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	$\mathrm{J K^{-1}\,mol^{-1}}$
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}	$\mathrm{m\,K}$

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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
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

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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**

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PHOTONS AND ENERGY LEVELS

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

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

energy levels $$hf = E_1 - E_2$$

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

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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 $\sin \theta_c = \dfrac{n_2}{n_1}$ 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 $$v = u + a\,t \qquad s = \left(\frac{u + v}{2}\right) t$$

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

force $$F = m\,a$$

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

impulse

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

work, energy and power

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

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

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

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

[Turn over]

MATERIALS

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

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

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

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

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

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

$$R_{\mathrm{T}} = R_1 + R_2 + R_3 + \ldots$$

resistors in parallel

$$\frac{1}{R_{\mathrm{T}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

power

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

emf

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

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

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

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

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

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

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

$$C = \frac{A\varepsilon_0\,\varepsilon_r}{d}$$

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

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

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

time constant RC

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

transformer equations $\frac{N_{\text{s}}}{N_{\text{p}}} = \frac{V_{\text{s}}}{V_{\text{p}}}$

$$efficiency = \frac{I_{\text{s}}\, V_{\text{s}}}{I_{\text{p}}\, V_{\text{p}}}$$

[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	$T_{½} = \frac{\ln 2}{\lambda}$
nuclear radius	$R = R_0 A^{1/3}$
energy-mass equation	$E = mc^2$

OPTIONS

ASTROPHYSICS

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

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

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

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

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

[Turn over]

telescope in normal adjustment $M = \frac{f_0}{f_\mathrm{e}}$

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

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

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

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

Schwarzschild radius $R_S \approx \dfrac{2GM}{c^2}$

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

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

Hubble's law $v = Hd$

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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]

ENGINEERING PHYSICS

moment of inertia

$$I = \Sigma m r^2$$

angular kinetic energy

$$E_{\mathrm{k}} = \frac{1}{2} I \omega^2$$

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

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

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

[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 $$c = \frac{1}{\sqrt{\mu_0 \, \varepsilon_0}}$$

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

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special relativity

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

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

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

ELECTRONICS

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

***Q*-factor** $$Q = \frac{f_0}{f_B}$$

operational amplifiers: open loop $$V_{out} = A_{OL}(V_+ - V_-)$$

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

[Turn over]

non-inverting amplifier

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

summing amplifier

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

difference amplifier

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

Bandwidth requirement:

for AM $\quad bandwidth = 2 f_M$

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

END OF DATA SHEET

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