AQA 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	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
electron rest mass (equivalent to 5.5×10^{-4} u)	m_e	9.11×10^{-31}	kg
magnitude of electron charge/mass ratio	$\dfrac{e}{m_e}$	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	$\dfrac{e}{m_p}$	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 (1u is equivalent to 931.5 MeV)	u	1.661×10^{-27}	kg

ALGEBRAIC EQUATION

quadratic equation $\qquad x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

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

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 $\qquad E = hf = \dfrac{hc}{\lambda}$

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

energy levels $\qquad hf = E_1 - E_2$

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

Waves

wave speed $\quad c = f\lambda \qquad$ *period* $\qquad f = \dfrac{1}{T}$

first harmonic $\quad f = \dfrac{1}{2l}\sqrt{\dfrac{T}{\mu}}$

fringe spacing $\quad w = \dfrac{\lambda D}{s} \qquad$ *diffraction grating* $\quad d\sin\theta = n\lambda$

refractive index of a substance s, $\; n = \dfrac{c}{c_s}$

for two different substances of refractive indices n_1 and n_2,

law of refraction $\quad n_1\sin\theta_1 = n_2\sin\theta_2$

critical angle $\quad \sin\theta_c = \dfrac{n_2}{n_1}$ *for* $n_1 > n_2$

Mechanics

moments $\qquad$ $\text{moment} = Fd$

velocity and acceleration $\qquad v = \dfrac{\Delta s}{\Delta t} \qquad a = \dfrac{\Delta v}{\Delta t}$

equations of motion $\qquad v = u + at \qquad s = \left(\dfrac{u+v}{2}\right)t$

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

force $\qquad F = ma$

force $\qquad F = \dfrac{\Delta(mv)}{\Delta t}$

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

work, energy and power $\qquad W = F\,s\cos\theta$

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

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

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

Materials

density $\quad \rho = \dfrac{m}{V} \qquad$ *Hooke's law* $\quad F = k\,\Delta L$

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

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

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

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

Electricity

current and pd	$I = \dfrac{\Delta Q}{\Delta t} \qquad V = \dfrac{W}{Q} \qquad R = \dfrac{V}{I}$
resistivity	$\rho = \dfrac{RA}{L}$
resistors in series	$R_T = R_1 + R_2 + R_3 + ...$
resistors in parallel	$\dfrac{1}{R_T} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} + \cdots$
power	$P = VI = I^2R = \dfrac{V^2}{R}$
emf	$\varepsilon = \dfrac{E}{Q} \qquad \varepsilon = I(R + r)$

Circular motion

magnitude of angular speed	$\omega = \dfrac{v}{r}$
	$\omega = 2\pi f$
centripetal acceleration	$a = \dfrac{v^2}{r} = \omega^2 r$
centripetal force	$F = \dfrac{mv^2}{r} = m\omega^2 r$

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	$T = 2\pi\sqrt{\dfrac{m}{k}}$
for a simple pendulum	$T = 2\pi\sqrt{\dfrac{l}{g}}$

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	$pV = \dfrac{1}{3}Nm(c_{rms})^2$
kinetic energy of gas molecule	$\dfrac{1}{2}m(c_{rms})^2 = \dfrac{3}{2}kT = \dfrac{3RT}{2N_A}$

Gravitational fields

force between two masses	$F = \dfrac{Gm_1m_2}{r^2}$
gravitational field strength	$g = \dfrac{F}{m}$
magnitude of gravitational field strength in a radial field	$g = \dfrac{GM}{r^2}$
work done	$\Delta W = m\Delta V$
gravitational potential	$V = -\dfrac{GM}{r}$
	$g = -\dfrac{\Delta V}{\Delta r}$

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	$C = \dfrac{Q}{V}$
	$C = \dfrac{A\varepsilon_0\varepsilon_r}{d}$
capacitor energy stored	$E = \dfrac{1}{2}QV = \dfrac{1}{2}CV^2 = \dfrac{1}{2}\dfrac{Q^2}{C}$
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	$\varepsilon = N\dfrac{\Delta\Phi}{\Delta t}$
	$N\Phi = BAN\cos\theta$
emf induced in a rotating coil	$\varepsilon = BAN\omega\sin\omega t$
alternating current	$I_{\text{rms}} = \dfrac{I_0}{\sqrt{2}}$ $V_{\text{rms}} = \dfrac{V_0}{\sqrt{2}}$
transformer equations	$\dfrac{N_{\text{s}}}{N_{\text{p}}} = \dfrac{V_{\text{s}}}{V_{\text{p}}}$
	$\text{efficiency} = \dfrac{I_{\text{s}}V_{\text{s}}}{I_{\text{p}}V_{\text{p}}}$

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	$T_{\frac{1}{2}} = \dfrac{\ln 2}{\lambda}$
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}

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

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	$R_{\text{s}} \approx \dfrac{2GM}{c^2}$
Doppler shift for $v \ll c$	$\dfrac{\Delta f}{f} = -\dfrac{\Delta\lambda}{\lambda} = \dfrac{v}{c}$
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	$\text{intensity level} = 10\log\dfrac{I}{I_0}$
absorption	$I = I_0 e^{-\mu x}$
	$\mu_{\text{m}} = \dfrac{\mu}{\rho}$
ultrasound imaging	$Z = p\,c$
	$\dfrac{I_{\text{r}}}{I_{\text{i}}} = \left(\dfrac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2$
half-lives	$\dfrac{1}{T_{\text{E}}} = \dfrac{1}{T_{\text{B}}} + \dfrac{1}{T_{\text{P}}}$

Engineering physics

moment of inertia $I = \Sigma mr^2$

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

equations of angular motion

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

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

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

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

torque $T = I\,\alpha$

$T = F\,r$

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

isothermal change $pV = \text{constant}$

heat engines

$$\text{efficiency} = \dfrac{W}{Q_H} = \dfrac{Q_H - Q_C}{Q_H}$$

$$\text{maximum theoretical efficiency} = \dfrac{T_H - T_C}{T_H}$$

work done per cycle = area of loop

input power = calorific value × fuel flow rate

$$\text{indicated power} = \begin{array}{l}(area\ of\ p - V\ loop) \\ \times\,(number\ of\ cycles\ per\ second) \\ \times\,(number\ of\ cylinders)\end{array}$$

output or brake power $P = T\omega$

friction power = indicated power – brake power

heat pumps and refrigerators

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

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

Turning points in physics

electrons in fields $F = \dfrac{eV}{d}$

$F = Bev$

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

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

Millikan's experiment $\dfrac{QV}{d} = mg$

$F = 6\pi\eta rv$

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

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

special relativity $t = \dfrac{t_0}{\sqrt{1 - \dfrac{v^2}{c^2}}}$

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

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

Electronics

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

Q-factor $Q = \dfrac{f_0}{f_B}$

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

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

non-inverting amplifier $\dfrac{V_{out}}{V_{in}} = 1 + \dfrac{R_f}{R_l}$

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

difference amplifier $V_{out} = (V_+ - V_-)\dfrac{R_f}{R_l}$

Bandwidth requirement:

for AM $bandwidth = 2f_M$

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