Paper 1 Cheat Sheet

1 Measurements and their errors

Precision - There is very little spread around the mean value
Repeatability - If the same experimenter repeats the investigation using the same method and equipment and obtains the same results
Reproducibility - If a different experimenter repeats the investigation, or uses a different experiment or technique, the same results are obtained
Accuracy - Close to the true value

Combination	Operation
Adding or subtracting $a = b + c$	Add the absolute uncertainties $\Delta a = \Delta b + \Delta c$
Multiplying values $a = b \times c$	Add the percentage uncertainties $\epsilon a = \epsilon b + \epsilon c$
Dividing values $a = \frac{b}{c}$	Add the percentage uncertainties $\epsilon a = \epsilon b + \epsilon c$
Power rules $a = b^c$	Multiply the percentage uncertainty by the power $\epsilon a = c \times \epsilon b$

2 Particles and radiation

2.1 Constituents of the atom

Protons and neurons in the centre, with shells of electrons around them

$$\text{Specific charge} = \frac{Q}{m}$$

Isotope - An atom with the same number of protons and electrons as an element, but a different number of neutrons

2.2 Stable and unstable nuclei

2.2.1 The strong nuclear force

$< 0.5fm$	Repulsion
$0.5 - 3fm$	Attraction
$3fm+$	No force

2.2.2 Alpha decay

$$^A_ZX \rightarrow ^{A-4}_{Z-2}Y + ^4_2\alpha$$

2.2.3 Beta decay

$$^A_ZX \rightarrow ^A_{Z+1} + ^0_{-1}\beta + \overline{\nu}$$

Neutrinos were hypothesised to allow for energy to be conserved in the interaction

2.3 Particles, antiparticles and photons

2.3.1 Particle antiparticle pairs and their properties

Property	**Particle**	**Antiparticle**
Mass	x	x
Charge	x	-x
Rest Energy	x	x
Baryon Number	x	-x
Lepton Number	x	-x
Strangeness	x	-x

2.3.1.1 Mesons

2.3.1.1.1 Pions(All 0 Strangeness)

π^0	$U\bar{U}$ or $D\bar{D}$
π^+	$U\bar{D}$
π^-	$D\bar{U}$

2.3.1.1.2 Kaons (All strange)

K^+	$U\bar{S}$
K^-	$\bar{U}S$
K^0	$D\bar{S}$
$\bar{K}^0$	$\bar{D}S$

2.3.2 The photon model of electromagnetic radiation

A photon is a particle whose energy depends on its frequency. Formulas can be found on the data sheet to calculate this relationship

2.3.3 Methods of annihilation and pair production

2.3.3.1 Annihilation

When a particle and an antiparticle meet, they annihilate each other, releasing two photons, with energy sum equivalent to the sum of the energy of the particle and antiparticle. This energy can be calculated from the rest energy values on the data sheet.

$$hf_{min} = E_0$$

2.3.3.2 Pair production

In pair production a photon creates a particle and an antiparticle

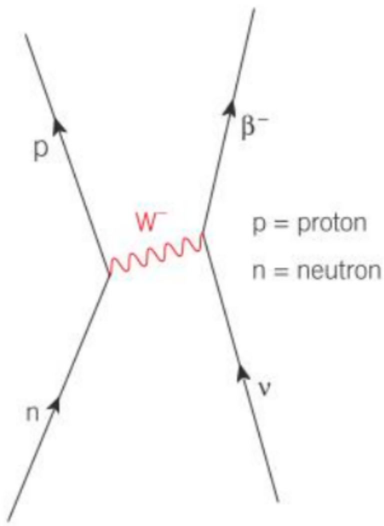
$$hf_{min} = 2E_0$$

2.4 Particle interactions

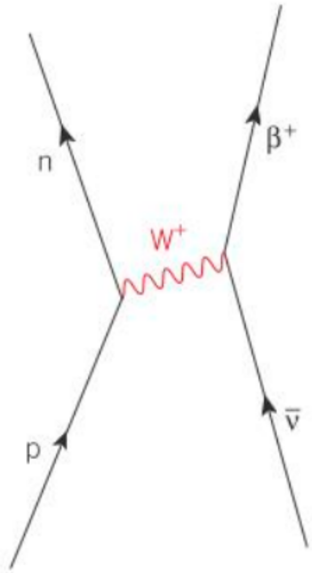
2.4.1 The four fundamental interactions

Force	**Affects**	**Gauge Boson**	**Range**
Gravitational	Mass	Graviton	Infinite
Electromagnetic	Charge	Photon	Infinite
Nuclear Strong	Quarks	Gluon(Pion)	10^{-15}m
Nuclear Weak	Leptons+Quarks	W^+, W^-, Z^0	10^{-18}m

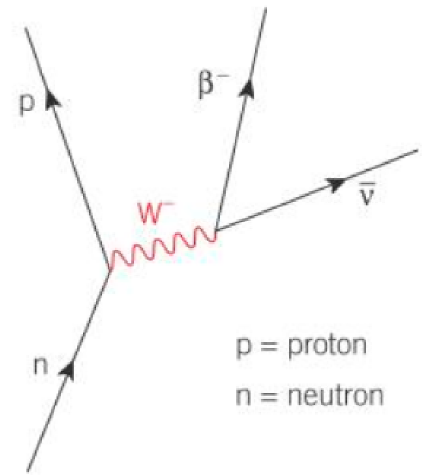
2.4.2 Diagrams to represent the interactions



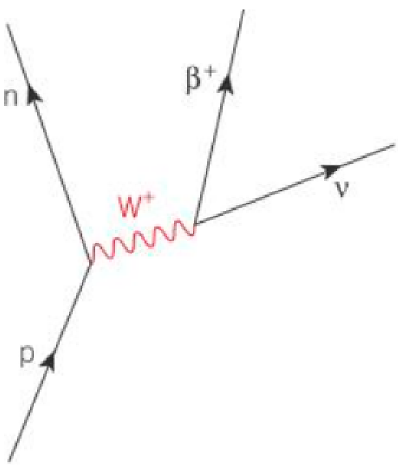
a *A neutron–neutrino interaction*



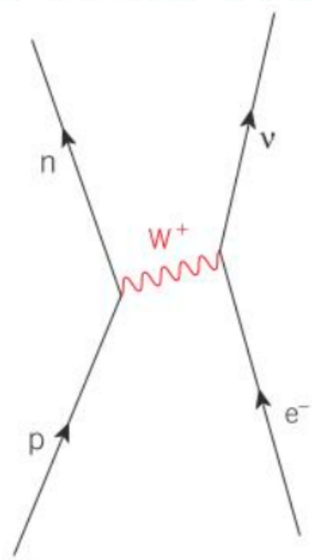
b *A proton–antineutrino interaction*



a *β− decay*



b *β+ decay*



▲ **Figure 5** *Electron capture*

2.5 Classifications of particles

	Hadron		Lepton			
	Baryon	Meson	Electron	Muon	Electron neutrino	Muon neutrino
What it is	3 quarks	Quark antiquark pair				

2.5.0.1 Baryons

- Baryon number is conserved during interactions
- The proton is the only stable baryon, all other baryons decay to it

2.5.0.2 Kaons and pions

Kaons (K mesons) decay into Pions(π mesons), they decay by the weak interaction, so strangeness need not be conserved

$$K^+ \rightarrow \mu^+ + \nu_\mu$$
$$K^+ \rightarrow \pi^+ + \pi^0$$
$$K^- \rightarrow \mu^- + \overline{\nu_\mu}$$
$$K^- \rightarrow \pi^- + \pi^0$$
$$K^- \rightarrow \pi^0 + \mu^- + \overline{\nu_\mu}$$

2.5.0.3 Leptons

Lepton number is conserved in an interaction, muons decay into electrons

$$\mu^- \rightarrow e^- + \overline{\nu_e} + \nu_\mu$$

$$\mu^+ \rightarrow e^+ + \nu_e + \overline{\nu_\mu}$$

2.5.0.4 Strange particles

Strange particles are produced through the strong interaction and decay through the weak interaction, this is because strangeness is conserved during the strong interaction, but not during the weak interaction.

2.5.1 Quarks and antiquarks

Differences between quarks and antiquarks

- Opposite strangeness
- Opposite charge
- Opposite strangeness

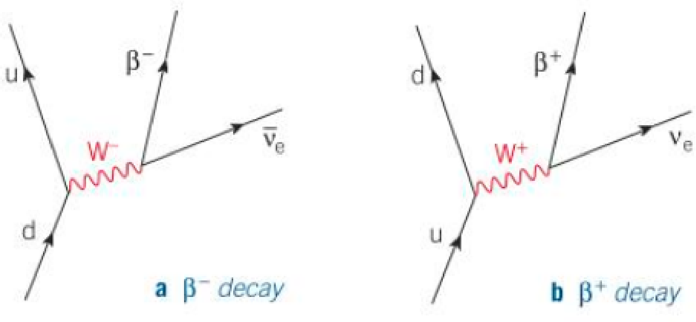
2.5.1.1 Quark compositions

- Proton -UUD
- Neutron - DUD
- Pion - Not strange, sign indicates charge
- Kaon - Strange, sign indicates charge

2.5.2 Applications of conservation laws

Changes of quark nature

- β^-, down $\rightarrow$ up
- β^+, up $\rightarrow$ down



▲ **Figure 3** *Quark changes in beta decay*

In all interactions, energy and momentum must be conserved

2.6 Electromagnetic radiation and quantum phenomena

2.6.1 The photoelectric effect

Photoelectric effect - The emission of electrons from a metal surface when the surface is illuminated by a light of frequency greater than a minimum value known as the threshold frequency

2.6.1.1 Threshold frequency

Because the energy of a photon is proportional to its frequency ($E = hf$), a minimum frequency must be reached so that the electrons have sufficient energy to escape the surface

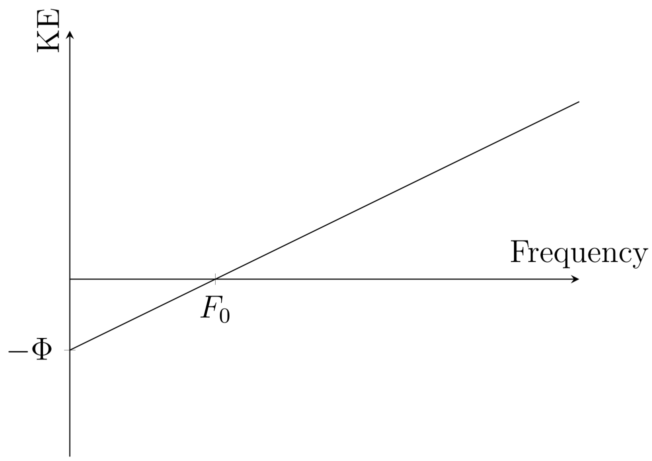
2.6.1.2 Work function and stopping potential

Work function - The minimum amount of energy needed by an electron to escape from a metal surface
Stopping potential - The potential difference required to stop an electron

2.6.1.3 The photoelectric equation

$$hf = \phi + E_{K(Max)}$$

hf is the energy of the incident photon
ϕ is the work function
$E_{K(max)}$ is the maximum kinetic energy
Electrons emitted will have a range of kinetic energies, depending how much work is done to escape the metal



The gradient of the line is Planck's constant

2.6.2 Collisions of electrons with atoms

2.6.2.1 Ionisation and excitation

Ion - A charged atom
Ionisation - The process of creating ions
Excitation - The process in which an atom absorbs energy without becoming ionised as a result of an electron inside an atom moving from an inner shell to an outer shell

2.6.2.2 The fluorescent tube

- Ionisation and excitation of the mercury atoms as they collide with each other and the electrons in the tube
- The mercury atoms emit visible and ultraviolet photons when they de excite
- The ultraviolet photons are absorbed by the atoms in the fluorescent coating, causing them to excite
- The atoms in the coating de excite, emitting visible light

2.6.2.3 The electron volt

Electron volt - The work done when an electron is moved through a P.D. of 1V

2.6.3 Energy levels and photon emission

2.6.3.1 Line spectra

Light is emitted from an atom when the electrons in it de-excite. Because the line spectra are discrete, this suggests that only certain changes in energies are possible in the atom, implying discrete energy levels

$$hf = E_1 - E_2$$

Energies given in joules

2.6.4 Wave particle duality

2.6.4.1 Electron diffraction

When electrons are fired at a slit, they exhibit the same behaviour as light does, implying that particles can posses wave properties.

2.6.4.2 The photoelectric effect

Because there is a threshold frequency for the photoelectric effect, light must have a particle nature, where one particle provides the energy to release the electron. If it had a wave nature, given enough time, an electron would be released, regardless of frequency

2.6.4.3 The de Broglie Wavelength

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

This causes the amount of diffraction to change based on the momentum of the particle, the greater the momentum, the smaller the wavelength, and so the less diffraction.

3 Waves

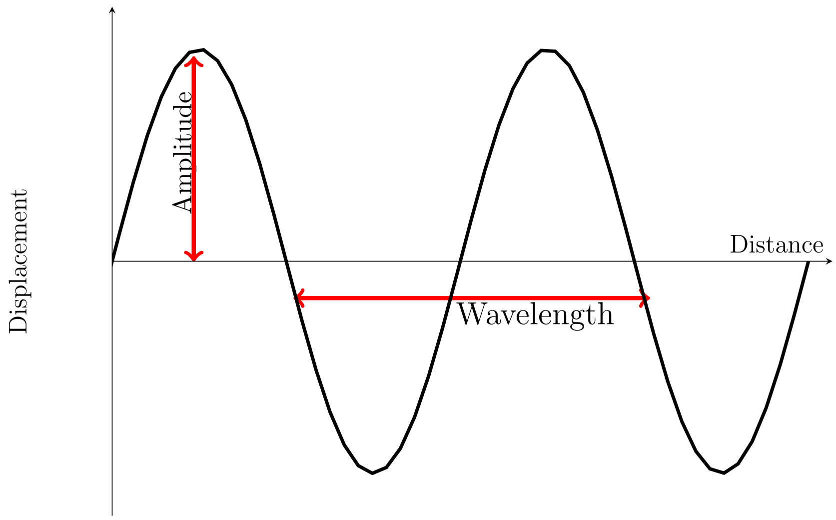
3.1 Progressive and stationary waves

3.1.1 Progressive waves

Amplitude - The maximum displacement of a vibrating particle
Frequency - The number of cycles of a wave that pass a point per second
Period - The time for one complete cycle of a wave to pass a point
Wavelength - The least distance between two vibrating particles with the same displacement and velocity at the same time
Phase - The position of a point in time on a waveform cycle
Phase difference - The fraction of a cycle between the vibrations of two vibrating particles

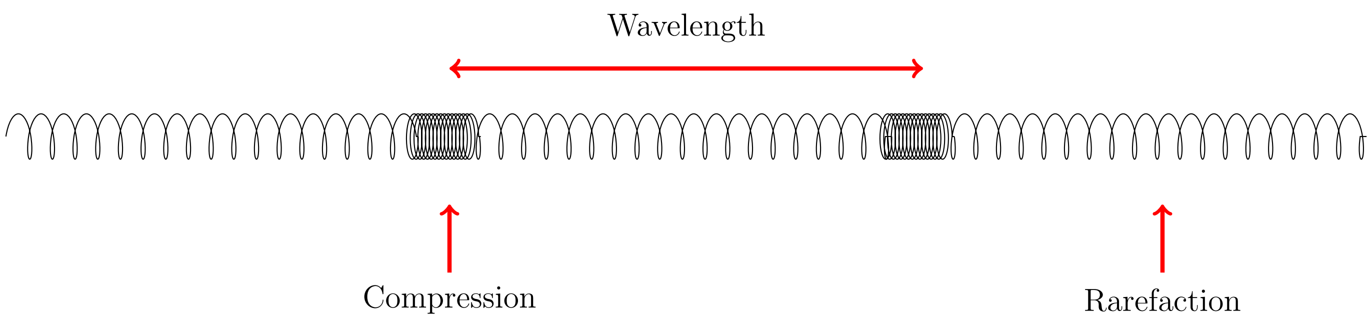
3.1.2 Longitudinal and transverse waves

3.1.2.1 Transverse wave



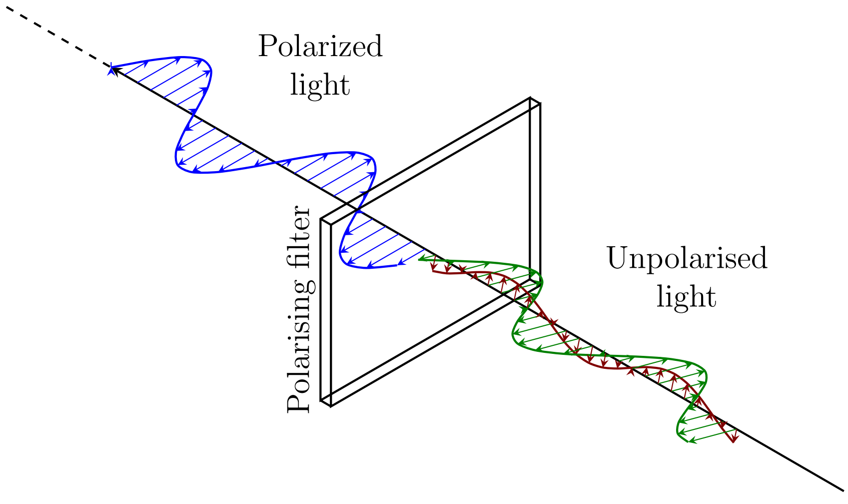
Wave direction and energy are perpendicular

3.1.2.2 Longitudinal wave



Wave direction and energy are parallel

3.1.2.3 Polarisation

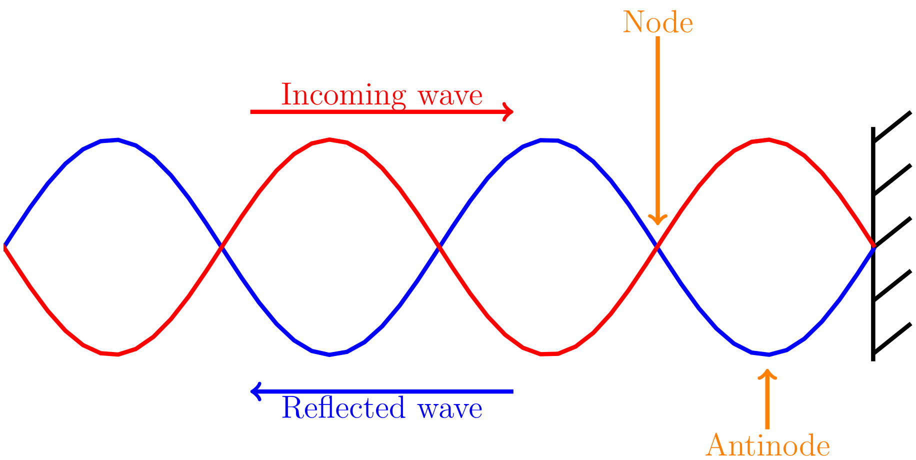


Polarised light all travels in the same direction
Unpolarised light travels in all directions

Unpolarised light can be polarised using a polarising filter which contains stripes, only allowing one direction of light through
Only transverse waves can be polarised

3.1.3 Principle of superposition of waves and formation of stationary waves

Stationary waves are formed when a wave collides with itself after reflection



When both waves are at equilibrium there is a **node**
When one wave is at a maximum and one at a minimum there is an **antinode**

Stationary wave - Wave pattern with nodes and antinodes formed when two or more progressive waves of the same frequency and amplitude pass through each other
Node - A fixed point in a stationary wave pattern where the amplitude is zero
Antinode - A fixed point in a stationary wave pattern where the amplitude is a maximum

3.1.3.1 Harmonics

$$f_1 = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$$

T - String tension
μ - Mass/Length

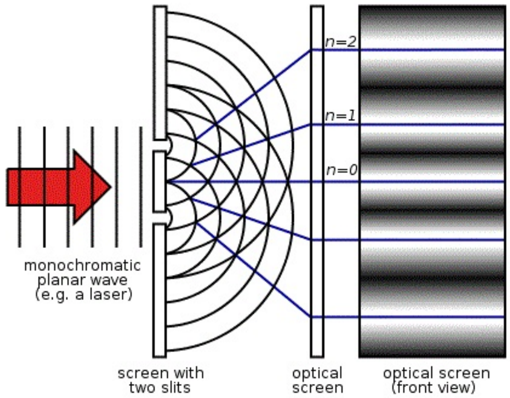
The formula for the nth harmonic is:

$$f_n = \frac{n}{2l}\sqrt{\frac{T}{\mu}}$$

3.2 Refraction, diffraction and interference

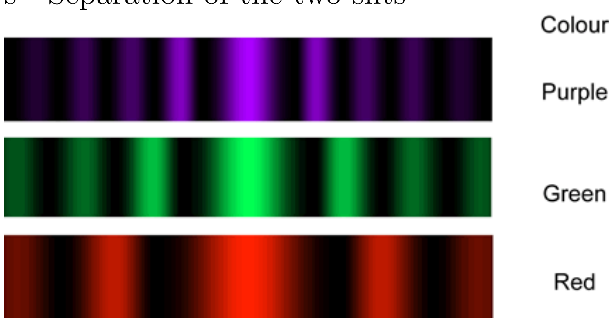
3.2.1 Interference

Path difference - The difference in distances from two coherent sources to an interference fringe
Coherence - Constant phase difference

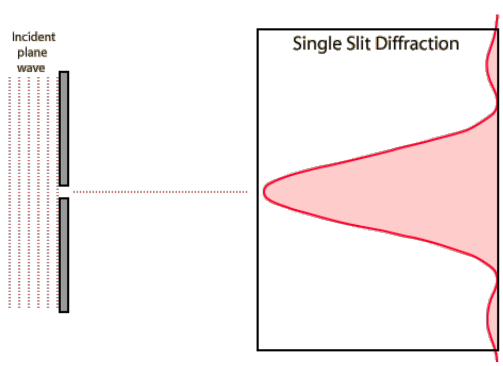


$$w = \frac{\lambda D}{s}$$

w- Separation of fringes (Distance between adjacent brightest points etc)
λ - Wavelength
D - Distance from slits to screen
s - Separation of the two slits

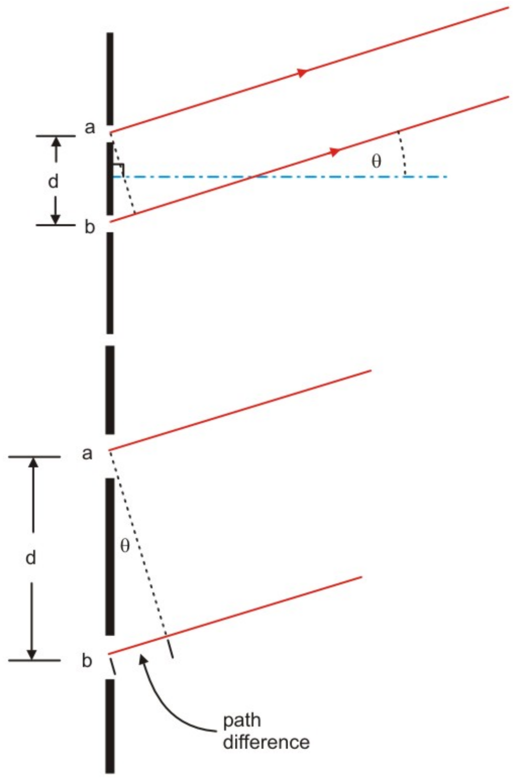


3.2.2 Diffraction



Increasing the width of the slit causes the central maxima to get narrower, this can be remembered from the fringe spacing formula, remember the central maxima is double the width calculated using that formula though.

3.2.2.1 Diffraction grating equation



Path difference $=d \sin \theta$
$n\lambda = d \sin \theta$

A diffraction grating can be used to analyse spectra

3.2.3 Refraction

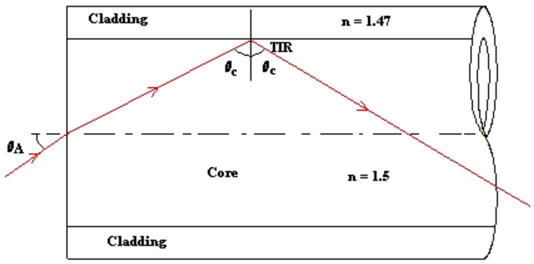
Refractive index - $\frac{\text{Speed of light in free space}}{\text{Speed of light in that medium}}$

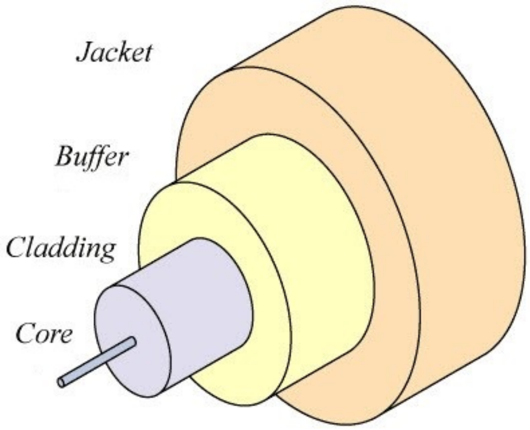
$$\text{Snell's law:} - n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\sin \theta_c = \frac{n_1}{n_2}$$

Total internal reflection occurs if the angle of incidence is **larger** than the critical value

3.2.3.1 Fibre optics





3.2.4 Modal Dispersion

Waves entering the fibre at different angles will reflect differently and so will have different path lengths

3.2.5 Material Dispersion

Different wavelengths of light enter the same but refract differently, causing a difference in path length

4 Mechanics and materials

4.1 Forces, energy and momentum

4.1.1 Moments

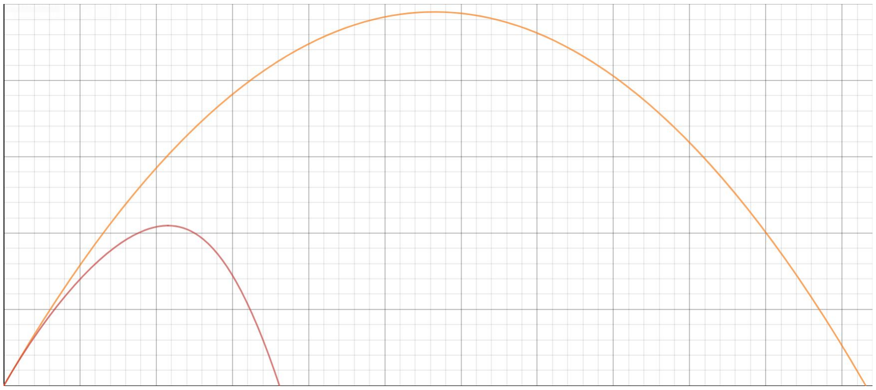
Moment - Force × perpendicular distance from the line of action of the force to the point
Couple - A pair of equal and opposite coplanar forces

$$\text{Moment of a couple} = Fd$$

Where F is one of the forces, and d is the distance between them
Principle of moments - For an object in equilibrium, the sum of clockwise moments equals the sum of anticlockwise moments
Centre of mass - The point through which a single force on the body has no turning effect

4.1.2 Projectile motion

4.1.2.1 The effect of air resistance



No Air Resistance
Air resistance

- Steeper descent
- Peak Further Left
- Smaller Range

4.1.3 Newton's laws of motion

1st law - An object remains at rest or in uniform motion unless acted on by a resultant force
2nd law - $F = ma$
3rd law - Every action has an equal and opposite reaction

4.1.4 Momentum

Momentum - Mass×Velocity
Impulse - Change in momentum per second
Elastic collision - No loss of kinetic energy
Inelastic collision - Loss of kinetic energy

4.1.5 Work, energy and power

When **work** is done **energy** is transferred

$$W = FS\cos\theta$$

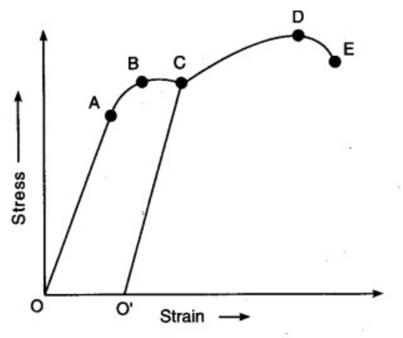
4.1.6 Conservation of energy

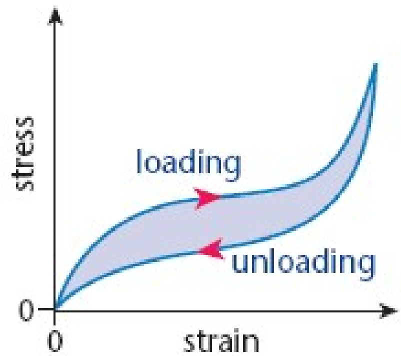
Principle of conservation of energy - Energy cannot be created or destroyed

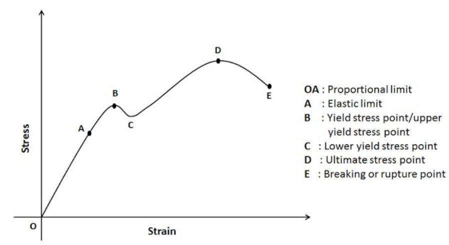
4.2 Materials

4.2.1 Bulk properties of solids

Hooke's law - Force is proportional to extension, provided the proportionality limit has not been reached
Breaking stress (Ultimate tensile stress) - Tensile stress needed to break a solid material
Plastic deformation - Deformation of a solid beyond its elastic limit
Brittle - Snaps without bending or stretching when subject to stress
Fracture - The separation of a material into two or more pieces when subject to stress







4.2.2 The Young Modulus

Young Modulus - Stress/Strain assuming the limit of proportionality has not been reached

5 Electricity

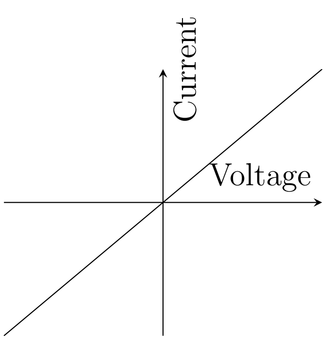
5.1 Current electricity

5.1.1 Basics of electricity

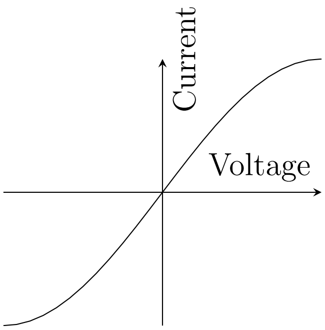
Current - The rate of flow of charge
Potential difference - Work done per unit charge
Resistance - Voltage/current

5.1.2 Current - Voltage characteristics

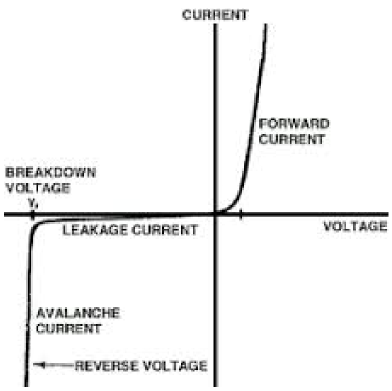
5.1.2.1 Ohmic Conductor



5.1.2.2 Bulb



5.1.2.3 Diode



Ohm's Law: Current is proportional to voltage under constant physical conditions

5.1.3 Resistivity

5.1.3.1 The effect of temperature on conductors

The lower the temperature, the less the vibration of the atoms, and resistance reduces
Superconductor - A material that has no electrical resistance
Critical temperature - The temperature below which a conductor becomes a superconductor

Superconductors are used for very high current applications.

5.1.4 Circuits

5.1.4.1 Resistor combinations

$$\text{Series}: R_T = R_1 + R_2 + R_3...$$
$$\text{Parallel}: \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ...$$

5.1.4.2 Voltage in series and parallel

Parallel: Voltage across components in parallel is the same
Series: The total voltage across all the components is the voltage supplied

5.1.4.3 Current in series and parallel

The current entering a component or junction is the same as the current leaving the component, meaning current in series is the same for each component.
For parallel circuits, use voltage and resistance to calculate

5.1.4.4 Power

$$P = \frac{E}{t}$$

5.1.4.5 Kirchoff's laws

Current in=Current out (Conservation of charge)
The sum of all the voltages around the system is zero (Conservation of energy)

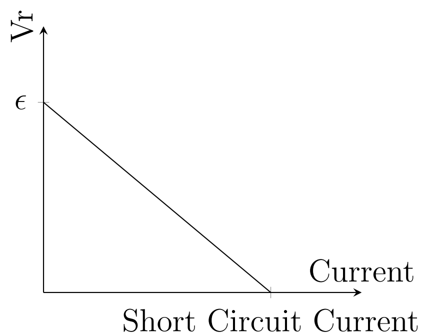
5.1.5 Potential divider

$$V_{Out} = V_{In}\frac{R_2}{R_1 + R_2}$$

Potential dividers can be used with environment sensors that change their resistance based on changed to the environment to change output voltage

5.1.6 The electromotive force and internal resistance

Electromotive force - The amount of electrical energy per unit charge produced inside a source of electrical energy
Internal resistance - Resistance inside a source of electrical energy
Terminal pd - The potential difference across the terminals of a power supply



The equation of this line can be derived from:

$$\epsilon = I(R + r)$$

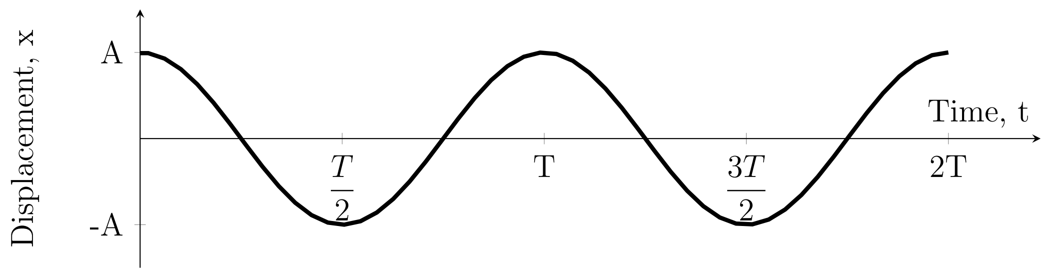
Remember that the terminal voltage is Ir

6 Periodic motion

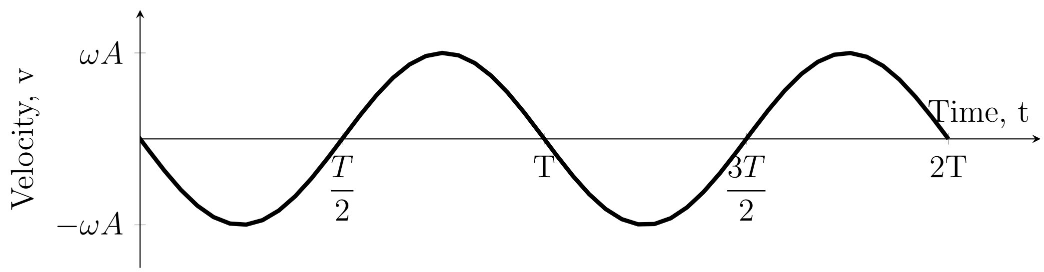
6.1 Circular motion

As circular motion has a constant speed but a changing direction, it is implied that there is a force perpendicular to the direction of motion, and so an acceleration
v (Velocity)- Displacement per unit time
ω (Angular velocity)- Angle per unit time

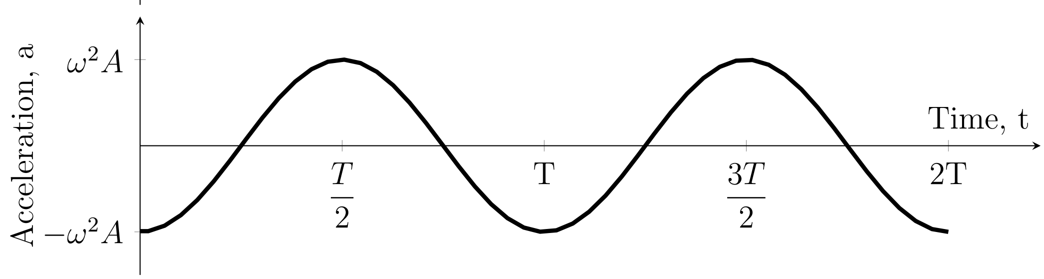
6.2 Simple harmonic motion



$x = Acos(\omega t)$



$v = -\omega A \sin(\omega t)$

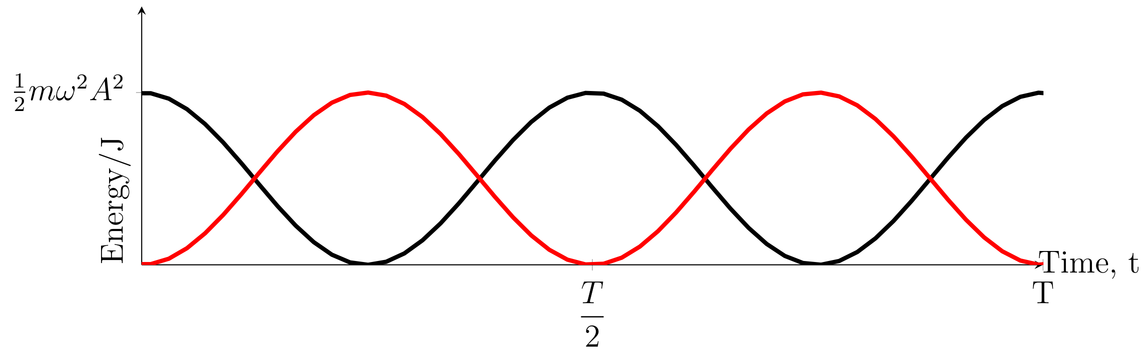


$a = -\omega^2 A \cos(\omega t)$

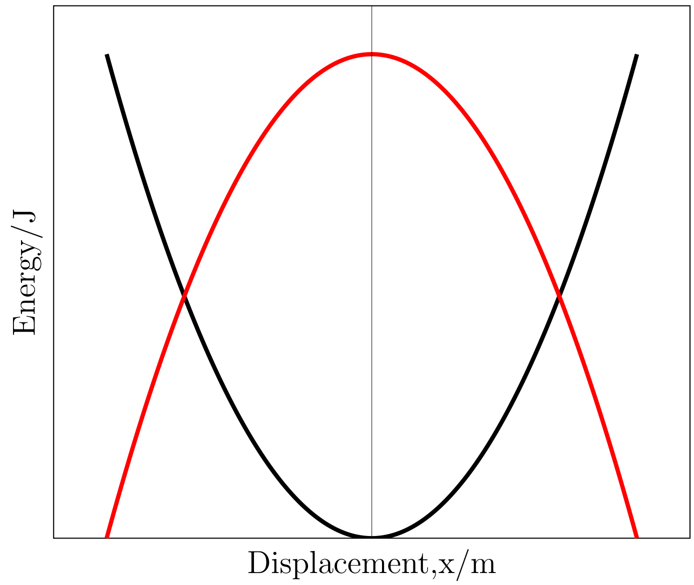
All these equations can be derived from the equation $x = A\cos(\omega t)$, by differentiating it with respect to time.
The maximum values of each of them can be found as the maximum value of cos or sin is 1

6.3 Simple harmonic systems

6.3.1 Energy in SHM

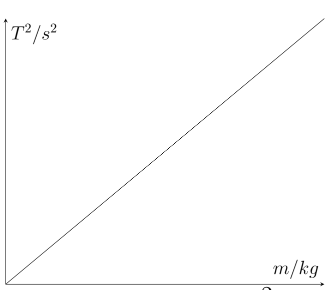


Red - Kinetic Energy
Black - Gravitational potential energy



6.3.2 Period of a mass-spring system

The period of a mass-spring system is $T = 2\pi\sqrt{\frac{m}{k}}$ or $T^2 = \frac{4\pi^2 m}{k}$



The gradient is $\frac{4\pi^2}{k}$
The line passes through the origin
This is only true for small oscillations as large oscillations go past the limit of proportionality

6.3.3 Energy in a vertically oscillating spring

	KE	GPE	Elastic Energy
Top	0	$2mgA$	$\frac{1}{2}k(e-A)^2$
Middle	Max=$\frac{1}{2}m\omega^2A^2$	mgA	$\frac{1}{2}ke^2$
Bottom	0	0	$\frac{1}{2}k(e+A)^2$

6.3.4 Damping

Damping is the reduction in amplitude due to energy losses (e.g. overcoming friction).

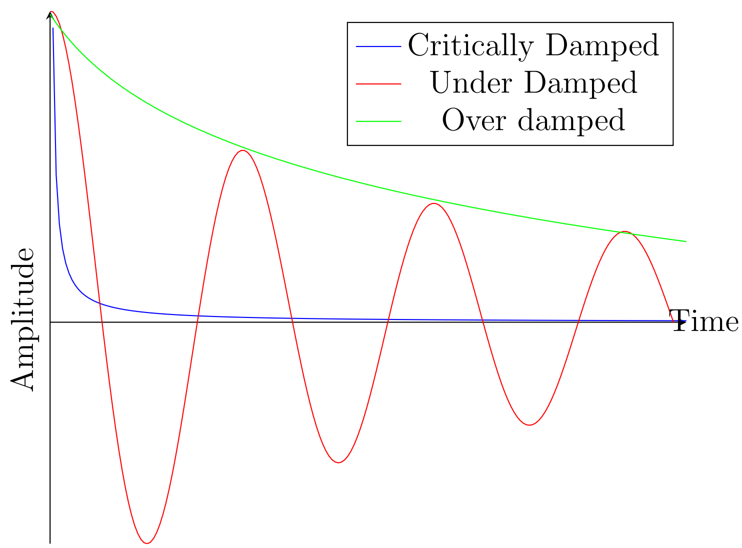
It will also cause the period to increase (it is essentially a driver).

Light(underdamping) - Small amplitude change per oscillation
Heavy(underdamping) - Large amplitude change per oscillation

Critical damping - Reaches equilibrium in the shortest possible time **without** oscillating

Over damping - Reaches equilibrium after a long period of time

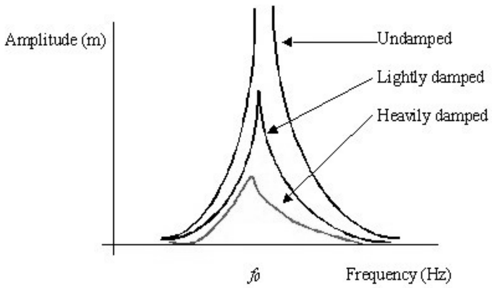
6.3.4.1 Damping graph



6.4 Forced vibrations and resonance

Free vibrations - Vibrations where there is no damping and no periodic force acting on the system, amplitude of the oscillations is constant
Forced vibrations - Vibrations of a system subjected to an external periodic force

6.4.1 The effects of damping on the sharpness of resonance



The less damping there is, the sharper the resonance

6.4.2 Standing waves

Standing waves can be produced at the resonant (natural) frequencies of a material, causing point on it to alternate between minimum and maximum amplitude, causing solid materials such as concrete to break.