Diploma Programme

Physics data booklet

For use during the course and in the examinations

First assessment 2025

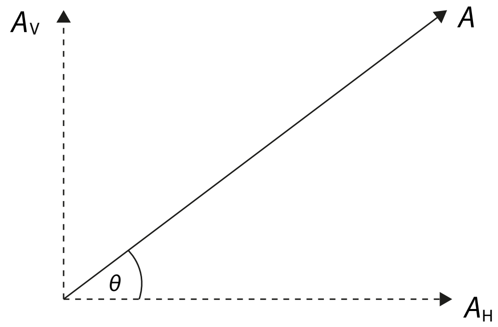
Version 1.1

Annotated by YPhysics (Version 1.0)

International Baccalaureate
Baccalauréat International
Bachillerato Internacional

Contents

Mathematical equations

Area of a triangle	$A = \frac{1}{2}(bh)$ where b is the base, h is the height
Area of a circle	$A = \pi r^2$ where r is the radius
Circumference of a circle	$C = 2\pi r$
Volume of a cuboid	$V = lwh$ where l is the length, w is the width, h is the height
Volume of a cylinder	$V = \pi r^2 h$
Volume of a prism	$V = Ah$ where A is the area of cross-section
Volume of a sphere	$V = \frac{4}{3}\pi r^3$
Area of the curved surface of a cylinder	$A = 2\pi rh$
Vectors	 $A_H = A\cos\theta$ $A_V = A\sin\theta$
Trigonometric relationships	$\tan\theta = \frac{\sin\theta}{\cos\theta}$ $\sin^2\theta + \cos^2\theta = 1$

Uncertainties

If: $y = a \pm b$	then: $\Delta y = \Delta a + \Delta b$
If: $y = \frac{ab}{c}$	then: $\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c}$
If: $y = a^n$	then: $\frac{\Delta y}{y} = \left\| n\frac{\Delta a}{a} \right\|$

Δy: absolute/raw uncertainty in y
y: value of y

Δa: absolute/raw uncertainty in a
a: value of a

Δb: absolute/raw uncertainty in b
b: value of b

Δc: absolute/raw uncertainty in c
c: value of c

Fundamental constants

Quantity	**Symbol**	**Approximate value**
Acceleration of free fall	g	$9.8\,\text{m}\,\text{s}^{-2}$ (Earth's surface)
Gravitational constant	G	$6.67 \times 10^{-11}\,\text{N}\,\text{m}^2\,\text{kg}^{-2}$
Avogadro constant	N_A	$6.02 \times 10^{23}\,\text{mol}^{-1}$
Gas constant	R	$8.31\,\text{J}\,\text{K}^{-1}\,\text{mol}^{-1}$
Boltzmann constant	k_B	$1.38 \times 10^{-23}\,\text{J}\,\text{K}^{-1}$
Stefan–Boltzmann constant	σ	$5.67 \times 10^{-8}\,\text{W}\,\text{m}^{-2}\,\text{K}^{-4}$
Coulomb constant	k	$8.99 \times 10^{9}\,\text{N}\,\text{m}^2\,\text{C}^{-2}$
Permittivity of free space	ε_0	$8.85 \times 10^{-12}\,\text{C}^2\,\text{N}^{-1}\,\text{m}^{-2}$
Permeability of free space	μ_0	$4\pi \times 10^{-7}\,\text{T}\,\text{m}\,\text{A}^{-1}$
Speed of light in vacuum	c	$3.00 \times 10^{8}\,\text{m}\,\text{s}^{-1}$
Planck constant	h	$6.63 \times 10^{-34}\,\text{J}\,\text{s}$
Elementary charge	e	$1.60 \times 10^{-19}\,\text{C}$
Electron rest mass	m_e	$9.110 \times 10^{-31}\,\text{kg} = 0.000549\,\text{u} = 0.511\,\text{MeV}\,\text{c}^{-2}$
Proton rest mass	m_p	$1.673 \times 10^{-27}\,\text{kg} = 1.007276\,\text{u} = 938\,\text{MeV}\,\text{c}^{-2}$
Neutron rest mass	m_n	$1.675 \times 10^{-27}\,\text{kg} = 1.008665\,\text{u} = 940\,\text{MeV}\,\text{c}^{-2}$
(Unified) atomic mass unit	u	$1.661 \times 10^{-27}\,\text{kg} = 931.5\,\text{MeV}\,\text{c}^{-2}$
Solar constant	S	$1.36 \times 10^{3}\,\text{W}\,\text{m}^{-2}$
Fermi radius	R_0	$1.20 \times 10^{-15}\,\text{m}$

Metric (SI) multipliers

Prefix	Abbreviation	Value
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deca	da	10^{1}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}

Unit conversions

$$1 \text{ radian (rad)} \equiv \frac{180°}{\pi}$$

$$\text{Temperature}(\text{K}) = \text{temperature}(°\text{C}) + 273$$

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

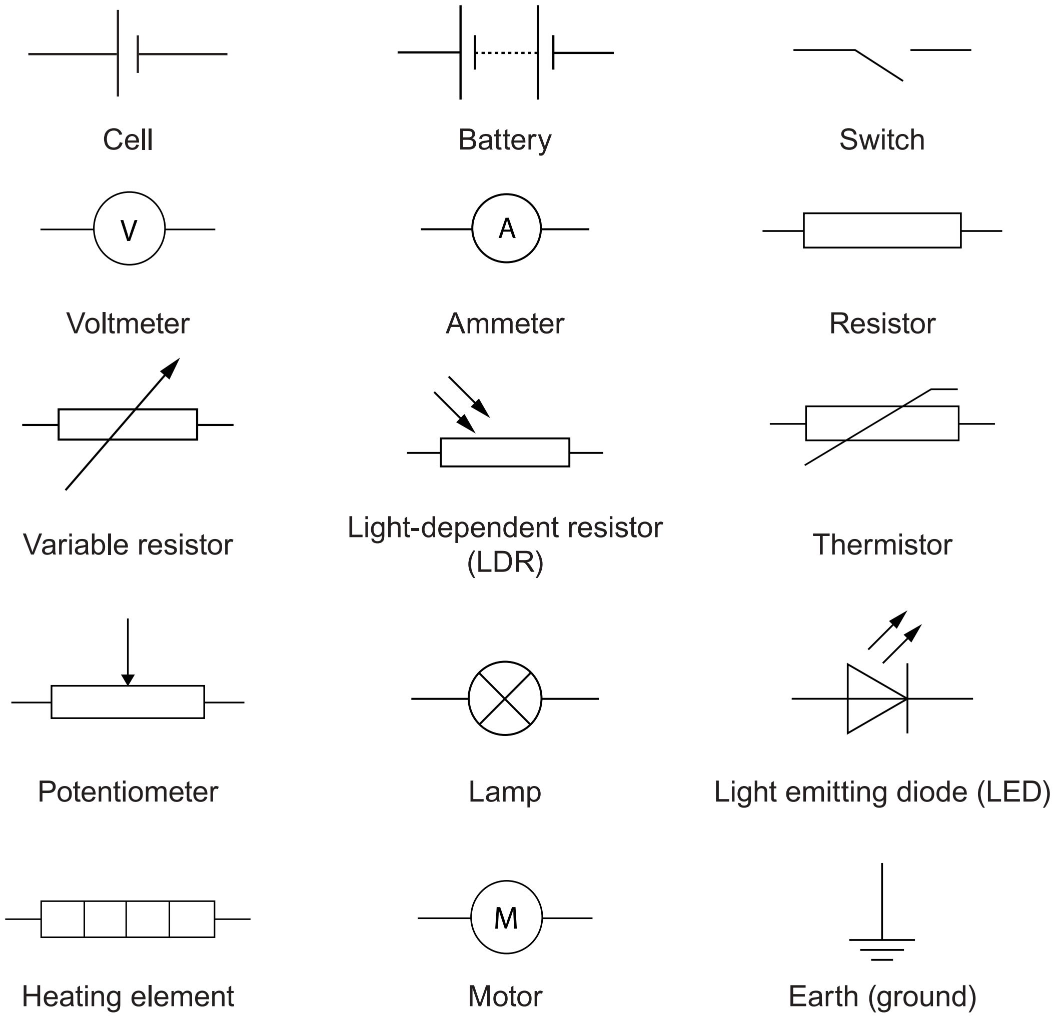
$$1 \text{ parsec}(\text{pc}) = 3.26 \text{ ly}$$

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

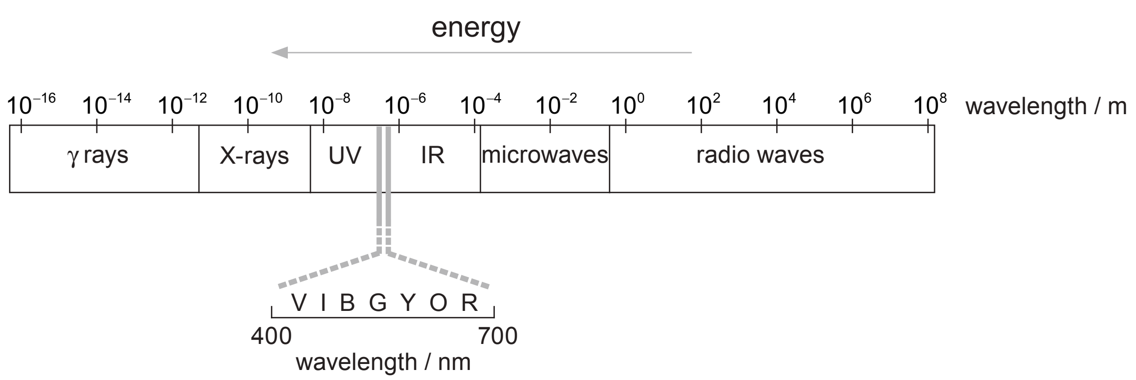
$$1 \text{ kilowatt-hour}(\text{kWh}) = 3.60 \times 10^{6} \text{ J}$$

$$hc = 1.99 \times 10^{-25} \text{ J m} = 1.24 \times 10^{-6} \text{ eV m}$$

Electrical circuit symbols



Electromagnetic spectrum



A. Space, time and motion

Standard level and higher level

A.1 Kinematics

s: displacement
u: initial velocity
v: final velocity
a: acceleration
t: time

(Use + or - to include direction)

$$s = \frac{u+v}{2}t$$

$$v = u + at$$

$$s = ut + \frac{1}{2}at^2$$

$$v^2 = u^2 + 2as$$

A.2 Forces and momentum

$$F_f \le \mu_s F_N$$

$$F_f = \mu_d F_N$$

F_f: frictional force (friction)
μ_s: coefficient of static friction
μ_d: coefficient of dynamic friction
F_N: normal contact force

$$F_H = -kx$$

F_H: elastic force from helical spring (Hooke's Law)
k: spring's constant
x: extension or compression of spring

$$F_d = 6\pi\eta rv$$

F_d: drag force (resistive force from fluids)
η: coefficient of viscosity
r: radius
v: speed

$$F_b = \rho V g$$

F_b: buoyant force (upthrust)
ρ: density of fluid
V: volume submerged in fluid
g: acceleration of free fall

$$F_g = mg$$

F_g: gravitational force (weight close to Earth's surface)
m: mass
g:acceleration of free fall

$$p = mv$$

p: momentum
m: mass
v: velocity

$$J = F\Delta t$$

J: impulse
F: force
Δ*t*: time taken

$$F = ma = \frac{\Delta p}{\Delta t}$$

F: resultant/net force
m: mass
a: acceleration
Δ*p*: change in momentum (Δ*p*=*mv*-*mu*)
Δ*t*: time taken

$$a = \frac{v^2}{r} = \omega^2 r = \frac{4\pi^2 r}{T^2}$$

$$v = \frac{2\pi r}{T} = \omega r$$

a: centripetal acceleration
v: linear speed
r: radius
T: period
ω: angular speed

A.3 Work, energy and power

$$W = Fs\cos\theta$$

W: work done by force *F*
F: force
s: displacement of point of action of force *F*
θ: angle between direction of *F* and direction of *s*

$$E_k = \frac{1}{2}mv^2 = \frac{p^2}{2m}$$

E_k: kinetic energy
m: mass
v: speed
p: momentum

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

ΔE_p: change in gravitational potential energy
m: mass
g: acceleration of free fall
Δ*h*: change in height

$$E_H = \frac{1}{2}k\Delta x^2$$

E_H: elastic potential energy stored in helical spring
k: spring's constant
Δ*x* : extension or compression of the spring

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

P: Power
Δ*W*: work done / energy transferred
Δ*t*: time taken
F: average force
v: average speed

$$\eta = \frac{\text{useful work out}}{\text{total work in}} = \frac{\text{useful power out}}{\text{total power in}}$$

η: efficiency

Additional higher level

A.4 Rigid body mechanics

$\tau = Fr\sin\theta$

τ: torque
F: force
r: distance from axis to point of action of F
θ: angle between direction of F and direction of r

$\Delta\theta = \frac{\omega_f + \omega_i}{2}t$

$\omega_f = \omega_i + \alpha t$

$\Delta\theta = \omega_i t + \frac{1}{2}\alpha t^2$

$\omega_f^2 = \omega_i^2 + 2\alpha\Delta\theta$

Δθ: angular displacement
ω_f: final angular velocity
ω_i: initial angular velocity
a: angular acceleration
t: time
(use + and - to include direction)

$I = \Sigma mr^2$

I: moment of inertia
m: mass
r: distance from point or axis of rotation
(Note: Σ means sum i.e $\Sigma mr^2 = m_1r_1^2 + m_2r_2^2 + m_3r_3^2 + \ldots$)

$\tau = I\alpha$

τ: resultant/net torque
I: moment of inertia
a: angular acceleration

$L = I\omega$

L: angular momentum
I: moment of inertia
ω: angular velocity

$\Delta L = \tau\Delta t$

ΔL: change in angular momentum
τ: resultant/net torque
Δt: time taken

$\Delta L = \Delta(I\omega)$

ΔL: change in angular momentum
I: moment of inertia
ω: angular velocity

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

E_k: rotational kinetic energy
I: moment of inertia
ω: angular speed
L: angular momentum

A.5 Galilean and special relativity

$x' = x - vt$

$t' = t$

$u' = u - v$

$x' = \gamma(x - vt)$ where $\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$

$t' = \gamma\left(t - \frac{vx}{c^2}\right)$

$u' = \frac{u - v}{1 - \frac{uv}{c^2}}$

x':position of an event in an inertial frame of reference moving with relative speed v to the original frame of reference

x:position of the same event in the original frame of reference

v: relative speed between the two inertial frames of reference

t': time of an event in an inertial frame of reference moving with relative speed v to the original frame of reference

t: time of the same event in the original frame of reference

u': velocity of body in n inertial frame of reference moving with relative speed v to the original frame of reference

u: velocity of the same body in the original frame of reference

γ: the Lorrentz factor

c: speed of light in vacuum (constant)

$(\Delta s)^2 = (c\Delta t)^2 - \Delta x^2$

Δs: space-time interval between two events
c: speed of ligh
Δt: time interval
Δx: distance between the events

$\Delta t = \gamma\Delta t_0$

Δt: time interval between two observed events (2 different clocks)

γ: the Lorrentz factor

Δt_0: proper time (time interval measured by same clock)

$L = \frac{L_0}{\gamma}$

L: observed length
L_0: proper length
γ: the Lorrentz factor

$\tan\theta = \frac{v}{c}$

θ: angle of worldline from the vertical axis in a space-time diagram
v: speed of the body

B. The particulate nature of matter

Standard level and higher level

B.1 Thermal energy transfers

$\rho = \frac{m}{V}$

ρ: density
m: mass
V: volume

$\overline{E}_k = \frac{3}{2}k_B T$

$\overline{E}_k$: average random kinetic energy of particles
k_B: Boltzmann constant
T: temperature

$Q = mc\Delta T$

$Q = mL$

Q: heat (energy transferred)
m: mass
c: specific heat capacity
L: specific latent heat
ΔT: change in temperature

$\frac{\Delta Q}{\Delta t} = kA\frac{\Delta T}{\Delta x}$

ΔQ: amount of heat (energy) transfer
Δt: time taken
k: thermal conductivity of material
A: surface area of the surface that emits heat
ΔT: temperature difference between hot and cold sides
Δx: thickness (distance between hot and cold sides)

$L = \sigma A T^4$

L: luminosity (total power output)
σ: Steffan-Boltzmann constant
A: surface area of body
T: temperature

$b = \frac{L}{4\pi d^2}$

b: brightness (intensity)
L: luminosity
d: distance from the source

$\lambda_{max} T = 2.9 \times 10^{-3}\,\mathrm{m\,K}$

λ_{max}: peak wavelength
T: temperature

B.2 Greenhouse effect

$\text{emissivity} = \frac{\text{power radiated per unit area}}{\sigma T^4}$

σ: Steffan-Boltzmann constant
T : temperature

$\text{albedo} = \frac{\text{total scattered power}}{\text{total incident power}}$

B.3 Gas laws

$P = \frac{F}{A}$

P: pressure
F: force
A: area

$n = \frac{N}{N_A}$

n: number of moles
N: number of particles (atoms or molecules)
N_A: Avogadro constant

$\frac{PV}{T} = \text{constant}$

$PV = nRT = Nk_B T$

P: pressure
V: volume
T: temperature
N:number of moles
R: gas constant
N: number of particles
K_B: Boltzmann constant
U: internal energy of gas

$P = \frac{1}{3}\rho v^2$

P: pressure
ρ: density of gas
v: root mean square speed of particles (r.m.s speed)

$U = \frac{3}{2}nRT = \frac{3}{2}Nk_B T$

B.5 Current and circuits

$I = \frac{\Delta q}{\Delta t}$

I: current
Δq: amount of charge passing through a surface
Δt: time taken

$V = \frac{W}{q}$

V: potential difference
W: work done
q: charge

$R = \frac{V}{I}$

R: resistance
V: potential difference
I: current

$\rho = \frac{RA}{L}$

ρ: resistivity
R: resistance
A: cross-sectional area
L: length

$P = IV = I^2R = \frac{V^2}{R}$

P: power
I: current
V: potential difference
R: resistance

Series circuits	Parallel circuits
$I = I_1 = I_2 = \dots$	$I = I_1 + I_2 + \dots$
$V = V_1 + V_2 + \dots$	$V = V_1 = V_2 = \dots$
$R_s = R_1 + R_2 + \dots$	$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$

$\varepsilon = I(R + r)$

ε: electromotive force (emf)
I: current
R: resistance of connected circuit
r: internal resistance

Additional higher level

B.4 Thermodynamics

$Q = \Delta U + W$

Q: amount of thermal energy (heat)
ΔU: change in internal energy
W: work done by the gas

$W = P\Delta V$

W: work done by gas
P: pressure
ΔV: change in volume

$\Delta U = \frac{3}{2}nR\Delta T = \frac{3}{2}Nk_B\Delta T$

ΔU: change in internal energy of a gas
n: number of moles
R: Gas constant
ΔT: change in temperature
N: number of atoms
k_B: Boltzmann constant

$\Delta S = \frac{\Delta Q}{T}$

ΔS: change in entropy
ΔQ: amount of thermal energy (heat) that flows into a body
T: temperature

$S = k_B \ln \Omega$

S: entropy
k_B: Boltzmann constant
Ω: number of possible micro states of the system

$PV^{\frac{5}{3}} = \text{constant}$

(Model for **adiabatic** processes)
P: Pressure of monatomic ideal gas
V: Volume of monatomic ideal gas

$\eta = \frac{\text{useful work}}{\text{input energy}}$

$\eta_{\text{Carnot}} = 1 - \frac{T_c}{T_h}$

η: efficiency
η_{Carnot}: efficiency of a Carnot cycle
T_c: temperature of cold gas
T_h: temperature of hot gas

C. Wave behaviour

Standard level and higher level

C.1 Simple harmonic motion

$a = -\omega^2 x$

a: acceleration
ω: angular frequency
x: displacement from equilibrium position

$T = \frac{1}{f} = \frac{2\pi}{\omega}$

T: period
f: frequency
ω: angular frequency

$T = 2\pi\sqrt{\frac{m}{k}}$

T: period of a mass-spring system
m: mass
k: spring's constant

$T = 2\pi\sqrt{\frac{l}{g}}$

T: period of simple pendulum
l: length
g: acceleration of free fall (constant)

C.2 Wave model

$v = f\lambda = \frac{\lambda}{T}$

v: wave speed
f: frequency
λ: wavelength

C.3 Wave phenomena

$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$

n_1: refractive index of medium 1
n_2: refractive index of medium 2
θ_1: angle of incidence
θ_2: angle of refraction
v_1: speed of wave in medium 1
v_2: speed of wave in medium 2

Constructive interference:
path difference $= n\lambda$

Destructive interference:
path difference $= (n + \frac{1}{2})\lambda$

n= 0, 1, 2, 3, …
λ: wavelength

$s = \frac{\lambda D}{d}$

s: distance between adjacent maxima
λ: wavelength
D: distance between slits and screen
d: distance between slits

C.5 Doppler effect

$\frac{\Delta f}{f} = \frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}$

Δf: change/shift in frequency
f: frequency of emitted wave
Δλ: change/shift in wavelength
λ: wavelength of emitted wave
v: relative speed between source and observer
c: speed of light (constant)

Additional higher level

C.1 Simple harmonic motion

$x = x_0 \sin(\omega t + \phi)$

$v = \omega x_0 \cos(\omega t + \phi)$

$v = \pm\omega\sqrt{x_0^2 - x^2}$

$E_T = \frac{1}{2} m\omega^2 x_0^2$

$E_p = \frac{1}{2} m\omega^2 x^2$

x: displacement from equilibrium position
x_0: amplitude
ω: angular frequency
t: time
ϕ: initial phase
v: velocity
E_T: total energy of simple harmonic oscillator
E_p: potential energy of simple harmonic oscillator
m: mass

θ: angle at which first diffraction minimum appears
λ: wavelength
b: slit width

C.3 Wave phenomena	$\theta = \frac{\lambda}{b}$ $n\lambda = d\sin\theta$
C.5 Doppler effect	Moving source: $f' = f\left(\frac{v}{v \pm u_s}\right)$ Moving observer: $f' = f\left(\frac{v \pm u_o}{v}\right)$

n: order (1, 2, 3, …)
λ: wavelength
d: distance between slits of diffraction grating
θ: angle at which this order minimum will appear

f': observed frequency
f: emitted frequency
v: wave speed
u_o: speed of observer
u_s: speed of source

D. Fields

Standard level and higher level

D.1 Gravitational fields

$$F = G\frac{m_1 m_2}{r^2}$$

F: gravitational force
G: gravitational constant
m_1: mass of body 1
m_2: mass of body 2
r: distance between the centres of the 2 bodies

$$g = \frac{F}{m} = G\frac{M}{r^2}$$

g: gravitational field strength
F: gravitational force
m: mass
G: gravitational constant
M: mass of the body that creates the gravitational field
r: distance from the centre of that body

D.2 Electric and magnetic fields

$$F = k\frac{q_1 q_2}{r^2} \quad \text{where} \quad k = \frac{1}{4\pi\varepsilon_0}$$

F: electric field force between two charged particles
k: Coulomb's constant
ε_0: permittivity of free space (constant)
q_1: charge of particle 1
q_2: charge of particle 2

$$E = \frac{F}{q}$$

E: electric field strength
F: electric field force
q: charge

$$E = \frac{V}{d}$$

E: electric field strength of a uniform electric field
V: potential difference between two points (or metal plates)
d: distance between the two points (or metal plates)

D.3 Motion in electromagnetic fields

$$F = qvB\sin\theta$$

F: magnetic force on moving charged particle
q: charge of particle
v: speed of particle
B: magnetic field strength
θ: angle between magnetic field lines and direction of speed

$$F = BIL\sin\theta$$

F: magnetic force on current currying wire
B: magnetic field strength
I: current
L: length of wire in the magnetic field
θ: angle between magnetic field lines and current

$$\frac{F}{L} = \mu_0 \frac{I_1 I_2}{2\pi r}$$

F: magnetic force between current currying wire
L: length of wire
μ_0: permeability of free space (constant)
I_1: current in wire 1
I_2: current in wire 2
r: distance between wires

Additional higher level

D.1 Gravitational fields

$$E_p = -G\frac{m_1 m_2}{r}$$

E_p: gravitational potential energy
G: gravitational constant
m_1: mass of body 1
m_2: mass of body 2
r: distance between the centres of bodies

$$V_g = -G\frac{M}{r}$$

V_g: gravitational potential at a point in a gravitational field
G: gravitational constant
M: mass of the body creating the field
r: distance of the point from the centre of the body.

$$g = -\frac{\Delta V_g}{\Delta r}$$

g: gravitational field strength
ΔV_g: change in the gravitational potential between two points
Δr: distance between the two points

$$W = m\Delta V_g$$

W: work done to move a mass in a gravitational field
m: mass of body that is moving
ΔV_g: change in the gravitational potential between two points

$$v_{esc} = \sqrt{\frac{2GM}{r}}$$

$$v_{orbital} = \sqrt{\frac{GM}{r}}$$

v_{esc}: speed needed to escape a gravitational field
$v_{orbital}$: orbital speed
G: gravitational constant
M: mass of body creating the gravitational field
r: distance from the centre of that body

D.2 Electric and magnetic fields

$$E_p = k\frac{q_1 q_2}{r}$$

E_p: electric potential energy
k: Coulomb's constant
q_1: charge on body 1
q_2: charge on body 2
r: distance between the centres of the bodies

$$V_e = \frac{kQ}{r}$$

V_e: electric potential at a point in an electric field
k: Coulomb's constant
Q: charge creating the field
r: distance between point and centre of charge

$$E = -\frac{\Delta V_e}{\Delta r}$$

E: electric field strength
ΔV: electric potential difference between two points in the field
Δr: distance between the points

$$W = q\Delta V_e$$

W: work done to move a charge in an electric field
q: charge moved
ΔV_e: electric potential difference between the points

Φ: magnetic flux
B: magnetic field strength
A: area
θ: angle between magnetic field lines and the perpendicular direction to the surface

D.4 Induction	$\Phi = BA\cos\theta$ $\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$ $\varepsilon = BvL$

ε: induced emf
N: number of loops on coil
ΔΦ: change in magnetic flux
Δt: time taken

ε: emf induced across the ends of a straight conductor moving in a magnetic field

B: magnetic field strength
v: speed of conductor
l: length of conductor in field

E. Nuclear and quantum physics

Standard level and higher level	
E.1 Structure of the atom	$E = hf$
E.3 Radioactive decay	$E = mc^2$
E.5 Fusion and stars	$\text{d(parsec)} = \frac{1}{\text{p(arc-second)}}$
Additional higher level	
E.1 Structure of the atom	$R = R_0 A^{\frac{1}{3}}$ $E = -\frac{13.6}{n^2}\text{eV}$ $mvr = \frac{nh}{2\pi}$
E.2 Quantum physics	$E_{max} = hf - \Phi$ $\lambda = \frac{h}{p}$ $\lambda_f - \lambda_i = \Delta\lambda = \frac{h}{m_e c}(1-\cos\theta)$
E.3 Radioactive decay	$N = N_0 e^{-\lambda t}$ $A = \lambda N = \lambda N_0 e^{-\lambda t}$ $T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$

E: energy of a photon
h: Planck's constant
f: frequency

E: energy released
m: mass 'loss' (change in mass)
c: speed of light (constant)

d: distance to star
p: parallax angle

R: radius of atom
R_0: Fermi radius (constant)
A: atomic number (number of protons)

E: energy value of energy level
n: quantum number of energy level (n= 1,2,3,..)
(eV is just the unit, energy here is calculated in electrovolts)

mvr: angular momentum
m: mass
v: linear speed
r: radius of circular path
n: quantum number (n=1,2,3,4,…)
h: Planck's constant

E_{max}: maximum kinetic of energy of emitted electrons
h: Planck's constant
f: frequency of incident radiation
Φ: work function of metal surface

λ: wavelength
h: Planck's constant
p: momentum

λ_f: final wavelength
λ_i: initial wavelength
Δλ: change in wavelength
h: Planck's constant
m_e: mass of electron (constant)
c: speed of light in vacuum (constant)
θ: scattering angle

N: number of nuclei left after time t
N_0: original number of nuclei in the sample (at t=0)
λ: decay constant of material
t: time
A: activity (number of decays per second)
$T_{1/2}$: half-life