General Certificate of Education
Advanced Level Examination
January 2011

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}	$\mathrm{m\ s^{-1}}$
permeability of free space	μ_o	$4\pi \times 10^{-7}$	$\mathrm{H\ m^{-1}}$
permittivity of free space	ε_o	8.85×10^{-12}	$\mathrm{F\ m^{-1}}$
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}	$\mathrm{N\ m^{2}\ kg^{-2}}$
the Avogadro constant	N_A	6.02×10^{23}	$\mathrm{mol^{-1}}$
molar gas constant	R	8.31	$\mathrm{J\ K^{-1}\ mol^{-1}}$
the Boltzmann constant	k	1.38×10^{-23}	$\mathrm{J\ K^{-1}}$
the Stefan constant	σ	5.67×10^{-8}	$\mathrm{W\ m^{-2}\ K^{-4}}$
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}	$\mathrm{C\ kg^{-1}}$
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}	$\mathrm{C\ kg^{-1}}$
neutron rest mass (equivalent to 1.00867 u)	m_n	$1.67(5) \times 10^{-27}$	kg
gravitational field strength	g	9.81	$\mathrm{N\ kg^{-1}}$
acceleration due to gravity	g	9.81	$\mathrm{m\ s^{-2}}$
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	$= \frac{4}{3}\pi r^3$

This insert page should **not** be sent to the examiner

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^-, ν_e ; μ^-, ν_μ	+1
antiparticles: e^+, $\overline{\nu_e}$; μ^+, $\overline{\nu_\mu}$	–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

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

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

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

MECHANICS

moments moment = Fd

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

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

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

force $F = ma$

work, energy and power $W = Fs\cos\theta$

$E_K = ½ m v^2$ $\Delta E_P = mg\Delta h$

$P = \frac{\Delta W}{\Delta t}$, $P = Fv$

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

MATERIALS

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

Young modulus = $\frac{\text{tensile stress}}{\text{tensile strain}}$ tensile stress = $\frac{F}{A}$

tensile strain = $\frac{\Delta L}{L}$

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

WAVES

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

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

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

for two different substances of refractive indices n_1 and n_2,

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

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

A2 FORMULAE

MOMENTUM

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

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

CIRCULAR MOTION

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

$\omega = 2\pi f$

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

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

OSCILLATIONS

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

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

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

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

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

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

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

GRAVITATIONAL FIELDS

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

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

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

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

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

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

ELECTRIC FIELDS AND CAPACITORS

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

force on a charge $F = EQ$

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

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

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

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

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

emf induced in a rotating coil $N\Phi = BAN\cos\theta$

$\varepsilon = BAN\omega\sin\omega t$

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

activity $A = \lambda N$

half-life $T_{½} = \frac{\ln 2}{\lambda}$

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 $pV = \frac{1}{3}Nm(c_{rms})^2$

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

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 = 3.261yr

Hubble constant, H = 65 km s^{-1} 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 $\lambda_{max} T = 0.0029$ m K

Hubble law $v = H d$

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

Doppler shift for v << 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 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 $I = \Sigma m r^2$

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

equations of angular motion

$\omega_2 = \omega_1 + \alpha t$

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

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

$\theta = ½ (\omega_1 + \omega_2) t$

torque $T = I \alpha$

angular momentum angular momentum = $I\omega$

work done $W = T\theta$

power $P = T\omega$

thermodynamics $Q = \Delta U + W$

$W = p\Delta V$

adiabatic change pV^γ = constant

isothermal change pV = constant

heat engines

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

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

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

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

TURNING POINTS IN PHYSICS

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

$F = Bev$

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

$½ mv^2 = eV$

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

$F = 6\pi \eta r v$

wave particle duality $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$

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

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

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