Formulae, Symbols, Units and Data

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Formulae and relationships

A booklet containing the values of physical data and mathematical formulae is supplied by OCR for *Advancing Physics* examinations. It is available from the OCR Web site, or from the *Advancing Physics* Web site at:
http://advancingphysics.iop.org/support_materials/student/PhysicsEquations.pdf

Imaging and signalling

focal length	$\frac{1}{v} = \frac{1}{u} + \frac{1}{f}$	Cartesian convention (object distance u, image distance v, focal length f)
refractive index	$n = \frac{\text{speed of light in vacuo}}{\text{speed of light in medium}}$	(refractive index n)
noise limitation on maximum bits per sample	$b = \log_2(\frac{V_{total}}{V_{noise}})$ or $2^b = \frac{V_{total}}{V_{noise}}$	(maximum bits per sample b, total voltage variation V_{total}, noise voltage V_{noise}

Electricity

current	$I = \frac{\Delta Q}{\Delta t}$	(current I, charge flow ΔQ, time interval Δt)
potential difference	$V = \frac{E}{Q}$	(potential difference V, energy E, charge Q)
power	$P = IV = I^2R$	(power P, potential difference V, current I, resistance R)
	$V_{load} = \varepsilon - Ir$	(emf ε, internal resistance r)
resistance and conductance	$R = \frac{V}{I} \quad G = \frac{I}{V}$	(resistance R, conductance G, potential difference V, current I)
	$G = G_1 + G_2 + ...$	(conductors in parallel)
	$R = R_1 + R_2 + ...$	(resistors in series)
conductivity and resistivity	$G = \frac{\sigma A}{l} \quad R = \frac{\rho l}{A}$	(conductivity σ, resistivity ρ , cross section A, length l)

capacitance	$C = \frac{Q}{V}$	(potential difference V, charge Q, capacitance C)
	energy stored $= \frac{1}{2}QV = \frac{1}{2}CV^2$	
discharge of capacitor	$Q = Q_0 e^{-t/RC}$	(initial charge Q_0, time constant RC, time t)
	$\tau = RC$	(time constant τ)

Materials

density	$\rho = \frac{M}{V}$	(density ρ, mass M, volume V)
Hooke's law	$F = kx$	(tension F, spring constant k, extension x)
stress, strain and the Young modulus	$\text{stress} = \frac{\text{tension}}{\text{cross-sectional area}}$ $\text{strain} = \frac{\text{extension}}{\text{original length}}$ $\text{Young modulus} = \frac{\text{stress}}{\text{strain}}$	
	elastic strain energy $= \frac{1}{2}kx^2$	

Energy and thermal effects

efficiency	$\text{efficiency} = \frac{\text{useful energy output}}{\text{energy input}}$	
energy	$\Delta E = mc\Delta\theta$	(change in energy ΔE, mass m, specific thermal capacity c, temperature change $\Delta\theta$)
Boltzmann factor	$e^{(-E/kT)}$	(energy difference E, kelvin temperature T, Boltzmann constant k)

Waves

	$v = f\lambda$	(wave speed v, frequency f, wavelength λ)
	$n\lambda = d \sin\theta$	(on a distant screen from a diffraction grating or double slit; slit spacing d , order n, wavelength λ, angles of maxima θ)

Oscillations

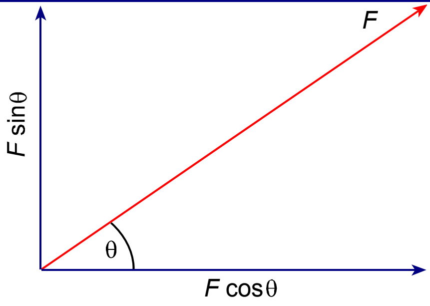
	$\frac{d^2x}{dt^2} = a = -\left(\frac{k}{m}\right)x = -(2\pi f)^2 x$	(time t, acceleration a, force per unit displacement k, mass m, displacement x, frequency f)
	$x = A \cos 2\pi ft$ $x = A \sin 2\pi ft$	(amplitude A, time t)
	$T = 2\pi\sqrt{\frac{m}{k}}$	(periodic time T)
	$f = \frac{1}{T}$	(frequency f)
total energy	$E = \frac{1}{2}kA^2 = \frac{1}{2}mv^2 + \frac{1}{2}kx^2$	

Gases

ideal gas equation	$pV = nRT$	(pressure p, volume V, number of moles n, molar gas constant R, temperature T)
kinetic theory of gases	$pV = \frac{1}{3}N m\overline{c^2}$	(pressure p, volume V, number of molecules N, mass of molecule m, mean square speed $\overline{c^2}$)

Motion and forces

equations for uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$ $v = u + at$ $v^2 = u^2 + 2as$	(initial speed u, final speed v, time taken t, acceleration a, distance travelled s)
momentum	$p = mv$	(momentum p, mass m, velocity v)
	power = Fv	(force F, velocity v)
	force = rate of change of momentum	
	impulse = $F\Delta t$	(force F)

components of a vector in two perpendicular directions		
	work = Fx	(force F, component of displacement in the direction of the force x)
for circular motion	$a = \frac{v^2}{r}$ $F = \frac{mv^2}{r}$	(radius of circle r)

Special relativity

relativistic factor γ	$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$	(speed of object v, speed of light c)
relativistic momentum	$p = \gamma mv$	(momentum p, relativistic factor γ, mass m, velocity v)
relativistic energy	$E_{total} = \gamma E_{rest}$ $E_{total} = \gamma mc^2$	(total energy E_{total}, relativistic factor γ, rest energy E_{rest})

Atomic and nuclear physics

radioactive decay	$\frac{\Delta N}{\Delta t} = -\lambda N$	(number N, decay constant λ, time t)
	$N = N_0 e^{-\lambda t}$	(initial number N_0)
	$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$	(half-life $T_{1/2}$)
	absorbed dose = energy deposited per unit mass dose equivalent = absorbed dose × quality factor risk = probability × consequence expected random variation in N random counts is of the order $\sqrt{N}$	
mass-energy relationship	$E_{rest} = mc^2$	(rest energy E_{rest}, mass m, speed of

		light *c*)
energy-frequency relationship for photons	$E = hf$	(photon energy *E*, Planck constant *h*, frequency *f*)
	$\lambda = \frac{h}{p}$	(wavelength λ, Planck constant *h*, momentum *p*; NOTE $p = mv$ for slow moving particles, $p = E / c$ for photons and particles moving close to speed of light)

Field and potential

for all fields	field strength $= -\frac{dV}{dr} \approx -\frac{\Delta V}{\Delta r}$	(potential *V*, distance *r* , potential gradient d*V* / d*r*)
gravitational fields	$g = \frac{F}{m}$	(gravitational field strength *g*, gravitational force *F,* mass *m*)
	$V_{grav} = -\frac{GM}{r}$ $F = -\frac{GMm}{r^2}$	(gravitational potential V_{grav}, radial component of force *F*, gravitational constant *G*, masses *m* and *M*, distance *r*)
electric fields	$E = \frac{F}{q}$	(electric field strength *E*, electric force *F*, charge *q*)
	$V_{elec} = \frac{kQ}{r}$ $F = \frac{kQq}{r^2}$	(electric potential V_{elec}, radial component of force *F*, electric force constant *k*, charges *q* and *Q*, distance *r*)

Electromagnetism

force on a current carrying conductor	$F = ILB$	(flux density *B*, current *I*, length *L*)
force on a moving charge	$F = qvB$	(charge *q* , velocity perpendicular to field *v*)
	$\varepsilon = -\frac{d(N\Phi)}{dt}$	(induced emf ε, flux Φ, number of turns linked *N*, time *t*)

Quantities, symbols and units

The following list illustrates the symbols and units which are used in *Advancing Physics*, and in the AS and A2 question papers.

Quantity	**Usual symbols**	**Usual unit**
absolute temperature	T	K
acceleration	a	m s^{-2}
acceleration of free fall	g	m s^{-2}
activity of radioactive source	A	Bq
angle	θ	°, rad
angular displacement	θ	°, rad
angular frequency	ω	rad s^{-1}
angular speed	ω	rad s^{-1}
amount of substance	n	mol
area	A	m^2
atomic mass	m_a	kg, u
Avogadro constant	L, N_A	mol^{-1}
Boltzmann constant	k	J K^{-1}
capacitance	C	F
Celsius temperature	θ	°C
conductance	G	S
conductivity	σ	S m^{-1}
decay constant	λ	s^{-1}
density	ρ	kg m^{-3}
displacement	x or s	m
distance	d , r , x	m
electric charge	Q, q	C
electric current	I	A
electric field strength	E	N C^{-1}, V m^{-1}
electric potential	V	V
electric potential difference	V	V
electromotive force (emf)	ε	V
electron mass	m_e	kg, u

Quantity	**Usual symbols**	**Usual unit**
elementary charge	e	C
energy	E, W	J
energy transferred thermally (heating)	Q	J
force	F	N
frequency	f	Hz
gravitational constant	G	N kg^{-2} m^{2}
gravitational field strength	g	N kg^{-1}
half-life	$t_{1/2}$	s
kinetic energy	E_{K}	J
length	l	m
magnetic flux	Φ	Wb
magnetic flux density	B	T
mass	m	kg
molar gas constant	R	J K^{-1} mol^{-1}
momentum	p	kg m s^{-1}
neutron mass	m_{n}	kg, u
neutron number	N	
nucleon number	A	
number	N, n, m	
number density (number per unit volume)	n	m^{-3}
period	T	s
permeability of free space	μ_0	H m^{-1}
permittivity of free space	ε_0	F m^{-1}
Planck constant	h	J s or J Hz^{-1}
potential energy	E_{P}	J
power	P	W
pressure	p	Pa
proton mass	m_{p}	kg, u
proton number	Z	
resistance	R	W
resistivity	ρ	W m
specific thermal capacity	c or C	J kg^{-1} K^{-1}

Quantity	**Usual symbols**	**Usual unit**
specific latent heat	L	J kg^{-1}
speed	u, v, c	m s^{-1}
speed of electromagnetic waves	c	m s^{-1}
spring constant	k	N m^{-1}
strain	σ	fraction or per cent
stress	ε	Pa
time	t	s
time constant	τ	s
velocity	u, v, c	m s^{-1}
volume	V	m^3
wavelength	λ	m
work	W	J
work function energy	W	J, eV
Young modulus	E	Pa

Useful data

This list of data is more comprehensive than lists issued with examination papers. Values are given to three significant figures, except where more – or less – are useful.

Physical constants

speed of light	c	3.00×10^{8} ms^{-1}
permittivity of free space	ε_n	8.85×10^{-12} C^{2} N^{-1} m^{-2} (or F m^{-1})
electric force constant	$k = \frac{1}{4\pi\varepsilon_0}$	8.98×10^{9} N m^{2} C^{-2}
permeability of free space	μ_0	$4\,\pi \times 10^{-7}$ N A^{-2} (or H m^{-1})
charge on electron	e	-1.60×10^{-19} C
mass of electron	m_e	9.11×10^{-31} kg = 0.000 55 u
mass of proton	m_p	1.673×10^{-27} kg = 1.007 3 u
mass of neutron	m_n	1.675×10^{-27} kg = 1.008 7 u
mass of alpha particle	m_α	6.646×10^{-27} kg = 4.001 5 u
Avogadro constant	L, N_A	6.02×10^{23} mol^{-1}
Planck constant	h	6.63×10^{-34} J s
Boltzmann constant	k	1.38×10^{-23} J K^{-1}
molar gas constant	R	8.31 J mol^{-1} K^{-1}
gravitational force constant	G	6.67×10^{-11} N m^{2} kg^{-2}

Other data

standard temperature and pressure (stp)		273 K (0 °C), 1.01×10^5 Pa (1 atmosphere)
molar volume of a gas at stp	V_m	$22.4\ dm^3 = 2.24 \times 10^{-2}\ m^3$
gravitational field strength at the Earth's surface in the UK	g	$9.81\ N\ kg^{-1}$ (or $m\ s^{-2}$)

Conversion factors

unified atomic mass unit	1 u	$= 1.661 \times 10^{-27}$ kg
	1 day	$= 8.64 \times 10^4$ s
	1 year	$\approx 3.16 \times 10^7$ s
	1 light year	$\approx 10^{16}$ m

Mathematical constants and equations

e = 2.72 $\pi = 3.14$ 1 radian = 57.3°

arc = $r\theta$	circumference of circle = $2\pi r$
$\sin\theta \approx \tan\theta \approx \theta$ and $\cos\theta \approx 1$ for small θ	area of circle = πr^2
	curved surface area of cylinder = $2\pi rh$
$\ln(x^n) = n \ln x$	volume of cylinder = $\pi r^2 h$
$\ln(e^{kx}) = kx$	surface area of sphere = $4\pi r^2$
	volume of sphere = $\frac{4}{3}\pi r^3$

Prefixes

10^{12}	T
10^{9}	G
10^{6}	M
10^{3}	k
10^{-3}	m
10^{-6}	μ
10^{-9}	n
10^{-12}	p