



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}
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

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QUANTITY	SYMBOL	VALUE	UNITS
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
gravitational field strength	g	9.81	N kg^{-1}
acceleration due to gravity	g	9.81	m s^{-2}
atomic mass unit (1 u is equivalent to 931.5 MeV)	u	1.661×10^{-27}	kg

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ALGEBRAIC EQUATION

quadratic equation

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

ASTRONOMICAL DATA

BODY	MASS/kg	MEAN RADIUS/m	6
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

$$= 2\pi rh$$

surface area of sphere

$$= 4\pi r^2$$

volume of sphere

$$= \frac{4}{3}\pi r^3$$

[Turn over]

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[±]	493.821
		K⁰	497.762
baryons	proton	p	938.257
	neutron	n	939.551

[Turn over]

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

[Turn over]

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

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

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[Turn over]

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

$$d \sin \theta = n\lambda$$

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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**

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

$$E_k = \frac{1}{2} m v^2 \quad \Delta E_p = mg \Delta h$$

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

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

[Turn over]

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

ELECTRICITY

current and pd

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

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

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

emf

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

[Turn over]

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

$$pV = nRT$$

$$pV = NkT$$

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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

$$F = \frac{1}{4 \pi \varepsilon_0} \frac{Q_1 Q_2}{r^2}$$

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

$$E = \frac{1}{4 \pi \varepsilon_0} \frac{Q}{r^2}$$

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**

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

[Turn over]

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

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

time constant RC

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[Turn over]

MAGNETIC FIELDS

force on a current

$$F = BIl$$

force on a moving charge

$$F = BQv$$

magnetic flux

$$\Phi = BA$$

magnetic flux linkage

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

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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

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

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

[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

$$A = \lambda N$$

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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 astronomical unit = 1.50×10^{11} m

1 light year = 9.46×10^{15} m

1 parsec = 2.06×10^5 AU = 3.08×10^{16} m = 3.26 ly

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

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

[Turn over]

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

Rayleigh criterion $\theta \approx \frac{\lambda}{D}$

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

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Wien's law $\lambda_{\text{max}} T = 2.9 \times 10^{-3} \text{ m K}$

Stefan's law $P = \sigma AT^4$

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

$$v = Hd$$

[Turn over]

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

$$I=I_0e^{-\mu x}$$

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

ultrasound imaging

$$Z=pc$$

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

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

$$\boldsymbol{T} = I \boldsymbol{\alpha}$$

$$\boldsymbol{T} = \boldsymbol{F} \boldsymbol{r}$$

angular momentum

$$\text{angular momentum} = I \boldsymbol{\omega}$$

angular impulse

$$\boldsymbol{T} \Delta t = \Delta(I \boldsymbol{\omega})$$

work done

$$\boldsymbol{W} = \boldsymbol{T} \boldsymbol{\theta}$$

power

$$\boldsymbol{P} = \boldsymbol{T} \boldsymbol{\omega}$$

thermodynamics

$$\boldsymbol{Q} = \Delta \boldsymbol{U} + \boldsymbol{W}$$

$$\boldsymbol{W} = p \Delta \boldsymbol{V}$$

adiabatic change

$$p \boldsymbol{V}^\gamma = \text{constant}$$

isothermal change

$$p \boldsymbol{V} = \text{constant}$$

[Turn over]

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 × fuel flow rate

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

output or brake power $P = T \omega$

friction power = indicated power — brake power

heat pumps and refrigerators

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

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

$$F = \frac{eV}{d}$$

$$F = Bev$$

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

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

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Millikan's experiment

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

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

Maxwell's formula

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$

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

[Turn over]

special relativity

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

$$l = l_0 \sqrt{1 - \frac{v^2}{c^2}}$$

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

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

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

[Turn over]

**non-inverting
amplifier**

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

summing amplifier

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

difference amplifier

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

Bandwidth requirement:

for AM bandwidth = $2 f_M$

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

END OF DATA SHEET

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