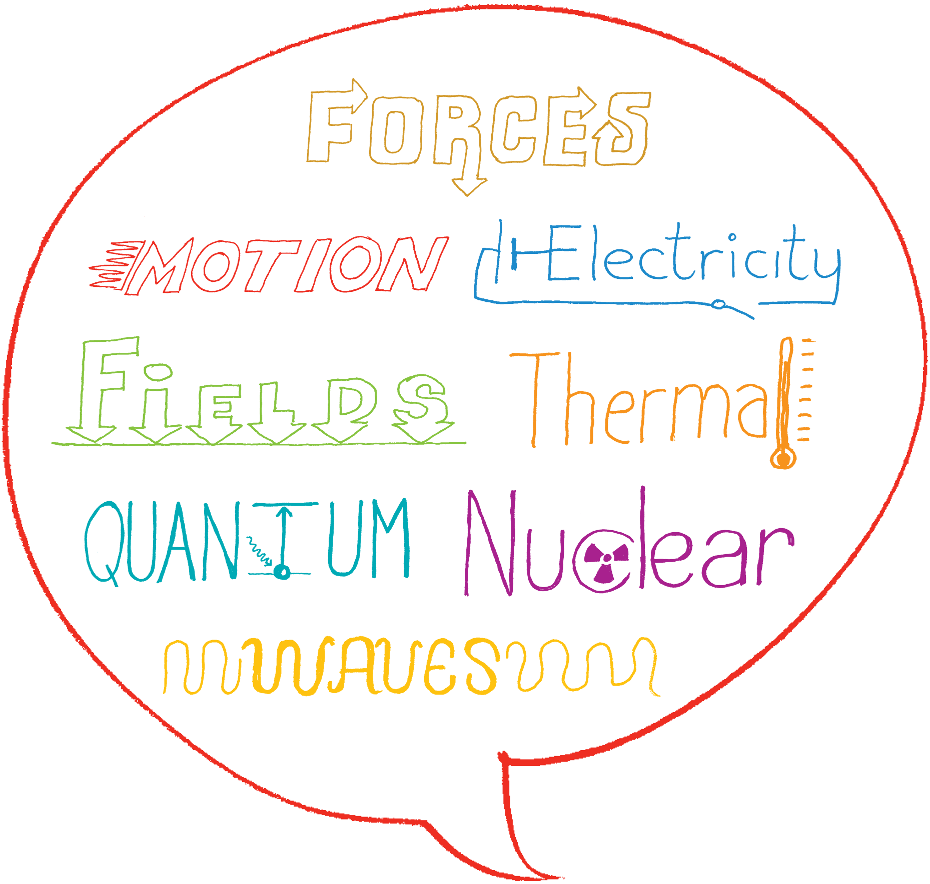
IOP Education

Pocket Physics

A study aid for 16-18 year olds



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Introduction

If you are aged 16-18 years old and studying physics in UK, this booklet is for you!

It is a quick reference guide that is suitable for whether you are studying for A-level, International Baccalaureate, Higher or Advanced Higher physics. Written by the Institute of Physics and National Physical Laboratory, it will be your trusted pocket companion for the topics of forces, motion, waves, electricity, thermal, quantum and nuclear physics. Your course may include additional topics, so we've added some blank pages the end of the booklet for you to make your own notes.

Forces and motion

Motion in a straight line

The equations for uniformly accelerated motion are:

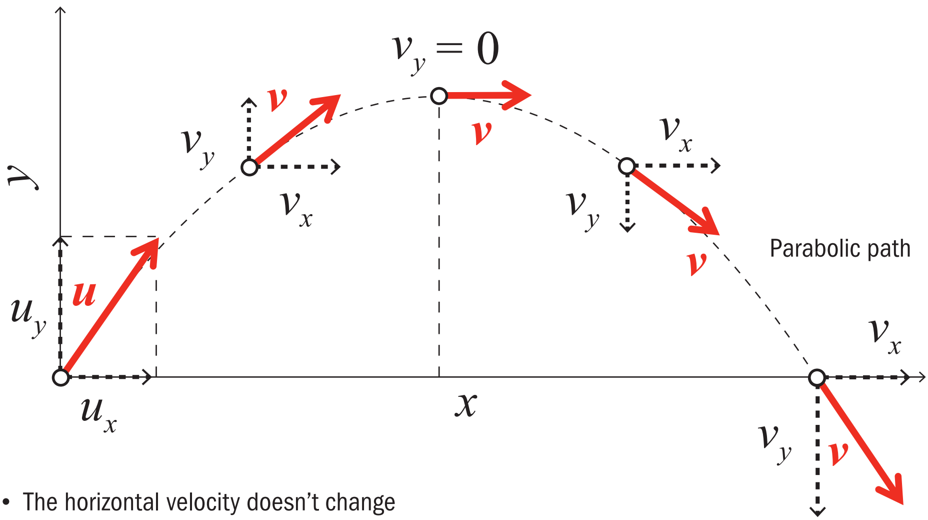
$$v = u + at \qquad s = ut + \frac{1}{2}at^2$$

$$s = \frac{1}{2}(u + v)t \qquad v^2 = u^2 + 2as$$

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

Projectile motion

The horizontal and vertical components of motion can be treated separately.



- The horizontal velocity doesn't change
- The acceleration in the vertical direction is due to gravity

Momentum

$$\boldsymbol{p} = m\boldsymbol{v}$$

$\boldsymbol{p}$ = momentum
m = mass
$\boldsymbol{v}$ = velocity

If two objects collide, momentum is conserved.

Total momentum before = Total momentum after

$$m_1\boldsymbol{u}_1 + m_2\boldsymbol{u}_2 = m_1\boldsymbol{v}_1 + m_2\boldsymbol{v}_2$$

Newton's laws of motion

1. If the resultant force F on an object is zero, it will stay at rest or continue to move with constant velocity.
2. The rate of change of momentum of an object is proportional to resultant force that acts on it (which can be written as $F = ma$ if mass is constant).
3. Forces occur in pairs. The forces that two interacting objects exert on one another are equal in magnitude, opposite in direction, and are both the same type of force.

Fundamental interactions

Gravitational	Acts between all masses. Responsible for large scale structure of universes (e.g. galaxies)
Electromagnetic	Acts between charges – binds atoms and molecules together
Weak Nuclear	Within the nucleus – governs radioactive beta decay
Strong Nuclear	Act between nucleons in the nucleus – binds protons and neutrons

Energy calculations

Kinetic energy

$$E = \frac{1}{2} mv^2$$

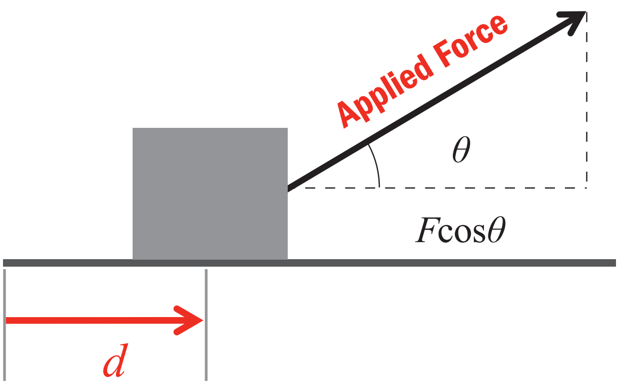
Work done mechanically

$$W = Fd\cos\theta$$

Change in gravitational potential energy

$$E = mgh$$

where h is change in height



Power

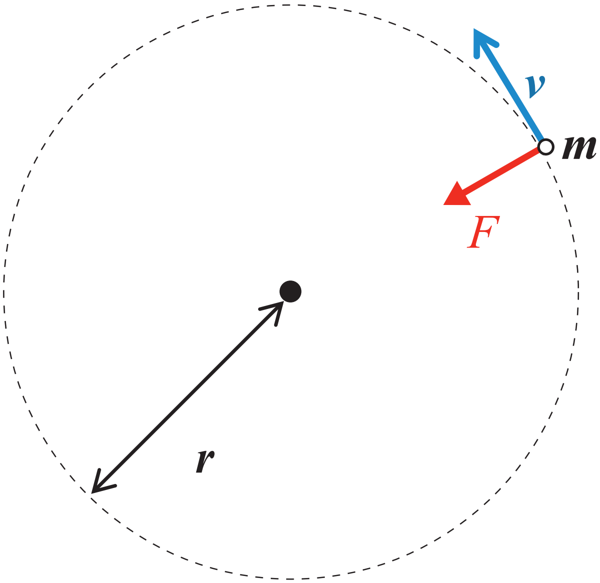
$$P = W/t$$

t = time taken

Uniform circular motion

Circular motion requires a resultant force that has an inward direction. The acceleration and force are centripetal (towards the centre of the circle).

In uniform circular motion the acceleration involves a change in direction but not a change in speed.



Time period T is time taken to go once around circle.

Frequency

$$f = \frac{1}{T}$$

Angular frequency

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

Speed

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

Acceleration

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

Resultant force

$$F = \frac{mv^2}{r} = m\omega^2 r$$

Simple harmonic motion (s.h.m.)

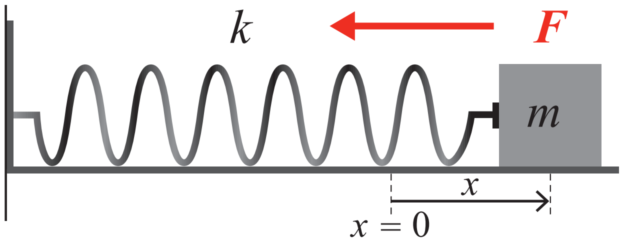
Simple harmonic motion occurs if the resultant force is proportional to the displacement from a fixed point ($x = 0$) but acts in the opposite direction.

$$\boldsymbol{F} = -k\boldsymbol{x}$$

k = constant

Mass-spring system

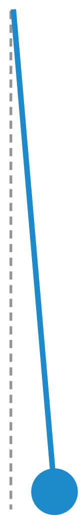
$$T = 2\pi\sqrt{\frac{m}{k}}$$



Simple pendulum

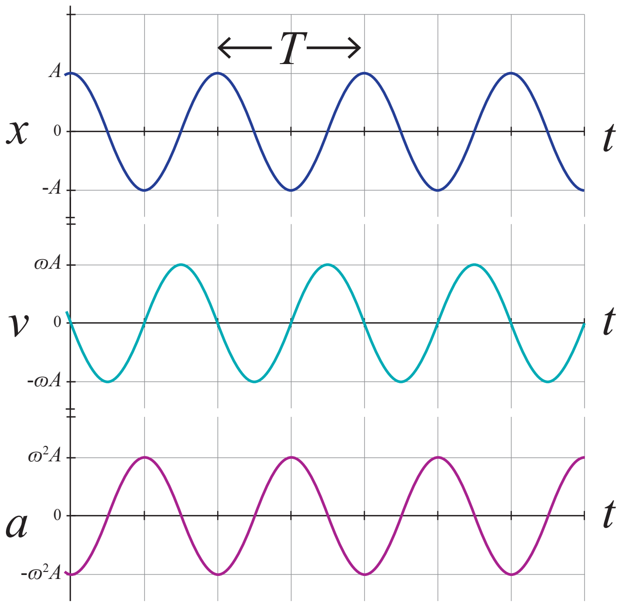
For small amplitude oscillations:

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



s.h.m. graphs

Time period T is time to complete one oscillation.



A = amplitude

ω = angular frequency

Waves

Wave speed

$$v = f\lambda$$

Refractive index of a material

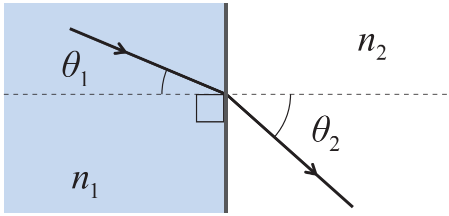
$$n = c/v$$

λ = wavelength

c = speed of light in a vacuum

Snell's Law

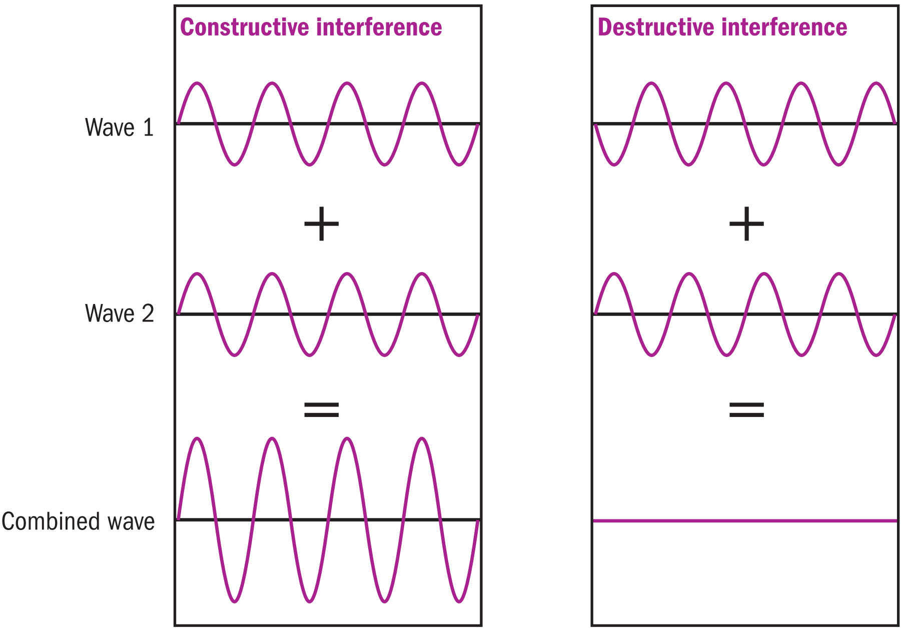
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$



Superposition

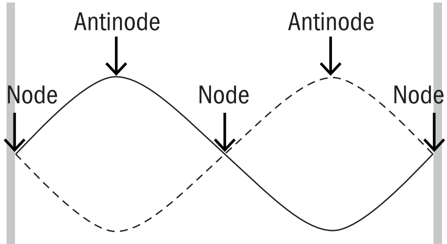
If the phase difference between two waves in radians is an even multiple of π (0, 2π, 4π etc) – constructive interference occurs.

If phase difference is an odd multiple of π (π, 3π, 5π etc)- destructive interference occurs.

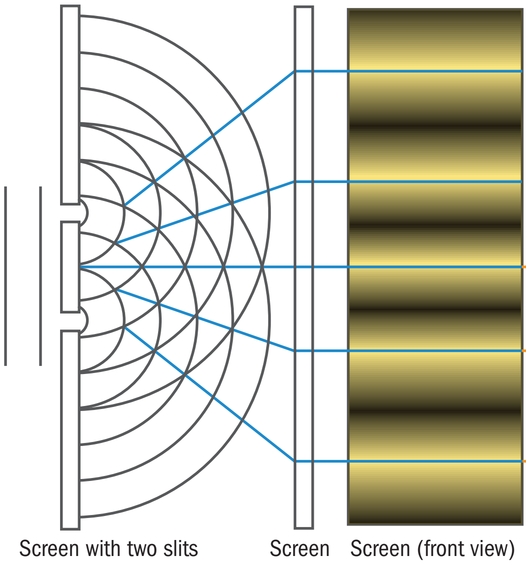


Standing waves

A standing wave is formed by waves travelling in opposite directions. Points where the waves destructively interfere are called nodes. Points of maximum disturbance are antinodes.



Double slit

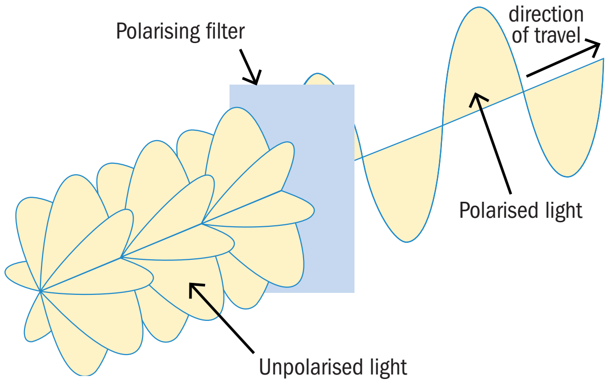


If light waves pass through closely spaced slits onto a screen, bright and dark fringes can be seen.

Appearance	Path difference	Phase difference
Bright	0	0
Dark	$\lambda/2$	π
Bright	λ	2π
Dark	$3\lambda/2$	3π
Bright	2λ	4π

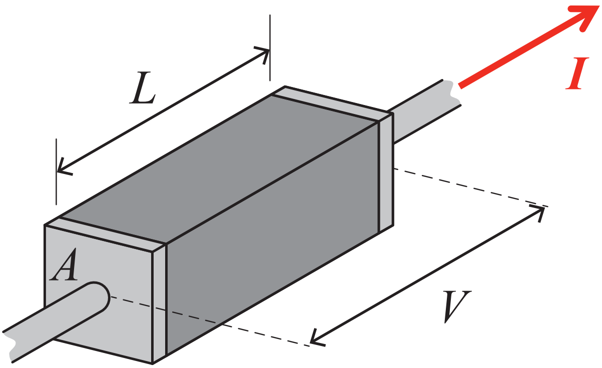
Polarisation

Plane polarised light waves are light waves in which the electric field variations occur in a single plane.



Electricity

For a resistor in an electric circuit:



Current

$$I = \frac{Q}{t}$$

Potential difference (p.d)

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

Where Q is the charge flowing into (or out of) the resistor and W is the energy transferred to the resistor by electrical working.

Electrical resistance

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

$$R = \rho \frac{L}{A}$$

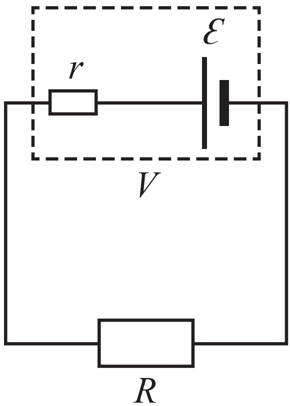
ρ = resistivity
A = cross sectional area
L = length of resistor

emf

$$\mathcal{E} = \frac{W}{Q}$$

Where Q is the charge flowing into (or out of) the power supply and W is the work done by the power supply.

Internal resistance



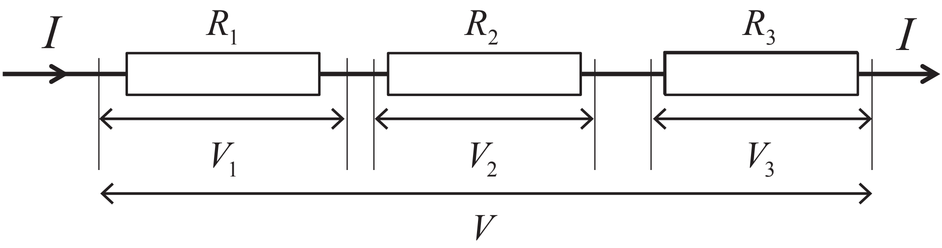
Real cells (and batteries) dissipate energy when there is a current. This can be represented by an "ideal" supply of emf $\mathcal{E}$ connected in series with an internal resistance r.

$$\mathcal{E} = Ir + V$$

Series circuits

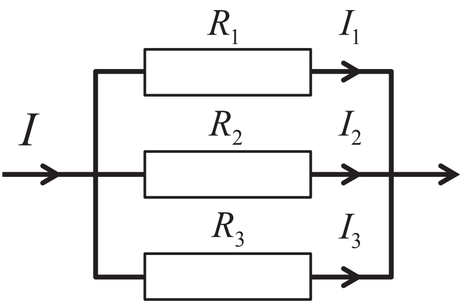
The current through the components is the same.

$$V = V_1 + V_2 + V_3 \qquad R = R_1 + R_2 + R_3$$



Parallel circuits

The p.d. across the components is the same.

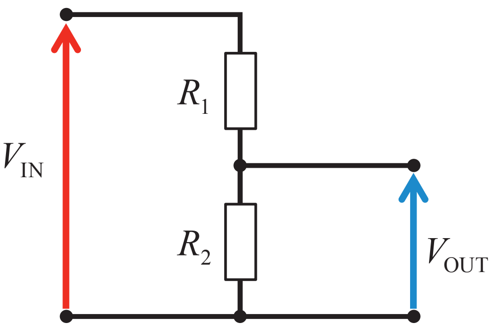


$$I = I_1 + I_2 + I_3$$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Potential divider

The total p.d. is divided between the two resistors according the ratio of their resistances.

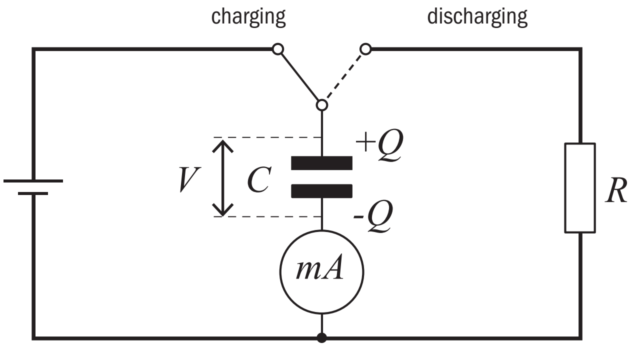


$$V_{\mathrm{OUT}} = V_{\mathrm{IN}} \times \frac{R_2}{R_1 + R_2}$$

Capacitance

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

Where Q is the size of the equal and opposite charge stored on the capacitor plates and V is the p.d across the capacitor.

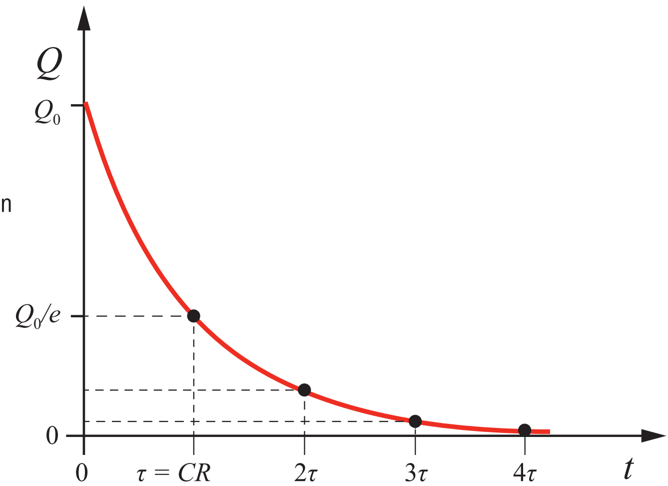


Discharge circuit

$$Q = Q_0 e^{-t/CR}$$

Time constant τ is time taken for Q to reach Q_0/e.

$$\tau = CR$$



The p.d. and current in discharge circuit also decay exponentially.

$$V = V_0 e^{-t/CR}$$

$$I = I_0 e^{-t/CR}$$

Energy calculations

Work done electrically

$$W = IVt$$

Energy stored by capacitor

$$E = \frac{1}{2} QV$$

Power dissipated by a resistor

$$P = IV$$

$$P = I^2R$$

$$P = V^2/R$$

Thermal Physics

Temperature scales

$T/K = \theta/°C + 273.15$, where T is temperature in kelvin and θ is temperature in degrees Celsius.

Changes in temperature have the same value in both scales ($\Delta T = \Delta\theta$).

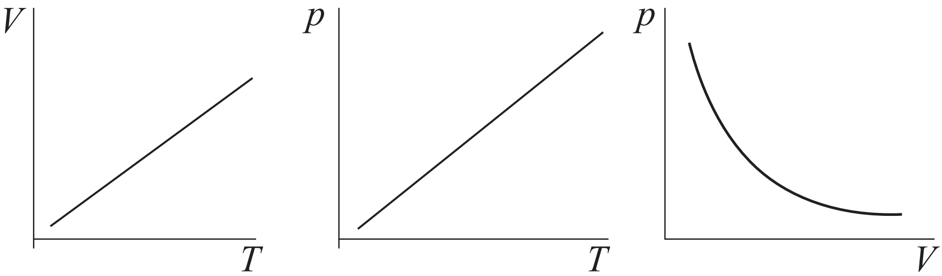
Zero on the kelvin scale is absolute zero, the temperature at which an ideal gas exerts zero pressure and occupies zero volume.

Ideal gas

For a fixed mass of gas:

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

p = gas pressure
V = volume of gas



$$pV = Nk_\mathrm{B}T$$

k_B = Boltzmann constant
N = number of particles in the gas

$$pV = \frac{1}{3}Nm\langle \mathrm{v}^2 \rangle$$

m = mass of each gas particle
$\langle \mathrm{v}^2 \rangle$ = mean squared speed of gas particles

Specific heat capacity

If the temperature of a mass m of the material changes, the associated energy E transferred into the material by heating is:

$$E = mc\Delta T$$

or

$$E = mc\Delta\theta$$

Where c is the specific heat capacity of the material.

Fields and Forces

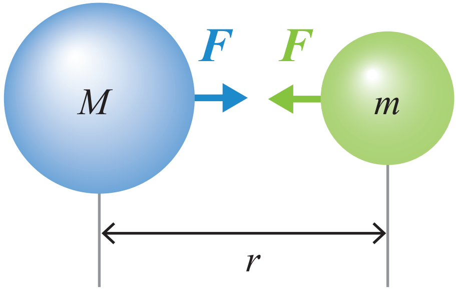
Gravitational forces

Force between two masses M and m is:

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

r = distance between centre of masses

G = Gravitational constant



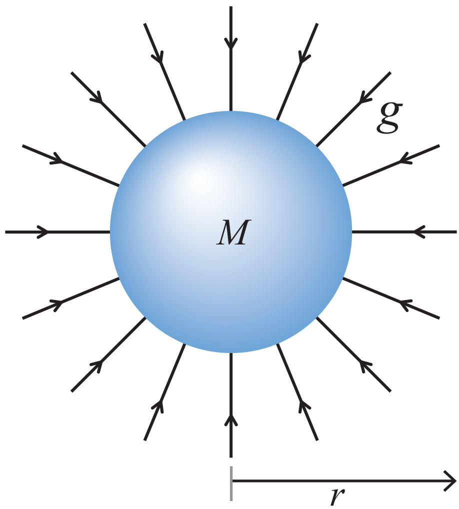
Gravitational fields

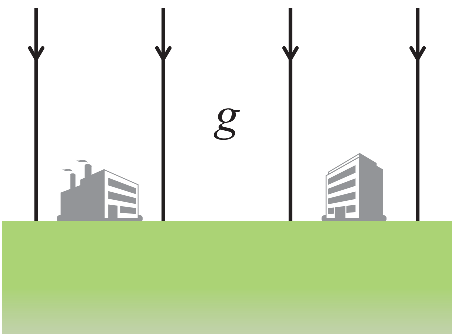
Gravitational field strength:

$$g = \frac{F}{m}$$

Field due to a spherical mass M:

$$g = \mathrm{G}\,\frac{M}{r^2}$$





Near the surface of the earth g is uniform and has a magnitude of $g = GM_E/R_E^2 = 9.8\ \mathrm{N\,kg^{-1}}$, where M_E is mass of the earth and R_E is radius of earth.

Electric forces

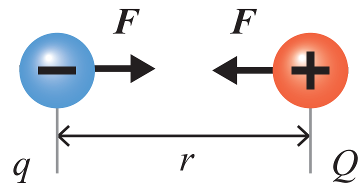
Force between two charges Q and q:

$$F = k\frac{Qq}{r^2}$$

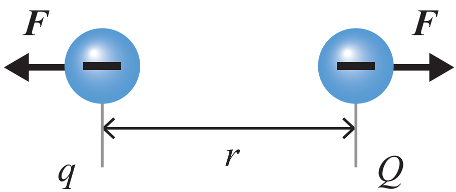
r = distance between centre of charges

k = electric force constant

Opposite charges attract:



Like charges repel

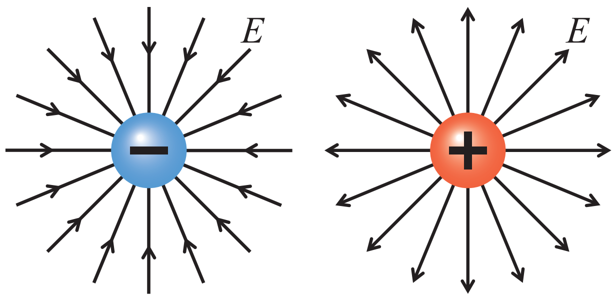


Electric fields

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

E = Electric field strength

q = small charge placed in the field

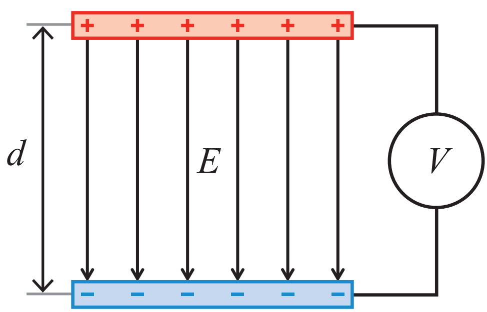


In a spherical electric field at a distance r from a point charge Q:

$$E = k\frac{Q}{r^2}$$

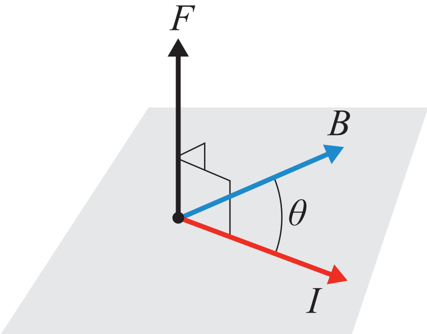
In a uniform electric field:

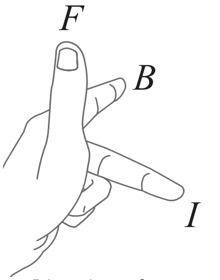
$$E = \frac{V}{d}$$



Magnetic forces

Force F on current carrying wire of length L in a magnetic field B:





$$F = BIL\sin\theta$$

Direction of current I is opposite to direction of electron flow.

Force on charged particle moving in a magnetic field

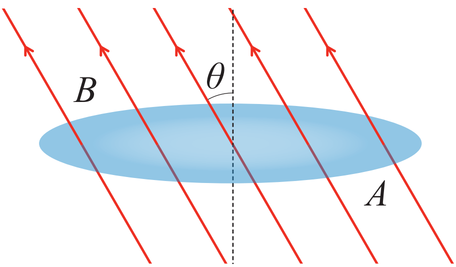
$$F = Bqv\sin\theta$$

q = particle's charge

v = particle's velocity

θ = angle between v and the B

Magnetic flux



$$\Phi = BA\cos\theta$$

For N turns total flux is $NBA\cos\theta$

Electromagnetic induction

Faraday's law

For a conductor in a changing magnetic field, the size of the emf induced is equal to the rate of change of magnetic flux or the rate of flux cutting.

$$\mathcal{E} = N\frac{\Delta\Phi}{\Delta t}$$

Lenz's law

The emf is induced in a direction which opposes whatever causes the induction.

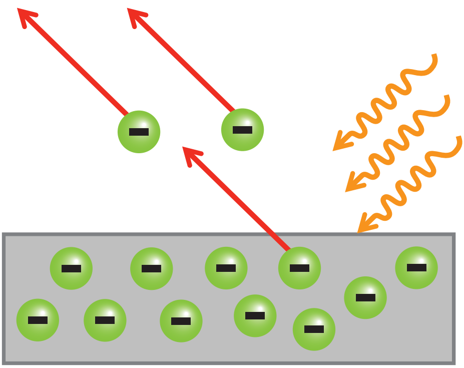
Quantum and Nuclear

Wave particle duality

Radiation and matter can behave as a wave or a particle.

Photoelectric effect: radiation behaving like a particle.

v_{max} is maximum speed of emitted electron.



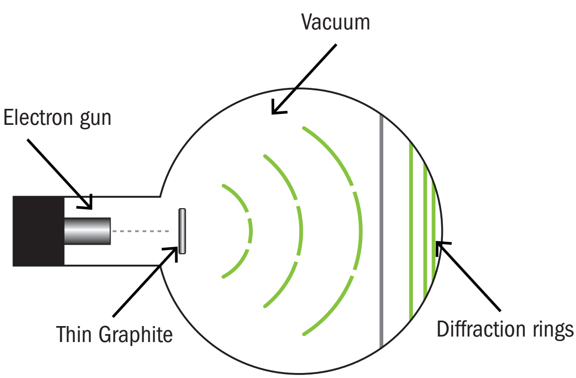
Energy of a photon is hf

$$hf = \Phi + \frac{1}{2}mv_{max}^2$$

Momentum of a photon $p = h/\lambda$,
where λ is the wavelength of the radiation.

Work function Φ is minimum energy required to free an electron from the surface of the metal.

Electron diffraction: matter behaving as a wave.

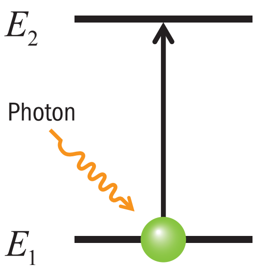


De Broglie Wavelength of an electron $\lambda = h/p$, where p is momentum of electron.

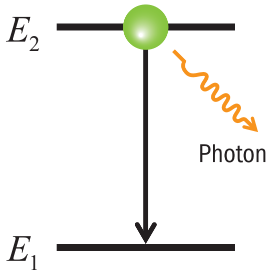
Electrons in atoms

Transitions only occur between discrete energy levels.

Absorption



Emission



Energy of the photon that is emitted or absorbed:

$$hf = E_2 - E_1$$

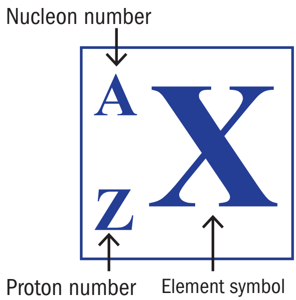
Atomic nuclei

Nuclei of atoms of the same element have the same number of protons.

Proton number is also known as charge number.

Nucleon number is total number of neutrons and protons (is also known as mass number).

Nuclei of the same element with different nucleon number are called isotopes.



Radioactive isotopes

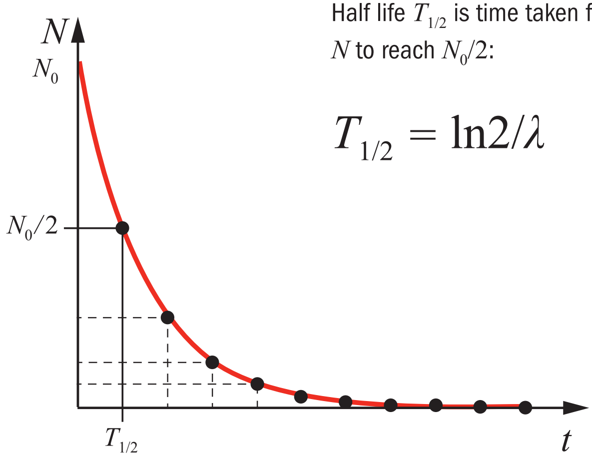
Unstable isotopes of nuclei undergo radioactive decay.

Activity of a radioactive source:

$$\frac{\Delta N}{\Delta t} = -\lambda N$$

Number of unstable nuclei:

$$N = N_0 e^{-\lambda t}$$



Half life $T_{1/2}$ is time taken for N to reach $N_0/2$:

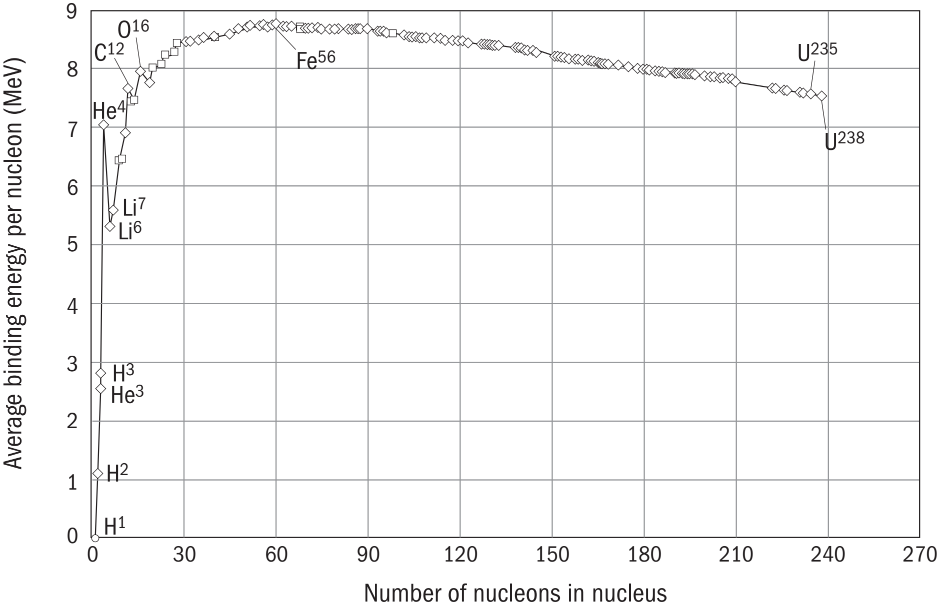
$$T_{1/2} = \ln 2/\lambda$$

Nuclear binding energy

$$E = \Delta mc^2$$

mass defect Δm = sum of mass of individual nucleons – mass of nucleus

c = the speed of light in a vacuum.



Nuclear reactions

Fusion: light nuclei join to make heavier nuclei.

Fission: heavy nuclei split to make lighter nuclei.

Units & Data

The International System of Units (SI) is the standard system of units for scientists and engineers worldwide. There are seven base units, from which all other units are derived.

Base quantity	**Base unit**
Mass	kilogram (kg)
Distance	metre (m)
Time	second (s)
Electric current	ampere (A)
Temperature	kelvin (K)
Amount of substance	mole (mol)
Luminous intensity	candela (cd)

All base units are defined in terms of fundamental natural constants such as c, the speed of light. Find out more at: **www.npl.co.uk/si-units**

Example of a derived quantity	**Unit**	**Expressed in base units**
Acceleration	metre per second squared	$m\,s^{-2}$
Force	newton (N)	$kg\,m\,s^{-2}$
Energy	joule (J)	$kg\,m^{2}\,s^{-2}$
Pressure	pascal (Pa)	$kg\,m^{-1}\,s^{-2}$
Charge	coulomb (C)	A s
EMF / potential difference	volt (V)	$A^{-1}\,kg\,m^{2}\,s^{-3}$
Electical field strength	newton per coulomb (NC^{-1}) or volt per metre (Vm^{-1})	$A^{-1}\,kg\,m\,s^{-3}$
Capacitance	farad (F)	$A^{2}\,kg^{-1}\,m^{-2}\,s^{4}$
Magnetic field strength	tesla (T)	$A^{-1}\,kg\,s^{-2}$

SI Prefixes

Greater than unity							
10^3	10^6	10^9	10^{12}	10^{15}	10^{18}	10^{21}	10^{24}
kilo	**M**ega	**G**iga	**T**era	**P**eta	**E**xa	**Z**etta	**Y**otta

Less than unity							
10^{-3}	10^{-6}	10^{-9}	10^{-12}	10^{-15}	10^{-18}	10^{-21}	10^{-24}
milli	μ (**micro**)	**n**ano	**p**ico	**f**emto	**a**tto	**z**epto	**y**octo

Selected constants

Constant	**Symbol**	**Value**	**Unit**
Speed of light in a vacuum	c	2.9979×10^8	m s^{-1}
Elementary charge (magnitude of the charge of electron)	e	1.6022×10^{-19}	C
Planck constant	h	6.6261×10^{-34}	J s
Gravitational constant	G	6.6743×10^{-11}	N m^2 kg^{-2}
Boltzmann constant	k_B	1.3806×10^{-23}	J K^{-1}
Electric force constant	k	8.9876×10^9	N m^2 C^{-2}

Astronomical data

Body	**Mass/kg**	**Mean radius/m**
Sun	1.9891×10^{30}	6.9551×10^8
Earth	5.9722×10^{24}	6.3710×10^6

Atomic data and units

Particle	**Rest mass/kg**
Electron	9.1095×10^{-31}
Proton	1.6726×10^{-27}
Neutron	1.6750×10^{-27}

Unit	**Symbol**	**Equivalent to**
Electronvolt	eV	1.6022×10^{-19} J
Atomic mass unit	u	1.6605×10^{-27} kg

All values given to 5 significant figures

Notes

Notes

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