

A



A-level

Physics data and formulae

For use in exams from the June 2017 Series onwards

[Turn over]

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_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}

QUANTITY	SYMBOL	VALUE	UNITS
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
magnitude of electron charge/mass ratio	$\frac{e}{m_e}$	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	$\frac{e}{m_p}$	9.58×10^7	C kg^{-1}
neutron rest mass (equivalent to 1.00867 u)	m_n	$1.67 (5) \times 10^{-27}$	kg

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QUANTITY	SYMBOL	VALUE	UNITS
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 931.5 MeV)	u	1.661×10^{-27}	kg

ALGEBRAIC EQUATION

quadratic equation $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

ASTRONOMICAL DATA

BODY	MASS/kg	MEAN RADIUS/m
Sun	1.99×10^{30}	6.96×10^8
Earth	5.97×10^{24}	6.37×10^6

GEOMETRICAL EQUATIONS

arc length $= r\theta$

circumference of circle $= 2\pi r$

area of circle $= \pi r^2$

curved surface area of cylinder $= 2\pi rh$

area of sphere $= 4\pi r^2$

volume of sphere $= \frac{4}{3} \pi r^3$

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PARTICLE PHYSICS

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

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PHOTONS AND ENERGY LEVELS

photon energy $E = hf = \frac{hc}{\lambda}$

photoelectricity $hf = \phi + E_{\text{k (max)}}$

energy levels $hf = E_1 - E_2$

de Broglie wavelength $\lambda = \frac{h}{p} = \frac{h}{mv}$

WAVES

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

first harmonic $f = \frac{1}{2l} \sqrt{\frac{T}{\mu}}$

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 $n_1 > n_2$

[Turn over]

MECHANICS**moments**

$$\text{moment} = Fd$$

velocity and acceleration

$$v = \frac{\Delta s}{\Delta t}$$

$$a = \frac{\Delta v}{\Delta t}$$

equations of motion

$$v = u + at$$

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

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

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

force

$$F = ma$$

force

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

impulse

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

work, energy and power

$$W = F s \cos \theta$$

$$E_k = \frac{1}{2} m v^2$$

$$\Delta E_p = mg \Delta h$$

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

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

MATERIALS

density $\rho = \frac{m}{V}$

Hooke's law $F = k \Delta L$

Young modulus $= \frac{\textit{tensile stress}}{\textit{tensile strain}}$

tensile stress $= \frac{F}{A}$

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

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

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ELECTRICITY

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

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

resistors in series $R_T = R_1 + R_2 + R_3 + \dots$

resistors in parallel $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$

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

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

CIRCULAR MOTION

magnitude of angular speed $\omega = \frac{v}{r}$

$$\omega = 2\pi f$$

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

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

SIMPLE HARMONIC MOTION

acceleration $a = -\omega^2 x$

displacement $x = A \cos(\omega t)$

speed $v = \pm \omega \sqrt{(A^2 - x^2)}$

maximum speed $v_{\max} = \omega A$

maximum acceleration $a_{\max} = \omega^2 A$

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

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

[Turn over]

THERMAL PHYSICS**energy to change temperature**

$$Q = mc\Delta\theta$$

energy to change state

$$Q = ml$$

gas law

$$pV = nRT$$

$$pV = NkT$$

kinetic theory model

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

kinetic energy of gas molecule

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

GRAVITATIONAL FIELDS**force between two masses**

$$F = \frac{Gm_1 m_2}{r^2}$$

gravitational field strength

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

magnitude of gravitational field strength in a radial field

$$g = \frac{GM}{r^2}$$

work done

$$\Delta W = m\Delta V$$

gravitational potential

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

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

[Turn over]

ELECTRIC FIELDS AND CAPACITORS**force between two point charges**

$$F = \frac{1}{4 \pi \epsilon_0} \frac{Q_1 Q_2}{r^2}$$

force on a charge

$$F = E Q$$

field strength for a uniform field

$$E = \frac{V}{d}$$

work done

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

field strength for a radial field

$$E = \frac{1}{4 \pi \epsilon_0} \frac{Q}{r^2}$$

electric potential

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

field strength

$$E = \frac{\Delta V}{\Delta r}$$

capacitance

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

$$C = \frac{A \epsilon_0 \epsilon_r}{d}$$

capacitor energy stored

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

capacitor charging

$$Q = Q_0 (1 - e^{-\frac{t}{RC}})$$

decay of charge

$$Q = Q_0 e^{-\frac{t}{RC}}$$

time constant

$$RC$$

MAGNETIC FIELDS

force on a current $F = BIl$

force on a moving charge $F = BQv$

magnetic flux $\Phi = BA$

magnetic flux linkage $N\Phi = BAN \cos \theta$

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

$N\Phi = BAN \cos \theta$

emf induced in a rotating coil $\varepsilon = BAN\omega \sin \omega t$

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

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

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

[Turn over]

NUCLEAR PHYSICS

**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**

$$E = mc^2$$

OPTIONS**ASTROPHYSICS**

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

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

$$1 \text{ parsec} = 2.06 \times 10^5 \text{ AU} = 3.08 \times 10^{16} \text{ m} = 3.26 \text{ ly}$$

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

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

telescope in normal adjustment	$M = \frac{f_o}{f_e}$
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Rayleigh criterion	$\theta \approx \frac{\lambda}{D}$
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magnitude equation	$m - M = 5 \log \frac{d}{10}$
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Wien's law	$\lambda_{\text{max}} T = 2.9 \times 10^{-3} \text{ m K}$
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Stefan's law	$P = \sigma A T^4$
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[Turn over]

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

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

red shift $z = - \frac{v}{c}$

Hubble's law $v = Hd$

MEDICAL PHYSICS**lens equations**

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

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

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

threshold of hearing

$$I_0 = 1.0 \times 10^{-12} \text{ W m}^{-2}$$

intensity level

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

absorption

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

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

ultrasound imaging

$$Z = p c$$

$$\frac{I_r}{I_i} = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1} \right)^2$$

half-lives

$$\frac{1}{T_E} = \frac{1}{T_B} + \frac{1}{T_P}$$

[Turn over]

ENGINEERING PHYSICS

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

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

equations of angular motion

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

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

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

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

torque $T = I \alpha$

$$T = F r$$

angular momentum angular momentum = $I \omega$

angular impulse $T \Delta t = \Delta(I \omega)$

work done $W = T \theta$

power $P = T \omega$

thermodynamics $Q = \Delta U + W$

$$W = p \Delta V$$

adiabatic change $p V^\gamma = \text{constant}$

isothermal change $p V = \text{constant}$

heat engines

$$\text{efficiency} = \frac{W}{Q_H} = \frac{Q_H - Q_C}{Q_H}$$

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

work done per cycle = area of loop

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

indicated power = (area of $p - V$ loop)
 $\times$ (number of cycles per second)
 $\times$ (number of cylinders)

output or brake power $P = T \omega$

friction power = indicated power $-$ brake power

heat pumps and refrigerators

$$\text{refrigerator: } COP_{\text{ref}} = \frac{Q_C}{W} = \frac{Q_C}{Q_H - Q_C}$$

$$\text{heat pump: } COP_{\text{hp}} = \frac{Q_H}{W} = \frac{Q_H}{Q_H - Q_C}$$

[Turn over]

TURNING POINTS IN PHYSICS

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

$$F = Bev$$

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

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

Millikan's experiment $\frac{QV}{d} = mg$

$$F = 6\pi\eta rv$$

Maxwell's formula $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$

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

special relativity

$$t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$I = I_0 \sqrt{1 - \frac{v^2}{c^2}}$$

$$E = m c^2 = \frac{m_0 c^2}{\sqrt{1 - \frac{v^2}{c^2}}}$$

ELECTRONICS

resonant
frequency

$$f_0 = \frac{1}{2\pi \sqrt{LC}}$$

Q-factor

$$Q = \frac{f_0}{f_B}$$

operational
amplifiers: open
loop

$$V_{\text{out}} = A_{\text{OL}} (V_+ - V_-)$$

inverting amplifier

$$\frac{V_{\text{out}}}{V_{\text{in}}} = - \frac{R_f}{R_{\text{in}}}$$

non-inverting
amplifier

$$\frac{V_{\text{out}}}{V_{\text{in}}} = 1 + \frac{R_f}{R_1}$$

[Turn over]

**summing
amplifier**

$$V_{\text{out}} = -R_f \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \dots \right)$$

**difference
amplifier**

$$V_{\text{out}} = (V_+ - V_-) \frac{R_f}{R_1}$$

Bandwidth requirement:

for AM *bandwidth* = $2 f_M$

for FM *bandwidth* = $2(\Delta f + f_M)$

END OF DATA SHEET

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IB/M/CH/Jun22/7408/INS/E1