



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

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**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         |

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**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**

$$\text{moment} = Fd$$

**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**

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

$$E_k = \frac{1}{2} m v^2$$

$$\Delta E_p = mg\Delta h$$

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

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

**[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

$$F = \frac{1}{4\pi\epsilon_0} \frac{Q_1Q_2}{r^2}$$

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

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

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**

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