



**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	$c$	$3.00 \times 10^8$	$\text{m s}^{-1}$
permeability of free space	$\mu_0$	$4\pi \times 10^{-7}$	$\text{H m}^{-1}$
permittivity of free space	$\epsilon_0$	$8.85 \times 10^{-12}$	$\text{F m}^{-1}$
magnitude of the charge of electron	$e$	$1.60 \times 10^{-19}$	C
the Planck constant	$h$	$6.63 \times 10^{-34}$	J s
gravitational constant	$G$	$6.67 \times 10^{-11}$	$\text{N m}^2 \text{kg}^{-2}$
the Avogadro constant	$N_A$	$6.02 \times 10^{23}$	$\text{mol}^{-1}$
molar gas constant	$R$	8.31	$\text{J K}^{-1} \text{mol}^{-1}$
the Boltzmann constant	$k$	$1.38 \times 10^{-23}$	$\text{J K}^{-1}$
the Stefan constant	$\sigma$	$5.67 \times 10^{-8}$	$\text{W m}^{-2} \text{K}^{-4}$
the Wien constant	$\alpha$	$2.90 \times 10^{-3}$	m K
electron rest mass (equivalent to $5.5 \times 10^{-4}$ u)	$m_e$	$9.11 \times 10^{-31}$	kg

electron charge/mass ratio	$\frac{e}{m_e}$	$1.76 \times 10^{11}$	$\text{C kg}^{-1}$
proton rest mass (equivalent to 1.00728 u)	$m_p$	$1.67(3) \times 10^{-27}$	kg
proton charge/mass ratio	$\frac{e}{m_p}$	$9.58 \times 10^7$	$\text{C kg}^{-1}$
neutron rest mass (equivalent to 1.00867 u)	$m_n$	$1.67(5) \times 10^{-27}$	kg
gravitational field strength	$g$	9.81	$\text{N kg}^{-1}$
acceleration due to gravity	$g$	9.81	$\text{m s}^{-2}$
atomic mass unit (1u is equivalent to 931.5 MeV)	u	$1.661 \times 10^{-27}$	kg

[Turn over]

**ALGEBRAIC EQUATION**

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

**ASTRONOMICAL DATA**

<b>Body</b>	<b>Mass/kg</b>	<b>Mean radius/m</b>
<b>Sun</b>	$1.99 \times 10^{30}$	$6.96 \times 10^8$
<b>Earth</b>	$5.97 \times 10^{24}$	$6.37 \times 10^6$

**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	$\gamma$	0
lepton	neutrino	$\nu_e$	0
		$\nu_\mu$	0
	electron	$e^\pm$	0.510999
	muon	$\mu^\pm$	105.659
mesons	$\pi$ meson	$\pi^\pm$	139.576
		$\pi^0$	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
<b>u</b>	$+\frac{2}{3}e$	$+\frac{1}{3}$	<b>0</b>
<b>d</b>	$-\frac{1}{3}e$	$+\frac{1}{3}$	<b>0</b>
<b>s</b>	$-\frac{1}{3}e$	$+\frac{1}{3}$	<b>-1</b>

## PROPERTIES OF LEPTONS

		Lepton number
Particles:	$e^-, \nu_e; \mu^-, \nu_\mu$	+ 1
Antiparticles:	$e^+, \bar{\nu}_e, \mu^+, \bar{\nu}_\mu$	- 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	$\lambda = \frac{h}{p} = \frac{h}{mv}$

[Turn over]

**WAVES**

<b>wave speed</b>	$c = f\lambda$	<b>period</b>	$f = \frac{1}{T}$
-------------------	----------------	---------------	-------------------

<b>first harmonic</b>	$f = \frac{1}{2l} \sqrt{\frac{T}{\mu}}$
-----------------------	---

<b>fringe spacing</b>	$w = \frac{\lambda D}{s}$	<b>diffraction grating</b>	$d \sin \theta = n\lambda$
-----------------------	---------------------------	----------------------------	----------------------------

**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 =  $\frac{\text{useful output power}}{\text{input power}}$**

**[Turn over]**

**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  $R_T = R_1 + R_2 + R_3 + \dots$

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

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

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

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

$$pV = \frac{1}{3}Nm(c_{\text{rms}})^2$$

kinetic energy of  
gas molecule

$$\frac{1}{2}m(c_{\text{rms}})^2 = \frac{3}{2}kT = \frac{3RT}{2N_A}$$

**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

$$F = \frac{1}{4\pi\epsilon_0} \frac{Q_1 Q_2}{r^2}$$

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

$$E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$$

electric potential

$$V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r}$$

field strength

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

capacitance

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

$$C = \frac{A\epsilon_0\epsilon_r}{d}$$

capacitor energy stored

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

[Turn over]

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

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

transformer equations  $\frac{N_s}{N_p} = \frac{V_s}{V_p}$

$$\text{efficiency} = \frac{I_s V_s}{I_p V_p}$$

**NUCLEAR PHYSICS**

inverse square law  
for  $\gamma$  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

$$E = mc^2$$

[Turn over]

## OPTIONS

## ASTROPHYSICS

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

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

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

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

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

$$\text{telescope in normal adjustment} \quad M = \frac{f_o}{f_e}$$

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

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

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

$$\text{Stefan's law} \quad P = \sigma AT^4$$

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



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

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**  $I_0 = 1.0 \times 10^{-12} \text{ W m}^{-2}$

**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  $E_k = \frac{1}{2} I\omega^2$

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 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  $pV = \text{constant}$

[Turn over]

**heat engines**

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

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

**work done per cycle = area of loop**

**input power = calorific value × fuel flow rate**

**indicated power = (area of  $p - V$  loop)  
 × (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**

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

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

## 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

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

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

Maxwell's formula

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$

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

[Turn over]

special relativity

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

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

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

**ELECTRONICS**resonant  
frequency

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

Q-factor

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

operational  
amplifiers: open  
loop

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

inverting amplifier

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

**non-inverting amplifier**  $\frac{V_{\text{out}}}{V_{\text{in}}} = 1 + \frac{R_f}{R_1}$

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

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

**Bandwidth requirement:**

for AM  $\text{bandwidth} = 2f_M$

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

**END OF FORMULAE**

**There are no formulae printed on this 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](http://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 © 2016 AQA and its licensors. All rights reserved.

**IB/M/Jun17/CD/7408/INS/E5**