A-level Physics data and formulae

For use in exams from the June 2017 Series onwards

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}	m K
electron rest mass (equivalent to 5.5×10^{-4} u)	m_e	9.11×10^{-31}	kg
electron charge/mass ratio	$\frac{e}{m_e}$	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	$\frac{e}{m_p}$	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

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

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

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

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 $n_1 > n_2$

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 $W = F s \cos\theta$

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

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

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

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	$I = \frac{\Delta Q}{\Delta t}$ $\quad V = \frac{W}{Q}$ $\quad R = \frac{V}{I}$
resistivity	$\rho = \frac{RA}{L}$
resistors in series	$R_{\mathrm{T}} = R_1 + R_2 + R_3 + \ldots$
resistors in parallel	$\frac{1}{R_{\mathrm{T}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$
power	$P = VI = I^2R = \frac{V^2}{R}$
emf	$\varepsilon = \frac{E}{Q}$ $\qquad \varepsilon = I(R + r)$

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	$v_{\max} = \omega A$
maximum acceleration	$a_{\max} = \omega^2 A$
for a mass-spring system	$T = 2\pi\sqrt{\frac{m}{k}}$
for a simple pendulum	$T = 2\pi\sqrt{\frac{l}{g}}$

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	$F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}$
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	$C = \frac{Q}{V}$
	$C = \frac{A\varepsilon_0\varepsilon_{\mathrm{r}}}{d}$
capacitor energy stored	$E = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$
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

AQA

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	$I_{\text{rms}} = \dfrac{I_0}{\sqrt{2}} \quad V_{\text{rms}} = \dfrac{V_0}{\sqrt{2}}$
transformer equations	$\dfrac{N_s}{N_p} = \dfrac{V_s}{V_p}$
	efficiency $= \dfrac{I_s V_s}{I_p V_p}$

Nuclear physics

inverse square law for γ radiation	$I = \dfrac{k}{x^2}$
radioactive decay	$\dfrac{\Delta N}{\Delta t} = -\lambda N, N = N_0 e^{-\lambda t}$
activity	$A = \lambda N$
half-life	$T_{½} = \dfrac{\ln 2}{\lambda}$
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, $H = 65$ km s^{-1} Mpc^{-1}

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

telescope in normal adjustment	$M = \dfrac{f_0}{f_e}$
Rayleigh criterion	$\theta \approx \dfrac{\lambda}{D}$
magnitude equation	$m - M = 5\log\dfrac{d}{10}$
Wien's law	$\lambda_{\max} T = 2.9 \times 10^{-3}$ 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	$v = Hd$

Medical physics

lens equations	$P = \dfrac{1}{f}$
	$m = \dfrac{v}{u}$
	$\dfrac{1}{f} = \dfrac{1}{u} + \dfrac{1}{v}$
threshold of hearing	$I_0 = 1.0 \times 10^{-12}$ W m^{-2}
intensity level	*intensity level* $= 10\log\dfrac{I}{I_0}$
absorption	$I = I_0 e^{-\mu x}$
	$\mu_m = \dfrac{\mu}{\rho}$
ultrasound imaging	$Z = \rho c$
	$\dfrac{I_r}{I_i} = \left(\dfrac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2$
half-lives	$\dfrac{1}{T_E} = \dfrac{1}{T_B} + \dfrac{1}{T_P}$

Engineering physics

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 $T = I\,\alpha$

$T = F\,r$

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

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 $pV^\gamma = \text{constant}$

isothermal change $pV = \text{constant}$

heat engines

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

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

output or brake power $P = T\omega$

friction power = indicated power – brake power

heat pumps and refrigerators

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

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

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

$F = 6\pi\eta r v$

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

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

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

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

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

Bandwidth requirement:

for AM $bandwidth = 2f_M$

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