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}	$\mathrm{J\ s}$
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}	$\mathrm{m\ K}$
electron rest mass (equivalent to 5.5×10^{-4} u)	m_{e}	9.11×10^{-31}	kg

electron charge/mass ratio	$\frac{e}{m_\mathrm{e}}$	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	$\frac{e}{m_\mathrm{p}}$	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 931.5 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 $= \frac{4}{3}\pi r^3$

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:	$e^-, \nu_e ; \mu^-, \nu_\mu$	$+1$
Antiparticles:	$e^+, \overline{\nu_e}, \mu^+, \overline{\nu_\mu}$	-1

PHOTONS AND ENERGY LEVELS

photon energy	$E = hf = \dfrac{hc}{\lambda}$
photoelectricity	$hf = \phi + E_{k\,(max)}$
energy levels	$hf = E_1 - E_2$
de Broglie wavelength	$\lambda = \dfrac{h}{p} = \dfrac{h}{mv}$

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

MECHANICS

moments	moment = Fd	
velocity and acceleration	$v = \frac{\Delta s}{\Delta t}$	$a = \frac{\Delta v}{\Delta t}$
equations of motion	$v = u + at$	$s = \left(\frac{u+v}{2}\right) t$
	$v^2 = u^2 + 2as$	$s = ut + \frac{at^2}{2}$
force	$F = ma$	
force	$F = \frac{\Delta(mv)}{\Delta t}$	
impulse	$F\,\Delta t = \Delta(mv)$	
work, energy and power	$W = F\,s\cos\theta$	
	$E_k = \frac{1}{2}\,m\,v^2$	$\Delta E_p = mg\Delta h$
	$P = \frac{\Delta W}{\Delta t}$, $P = Fv$	
	efficiency = $\frac{\text{useful output power}}{\text{input power}}$	

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

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

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

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

$$v_{\mathrm{max}} = \omega A$$

maximum acceleration

$$a_{\mathrm{max}} = \omega^2 A$$

for a mass-spring system

$$T = 2\pi\sqrt{\frac{m}{k}}$$

for a simple pendulum

$$T = 2\pi\sqrt{\frac{l}{g}}$$

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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	$F = \frac{Gm_1m_2}{r^2}$
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	$V = -\frac{GM}{r}$ $g = -\frac{\Delta V}{\Delta r}$

ELECTRIC FIELDS AND CAPACITORS

force between two point charges	$F = \dfrac{1}{4\pi\varepsilon_0} \dfrac{Q_1Q_2}{r^2}$
force on a charge	$F = EQ$
field strength for a uniform field	$E = \dfrac{V}{d}$
work done	$\Delta W = Q\Delta V$
field strength for a radial field	$E = \dfrac{1}{4\pi\varepsilon_0} \dfrac{Q}{r^2}$
electric potential	$V = \dfrac{1}{4\pi\varepsilon_0} \dfrac{Q}{r}$
field strength	$E = \dfrac{\Delta V}{\Delta r}$
capacitance	$C = \dfrac{Q}{V}$
	$C = \dfrac{A\varepsilon_0\varepsilon_{\mathrm{r}}}{d}$
capacitor energy stored	$E = \dfrac{1}{2}QV = \dfrac{1}{2}CV^2 = \dfrac{1}{2}\dfrac{Q^2}{C}$

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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	$I_{\mathrm{rms}} = \frac{I_0}{\sqrt{2}}$ $V_{\mathrm{rms}} = \frac{V_0}{\sqrt{2}}$
transformer equations	$\frac{N_{\mathrm{s}}}{N_{\mathrm{p}}} = \frac{V_{\mathrm{s}}}{V_{\mathrm{p}}}$
	efficiency $= \frac{I_{\mathrm{s}}V_{\mathrm{s}}}{I_{\mathrm{p}}V_{\mathrm{p}}}$

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	$E = mc^2$

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

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

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

Rayleigh criterion $\quad \theta \approx \dfrac{\lambda}{D}$

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

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

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

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

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	$v = Hd$

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

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

ENGINEERING PHYSICS

moment of inertia	$I = \Sigma mr^2$
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	$pV^{\gamma} =$ 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

$$\text{refrigerator: } COP_{\mathrm{ref}} = \frac{Q_{\mathrm{C}}}{W} = \frac{Q_{\mathrm{C}}}{Q_{\mathrm{H}} - Q_{\mathrm{C}}}$$

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

TURNING POINTS IN PHYSICS

electrons in fields

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

$$\boldsymbol{F = Bev}$$

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

$$\boldsymbol{½\, mv^2 = eV}$$

Millikan's experiment

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

$$\boldsymbol{F = 6\pi\eta r v}$$

Maxwell's formula

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

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

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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

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

non-inverting amplifier $$\frac{V_{\mathrm{out}}}{V_{\mathrm{in}}} = 1 + \frac{R_{\mathrm{f}}}{R_1}$$

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

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

Bandwidth requirement:

for AM bandwidth = $2f_{\mathrm{M}}$

for FM bandwidth = $2(\Delta f + f_{\mathrm{M}})$

END OF FORMULAE

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