad T = 2\pi \sqrt{\frac{l}{g}}$$

GRAVITATIONAL FIELDS

$$\text{force between two masses} \quad F = \frac{G m_1 m_2}{r^2}$$

$$\text{gravitational field strength} \quad g = \frac{F}{m}$$

$$\text{magnitude of gravitational field strength in a radial field} \quad g = \frac{GM}{r^2}$$

$$\text{gravitational potential} \quad \Delta W = m\Delta V$$

$$V = -\frac{GM}{r}$$

$$g = -\frac{\Delta V}{\Delta r}$$

ELECTRIC FIELDS AND CAPACITORS

$$\text{force between two point charges} \quad F = \frac{1}{4\pi\epsilon_0} \frac{Q_1 Q_2}{r^2}$$

$$\text{force on a charge} \quad F = EQ$$

$$\text{field strength for a uniform field} \quad E = \frac{V}{d}$$

$$\text{field strength for a radial field} \quad E = \frac{Q}{4\pi\epsilon_0 r^2}$$

electric potential

$$\Delta W = Q\Delta V$$

$$V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r}$$

capacitance

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

decay of charge

$$Q = Q_0 e^{-t/RC}$$

time constant

$$RC$$

capacitor energy stored

$$E = \frac{1}{2} QV = \frac{1}{2} CV^2 = \frac{1}{2} \frac{Q^2}{C}$$

MAGNETIC FIELDS*force on a current*

$$F = BIl$$

force on a moving charge

$$F = BQv$$

magnetic flux

$$\Phi = BA$$

magnetic flux linkage

$$N\Phi = BAN$$

magnitude of induced emf

$$\epsilon = N \frac{\Delta\Phi}{\Delta t}$$

emf induced in a rotating coil

$$N\Phi = BAN \cos \theta$$

$$\epsilon = BAN\omega \sin \omega t$$

transformer equations

$$\frac{N_s}{N_p} = \frac{V_s}{V_p}$$

$$\text{efficiency} = \frac{I_s V_s}{I_p V_p}$$

RADIOACTIVITY AND NUCLEAR PHYSICS*the inverse square law for γ radiation*

$$I = \frac{k}{x^2}$$

radioactive decay

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

activity

$$A = \lambda N$$

half-life

$$T_{1/2} = \frac{\ln 2}{\lambda}$$

nuclear radius

$$R = r_0 A^{1/3}$$

energy-mass equation

$$E = mc^2$$

GASES AND THERMAL PHYSICS*gas law*

$$pV = nRT$$

$$pV = NkT$$

kinetic theory model

$$pV = \frac{1}{3} N m (c_{\text{rms}})^2$$

kinetic energy of gas molecule

$$\frac{1}{2} m (c_{\text{rms}})^2 = \frac{3}{2} kT = \frac{3RT}{2N_A}$$

energy to change temperature

$$Q = mc\Delta T$$

energy to change state

$$Q = ml$$

OPTIONS FORMULAE

ASTROPHYSICS

1 astronomical unit = 1.50×10^{11} m

1 light year = 9.46×10^{15} m

1 parsec = 206265 AU = 3.08×10^{16} m = 3.26 ly

Hubble constant, $H = 65 \text{ km s}^{-1} \text{ Mpc}^{-1}$

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

$$M = \frac{\text{angle subtended by image at eye}}{\text{angle subtended by object at unaided eye}}$$

in normal adjustment $M = \frac{f_0}{f_e}$

resolving power $\theta \approx \frac{\lambda}{D}$

magnitude equation $m - M = 5 \log \frac{d}{10}$

Wien's law $\lambda_{\text{max}} T = 0.0029 \text{ m K}$

Hubble law $v = H d$

Stefan's law $P = \sigma A T^4$

Doppler shift for $v \ll c$ $z = \frac{\Delta f}{f} = -\frac{\Delta \lambda}{\lambda} = \frac{v}{c}$

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

MEDICAL PHYSICS

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

$$m = \frac{v}{u}$$

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

intensity level $\text{intensity level} = 10 \log \frac{I}{I_0}$

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

$$\mu_m = \frac{\mu}{\rho}$$

APPLIED PHYSICS

moment of inertia $I = \Sigma mr^2$

angular kinetic energy $E_k = \frac{1}{2} I \omega^2$

equations of angular motion

$$\omega_2 = \omega_1 + \alpha t$$

$$\omega_2^2 = \omega_1^2 + 2\alpha\theta$$

$$\theta = \omega_1 t + \frac{1}{2} \alpha t^2$$

$$\theta = \frac{1}{2} (\omega_1 + \omega_2) t$$

torque

angular momentum

work done

power

thermodynamics

adiabatic change

isothermal change

heat engines

$$\text{efficiency} = \frac{W}{Q_{\text{in}}} = \frac{Q_{\text{in}} - Q_{\text{out}}}{Q_{\text{in}}}$$

$$\text{maximum efficiency} = \frac{T_H - T_C}{T_H}$$

work done per cycle = area of loop

input power = calorific value $\times$ fuel flow rate

indicated power = (area of p-V loop) $\times$ (no of cycles per second) $\times$ number of cylinders

output of brake power $P = T \omega$

friction power = indicated power – brake power

heat pumps and refrigerators

$$\text{refrigerator: } COP_{\text{ref}} = \frac{Q_{\text{out}}}{W} = \frac{Q_{\text{out}}}{Q_{\text{in}} - Q_{\text{out}}}$$

$$\text{heat pump: } COP_{\text{hp}} = \frac{Q_{\text{in}}}{W} = \frac{Q_{\text{in}}}{Q_{\text{in}} - Q_{\text{out}}}$$

TURNING POINTS IN PHYSICS

electrons in fields $F = \frac{eV}{d}$

$$F = Bev$$

$$r = \frac{mv}{Be}$$

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

$$\frac{QV}{d} = mg$$

$$F = 6\pi \eta r v$$

wave particle duality $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}}$$

special relativity

$$E = mc^2 = \frac{m_0 c^2}{\left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}}$$

$$l = l_0 \left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}} \quad t = t_0 \left(1 - \frac{v^2}{c^2}\right)^{-\frac{1}{2}}$$