

# 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 neutrons in the centre, with shells of electrons around them

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

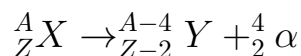
**Isotope** - An atom with the same number of protons and electrons as an element, but a different number of neutrons

### 2.2 Stable and unstable nuclei

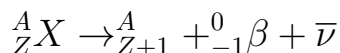
#### 2.2.1 The strong nuclear force

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

#### 2.2.2 Alpha decay



#### 2.2.3 Beta decay



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)

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

#### 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

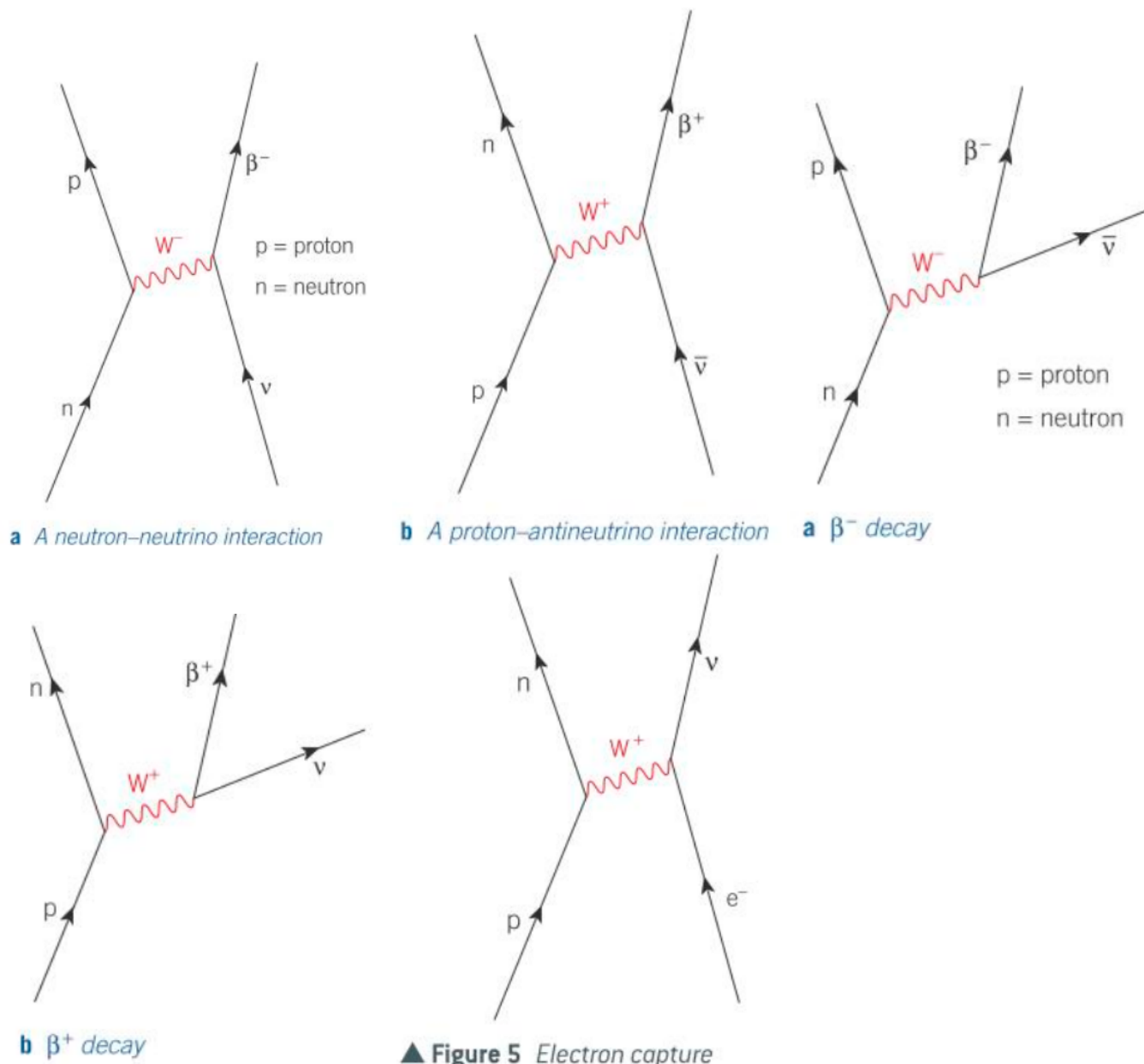
$$hf_{min} = 2E_0$$

## 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)	$10^{-15}\text{m}$
Nuclear Weak	Leptons+Quarks	$W^+, W^-, Z^0$	$10^{-18}\text{m}$

### 2.4.2 Diagrams to represent the interactions



### 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( $\pi$  mesons), they decay by the weak interaction, so strangeness need not be conserved

$$K^+ \rightarrow \mu^+ + \nu_\mu$$

$$K^+ \rightarrow \pi^+ + \pi^0$$

$$K^- \rightarrow \mu^- + \bar{\nu}_\mu$$

$$K^- \rightarrow \pi^- + \pi^0$$

$$K^- \rightarrow \pi^0 + \mu^- + \bar{\nu}_\mu$$

### 2.5.0.3 Leptons

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

$$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$$

$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

### 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

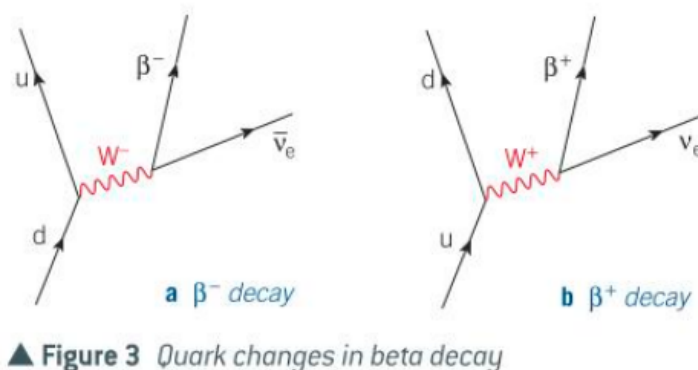
#### 2.5.1.1 Quark compositions

- 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

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



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

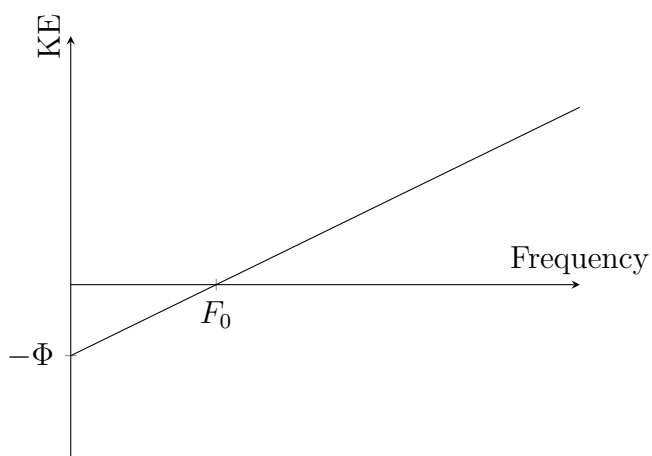
$$hf = \phi + E_{K(Max)}$$

$hf$  is the energy of the incident photon

$\phi$  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 possess 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

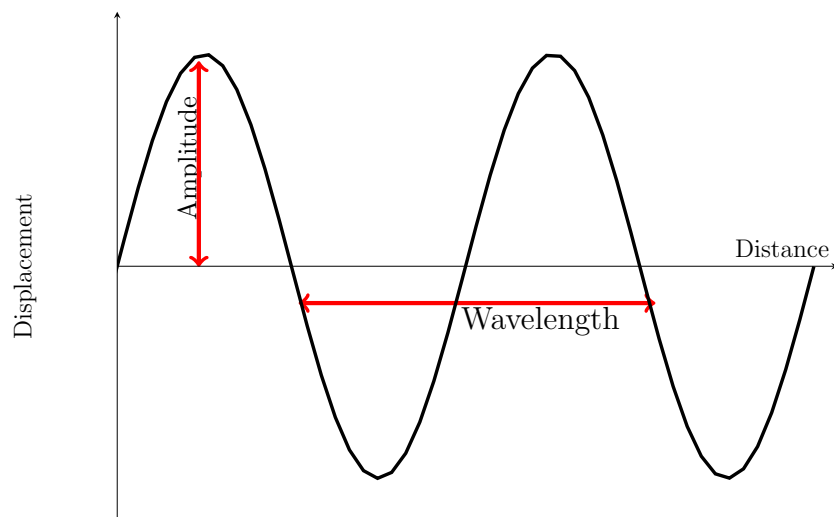
**Phase** - The position of a point in time on a waveform cycle

**Phase difference** - The fraction of a cycle between the vibrations of two vibrating particles



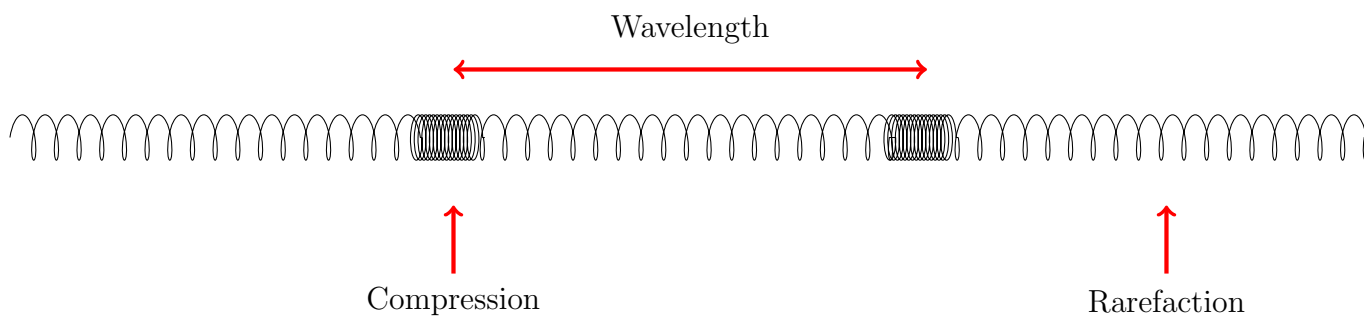
### 3.1.2 Longitudinal and transverse waves

#### 3.1.2.1 Transverse wave



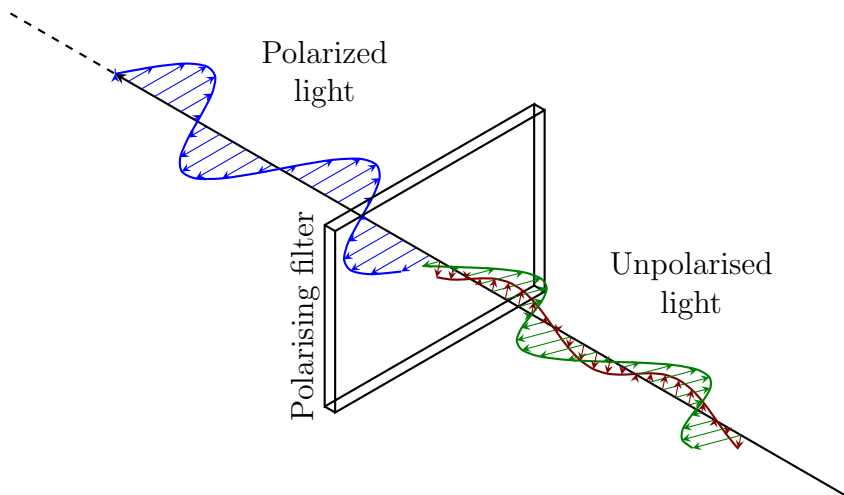
Wave direction and energy are perpendicular

#### 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

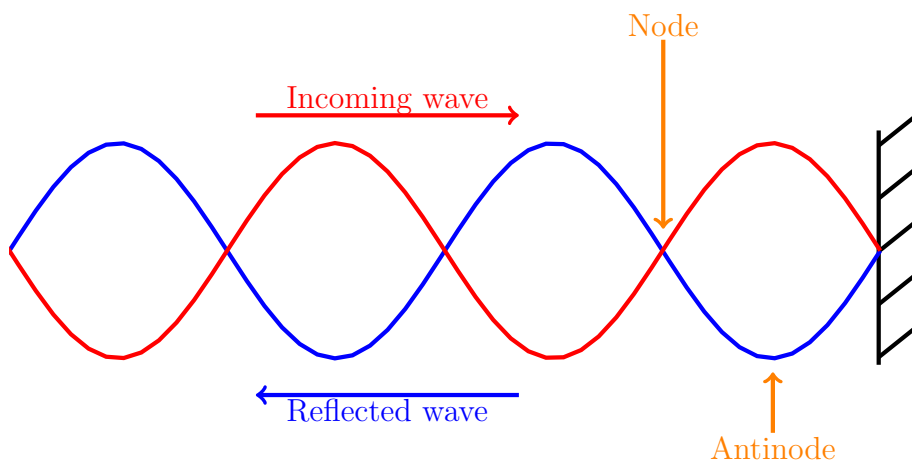
Unpolarised light travels in all directions

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

$\mu$  - Mass/Length

The formula for the nth harmonic is:

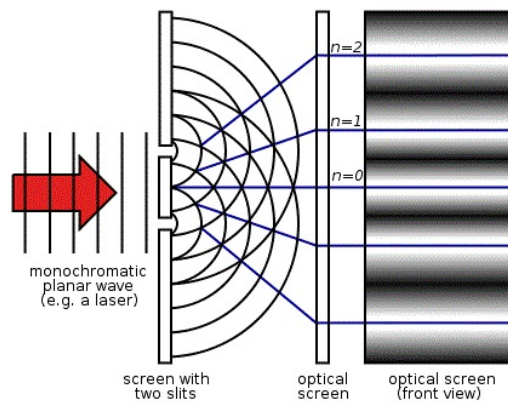
$$f_n = \frac{n}{2l} \sqrt{\frac{T}{\mu}}$$

## 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



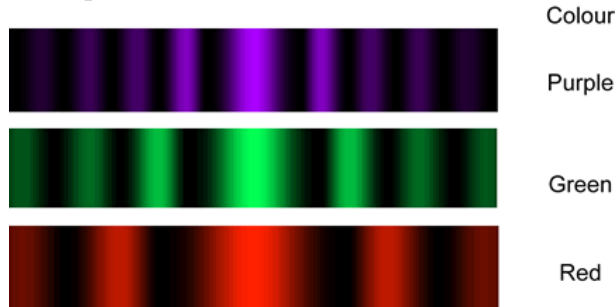
$$w = \frac{\lambda D}{s}$$

w- Separation of fringes (Distance between adjacent brightest points etc)

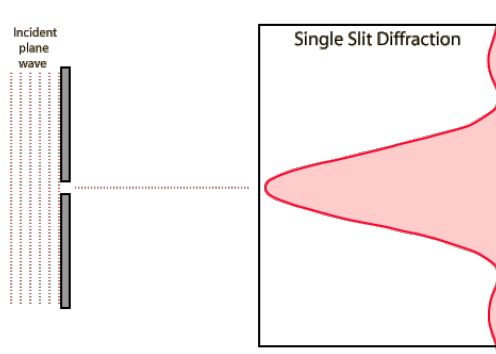
$\lambda$  - Wavelength

D - Distance from slits to screen

s - Separation of the two slits

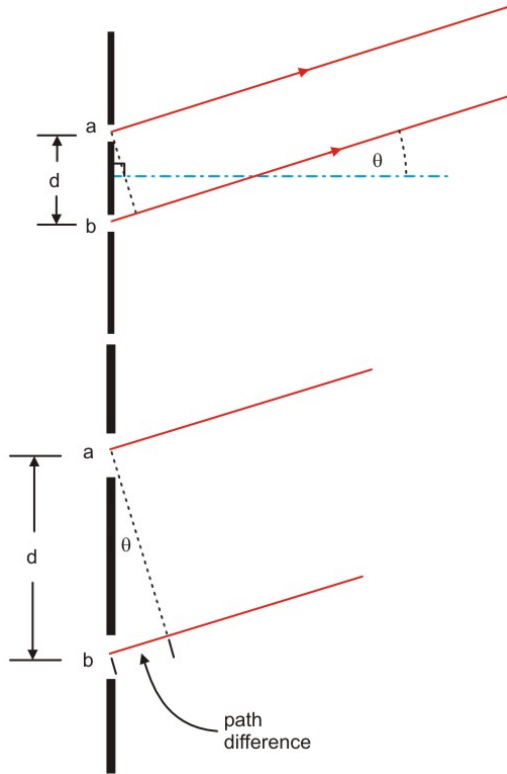


### 3.2.2 Diffraction



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

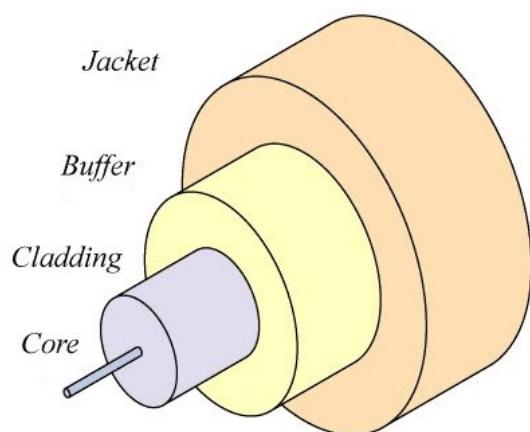
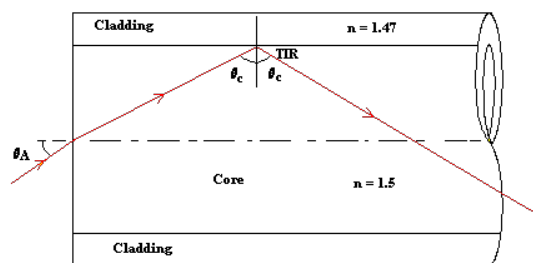
**Refractive index** -  $\frac{\text{Speed of light in free space}}{\text{Speed of light in that medium}}$

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

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

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  $\times$  perpendicular distance from the line of action of the force to the point

**Couple** - A pair of equal and opposite coplanar forces

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

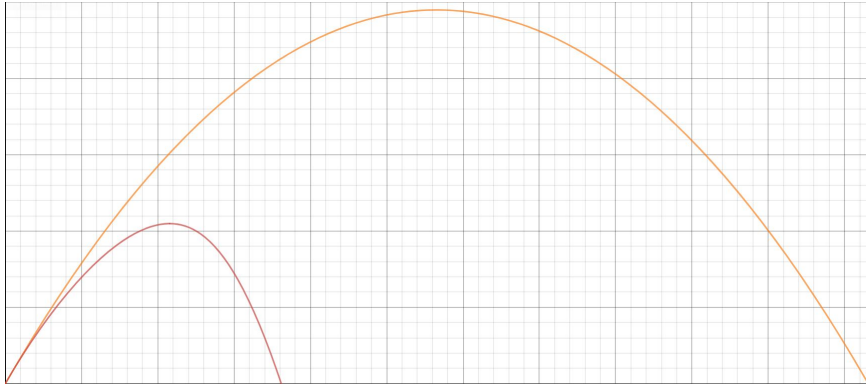
Where  $F$  is one of the forces, and  $d$  is the distance between them

**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  $\times$  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

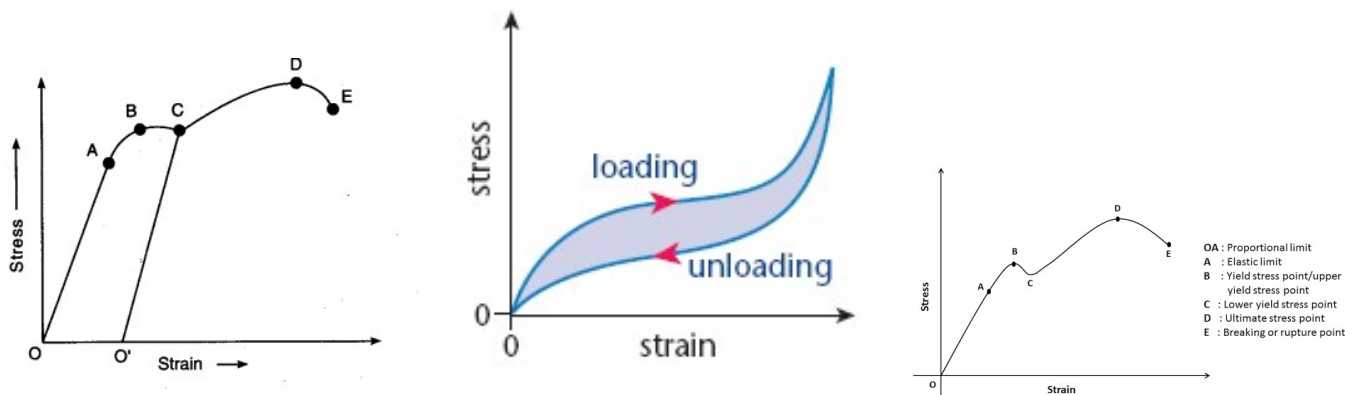
**Hooke's law** - Force is proportional to extension, provided the proportionality limit has not been reached

**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

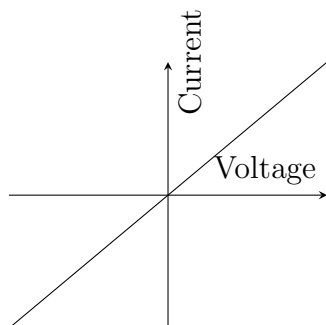
**Current** - The rate of flow of charge

**Potential difference** - Work done per unit charge

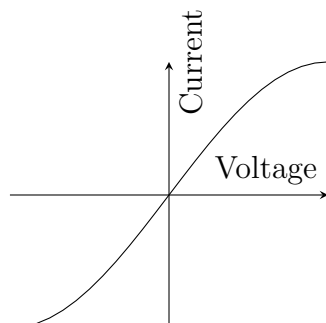
**Resistance** - Voltage/current

#### 5.1.2 Current - Voltage characteristics

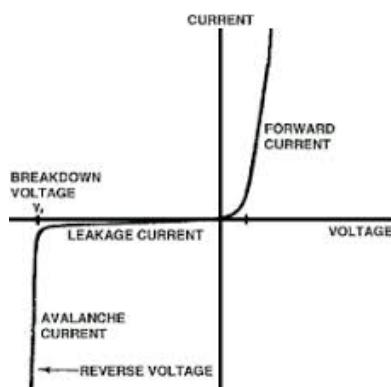
##### 5.1.2.1 Ohmic Conductor



### 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

$$\text{Series : } R_T = R_1 + R_2 + R_3 \dots$$

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

### 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

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

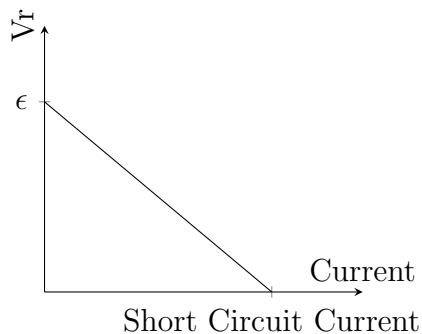
Potential dividers can be used with environment sensors that change their resistance based on changed to the environment to change output voltage

### 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  $Ir$