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}	$\mathrm{m\ s^{-1}}$
permeability of free space	μ_0	$4\pi \times 10^{-7}$	$\mathrm{H\ m^{-1}}$
permittivity of free space	ε_0	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	$\mathrm{JK^{-1}\,mol^{-1}}$
the Boltzmann constant	k	1.38×10^{-23}	$\mathrm{JK^{-1}}$
the Stefan constant	σ	5.67×10^{-8}	$\mathrm{Wm^{-2}\,K^{-4}}$
the Wien constant	α	2.90×10^{-3}	$\mathrm{m\,K}$

[Turn over]

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

[Turn over]

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

[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	$K^{\pm}$	493.821
		K^{0}	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^-, ν_e ; μ^-, ν_μ	+ 1
Antiparticles:	e^+, $\overline{\nu_e}$, μ^+, $\overline{\nu_\mu}$	− 1

[Turn over]

PHOTONS AND ENERGY LEVELS

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

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

energy levels $hf = E_1 - E_2$

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

BLANK PAGE

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

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

$$moment = Fd$$

velocity and acceleration

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

equations of motion

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

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

force

$$F = ma$$

force

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

impulse

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

work, energy and power

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

$$E_{\mathrm{k}} = \frac{1}{2} m v^2 \qquad \Delta E_p = mg \Delta h$$

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

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

[Turn over]

MATERIALS

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

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

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

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

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

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

ELECTRICITY

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

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

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

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

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

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

[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	$pV = nRT$
	$pV = NkT$
kinetic theory model	$pV = \frac{1}{3}Nm\,(c_{\mathrm{rms}})^2$
kinetic energy of gas molecule	$\frac{1}{2}m\,(c_{\mathrm{rms}})^2 = \frac{3}{2}kT = \frac{3RT}{2N_{\mathrm{A}}}$

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

$$F = EQ$$

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	$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$$
field strength	$$E = \frac{\Delta V}{\Delta r}$$
capacitance	$$C = \frac{Q}{V}$$
	$$C = \frac{A\varepsilon_0\varepsilon_r}{d}$$
capacitor energy stored	$$E = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$$

[Turn over]

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

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

time constant RC

BLANK PAGE

[Turn over]

MAGNETIC FIELDS

force on a current	$F = BIl$
force on a moving charge	$F = BQv$
magnetic flux	$\Phi = BA$
magnetic flux linkage	$N\Phi = BAN\cos\theta$
magnitude of induced emf	$\varepsilon = N\dfrac{\Delta\Phi}{\Delta t}$
	$N\Phi = BAN\cos\theta$
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 astronomical unit $= 1.50 \times 10^{11}\,\mathrm{m}$

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

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

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

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

[Turn over]

telescope in normal adjustment	$M = \frac{f_0}{f_e}$
Rayleigh criterion	$\theta \approx \frac{\lambda}{D}$
magnitude equation	$m - M = 5 \log \frac{d}{10}$
Wien's law	$\lambda_{max} T = 2.9 \times 10^{-3}\ \mathrm{m\ K}$
Stefan's law	$P = \sigma A T^4$

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

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

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

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]

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

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

equations of angular motion

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

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

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

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

Torque	$T = I\alpha$
	$T = Fr$
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	pV^{γ} = constant
isothermal change	pV = constant

[Turn over]

heat engines

$$\text{efficiency} = \frac{W}{Q_{\mathrm{H}}} = \frac{Q_{\mathrm{H}} - Q_{\mathrm{C}}}{Q_{\mathrm{H}}}$$

$$\text{maximum theoretical efficiency} = \frac{T_{\mathrm{H}} - T_{\mathrm{C}}}{T_{\mathrm{H}}}$$

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: $COP_{\text{ref}} = \dfrac{Q_{\text{C}}}{W} = \dfrac{Q_{\text{C}}}{Q_{\text{H}} - Q_{\text{C}}}$

heat pump: $COP_{\text{hp}} = \dfrac{Q_{\text{H}}}{W} = \dfrac{Q_{\text{H}}}{Q_{\text{H}} - Q_{\text{C}}}$

[Turn over]

TURNING POINTS IN PHYSICS

electrons in fields

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

$$F = Bev$$

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

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

Millikan's experiment

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

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

Maxwell's formula $$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

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

[Turn over]

special relativity

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

$$l = l0 \sqrt{1 - \frac{v^2}{c^2}}$$

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

ELECTRONICS

resonant frequency

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

Q-factor

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

operational amplifiers: open loop

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

inverting amplifier

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

[Turn over]

non-inverting amplifier

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

summing amplifier

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

difference amplifier

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

Bandwidth requirement:

$$for\ AM \qquad bandwidth = 2 f_M$$

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

END OF DATA SHEET

BLANK PAGE

Copyright Information

For confidentiality purposes, from the November 2015 examination series, acknowledgements of third party copyright material will be published in a separate booklet rather than including them on the examination paper or support materials. This booklet is published after each examination series and is available for free download from www.aqa.org.uk after the live examination series.

Permission to reproduce all copyright material has been applied for. In some cases, efforts to contact copyright-holders may have been unsuccessful and AQA will be happy to rectify any omissions of acknowledgements. If you have any queries please contact the Copyright Team, AQA, Stag Hill House, Guildford, GU2 7XJ.

Copyright © 2019 AQA and its licensors. All rights reserved.