Physics A   PHYA4

Unit 4   Fields and Further Mechanics

Data and Formulae Booklet

DATA
FUNDAMENTAL CONSTANTS AND VALUES

Quantity	Symbol	Value	Units
speed of light in vacuo	c	3.00×10^8	m s^{-1}
permeability of free space	μ_o	$4\pi \times 10^{-7}$	H m^{-1}
permittivity of free space	ε_o	8.85×10^{-12}	F m^{-1}
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

ASTRONOMICAL DATA

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

GEOMETRICAL EQUATIONS

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

AS FORMULAE

PARTICLE PHYSICS

Rest energy values

class	name	symbol	rest energy /MeV
photon	photon	γ	0
lepton	neutrino	v_e	0
		v_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: $e^-, v_e ; \mu^-, v_\mu$	+1
antiparticles: $e^+, \overline{v_e} ; \mu^+, \overline{v_\mu}$	−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	$\lambda = \dfrac{h}{p} = \dfrac{h}{mv}$

ELECTRICITY

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

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

resistors in series
$$R = R_1 + R_2 + R_3 + \ldots$$

resistors in parallel
$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

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

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

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

MECHANICS

moments   moment $= Fd$

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

equations of motion
$$v = u + at \qquad s = \frac{(u+v)}{2}t$$
$$v^2 = u^2 + 2as \qquad s = ut + \frac{at^2}{2}$$

force $F = ma$

work, energy and power
$$W = Fs \cos \theta$$
$$E_K = \tfrac{1}{2}mv^2 \qquad \Delta E_P = mg\Delta h$$
$$P = \frac{\Delta W}{\Delta t}, P = Fv$$

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

MATERIALS

density $\qquad \rho = \dfrac{m}{V}$ Hooke's law $\quad F = k\,\Delta L$

Young modulus $= \dfrac{\text{tensile stress}}{\text{tensile strain}}$

$$\text{tensile stress} = \frac{F}{A}$$
$$\text{tensile strain} = \frac{\Delta L}{L}$$

energy stored $\qquad E = \dfrac{1}{2}F\Delta L$

WAVES

wave speed $\quad c = f\lambda \qquad$ *period* $\qquad T = \dfrac{1}{f}$

fringe spacing $\quad w = \dfrac{\lambda D}{s} \qquad$ *diffraction grating* $\quad d \sin \theta = n\lambda$

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

for two different substances of refractive indices n_1 and n_2,

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

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

A2 FORMULAE

MOMENTUM

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

impulse $\quad F \Delta t = \Delta(mv)$

CIRCULAR MOTION

angular velocity $\quad \omega = \dfrac{v}{r}$

$\omega = 2\pi f$

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

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

OSCILLATIONS

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

displacement $\quad x = A \cos(2\pi f\, t)$

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

maximum speed $\quad v_{max} = 2\pi fA$

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

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

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

GRAVITATIONAL FIELDS

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

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

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

gravitational potential $\quad \Delta W = m\Delta V$

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

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

ELECTRIC FIELDS AND CAPACITORS

force between two point charges $\quad F = \dfrac{1}{4\pi\varepsilon_0} \dfrac{Q_1 Q_2}{r^2}$

force on a charge $\quad F = EQ$

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

field strength for a radial field $\quad E = \dfrac{Q}{4\pi\varepsilon_0 r^2}$

electric potential $\quad \Delta W = Q\Delta V$

$V = \dfrac{1}{4\pi\varepsilon_0 r} \dfrac{Q}{r}$

capacitance $\quad C = \dfrac{Q}{V}$

decay of charge $\quad Q = Q_0 e^{-t/RC}$

time constant $\quad RC$

capacitor energy stored $\quad E = \dfrac{1}{2} QV = \dfrac{1}{2} CV^2 = \dfrac{1}{2} \dfrac{Q^2}{C}$

MAGNETIC FIELDS

force on a current $\quad F = BIl$

force on a moving charge $\quad F = BQv$

magnetic flux $\quad \Phi = BA$

magnetic flux linkage $\quad N\Phi = BAN$

magnitude of induced emf $\quad \varepsilon = N \dfrac{\Delta \Phi}{\Delta t}$

emf induced in a rotating coil $\quad N\Phi = BAN \cos\theta$
$\varepsilon = BAN\omega \sin \omega t$

transformer equations $\quad \dfrac{N_s}{N_p} = \dfrac{V_s}{V_p}$

efficiency $= \dfrac{I_s V_s}{I_p V_p}$

RADIOACTIVITY AND NUCLEAR PHYSICS

the inverse square law for γ radiation $\quad I = \dfrac{k}{x^2}$

radioactive decay $\quad \dfrac{\Delta N}{\Delta t} = -\lambda N, \; N = N_o e^{-\lambda t}$

activity $\quad A = \lambda N$

half-life $\quad T_{\frac{1}{2}} = \dfrac{\ln 2}{\lambda}$

nuclear radius $\quad R = r_0 A^{1/3}$

energy-mass equation $\quad E = m c^2$

GASES AND THERMAL PHYSICS

gas law $\quad pV = n R T$

$pV = N k T$

kinetic theory model $\quad pV = \dfrac{1}{3} N m\, (c_{rms})^2$

kinetic energy of gas molecule $\quad \dfrac{1}{2} m\, (c_{rms})^2 = \dfrac{3}{2} kT = \dfrac{3RT}{2 N_A}$

energy to change temperature $\quad Q = mc\Delta T$

energy to change state $\quad Q = m l$

Turn over ▶

OPTIONS FORMULAE

ASTROPHYSICS

1 astronomical unit $= 1.50 \times 10^{11}$ m

1 light year $= 9.46 \times 10^{15}$ m

1 parsec $= 206265$ AU $= 3.08 \times 10^{16}$ m $= 3.261$yr

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

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

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

in normal adjustment $\qquad M = \dfrac{f_0}{f_e}$

resolving power $\qquad \theta \approx \dfrac{\lambda}{D}$

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

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

Hubble law $\qquad v = H\,d$

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

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

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

MEDICAL PHYSICS

lens equations $\qquad P = \dfrac{1}{f}$

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

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

intensity level $\qquad$ intensity level $= 10 \log \dfrac{I}{I_0}$

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

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

APPLIED PHYSICS

moment of inertia $\qquad I = \Sigma m r^2$

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

equations of angular motion

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

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

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

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

torque $\qquad T = I\,\alpha$

angular momentum $\qquad$ angular momentum $= I\omega$

work done $\qquad W = T\theta$

power $\qquad P = T\omega$

thermodynamics $\qquad Q = \Delta U + W$

$\qquad W = p\Delta V$

adiabatic change $\qquad pV^{\gamma} = $ constant

isothermal change $\qquad pV = $ constant

heat engines

efficiency $= \dfrac{W}{Q_{in}} = \dfrac{Q_{in} - Q_{out}}{Q_{in}}$

maximum efficiency $= \dfrac{T_H - T_C}{T_H}$

work done per cycle = area of loop

input power = calorific value × fuel flow rate

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

output of brake power $P = T\,\omega$

friction power = indicated power – brake power

heat pumps and refrigerators

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

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

TURNING POINTS IN PHYSICS

electrons in fields $\qquad F = \dfrac{eV}{d}$

$F = Bev$

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

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

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

$F = 6\pi \eta r v$

wave particle duality $\qquad c = \dfrac{1}{\sqrt{\mu_0\,\varepsilon_0}}$

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

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

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