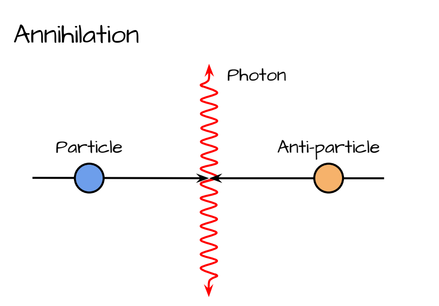
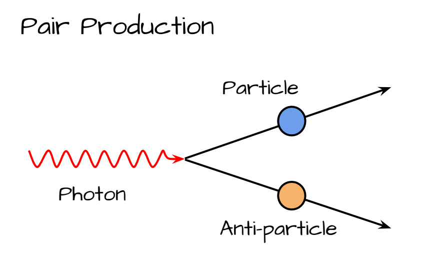
Particles and Radiation

Particles and Interactions

Electromagnetic Force	Responsible for interaction between charged particles	Virtual Photon	Infinite Range
Gravitational Force	Responsible for interaction between massive particles	Graviton (theoretical)	Infinite Range
Weak Nuclear Force	Responsible for the decay of particles	W^+, W^-, Z^0 Boson	Subatomic Range
Strong Nuclear Force	Responsible for keeping the atomic nucleus together, acts on Hadrons only	Gluons, Pions	Repulsive < 0.5 fm 0.5 fm < attractive < 3.0 fm 3.0 fm < Negligent

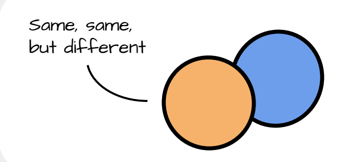


When a particle and its antiparticle collide, they annihilate to produce two photons that has a total energy of $E = mc^2 + ½mv^2$ and move in opposite direction



A gamma ray of minimum energy of $E = 2mc^2$ may produce a particle antiparticle pair that will move in opposite direction to each other

Antimatter: A type of particles with opposite charge, baryon number, and strangeness to their matter counterparts (but same rest mass). They annihilate upon contact with each other and are produced in pairs.



Alpha Decay	${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\alpha$
Beta-Minus Decay	${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}\beta + \overline{v}_e$
Beta-Plus Decay	${}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}\beta^{+} + v_e$
Gamma Decay	${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\alpha + \gamma$
Electron Capture	$P + e \rightarrow n + v_e$
Electron-Proton Collision	

Electron Volt: Work done to accelerate an electron through one Volt. 1 eV = 1.6×10^{-19} J

Specific Charge: The charge of an atom per unit mass (Ckg^{-1})

Mass Number (A): No. of Nucleons

Proton Number (Z): No. of Protons

Isotopes: A variant of an element with a different mass number (neutrons)

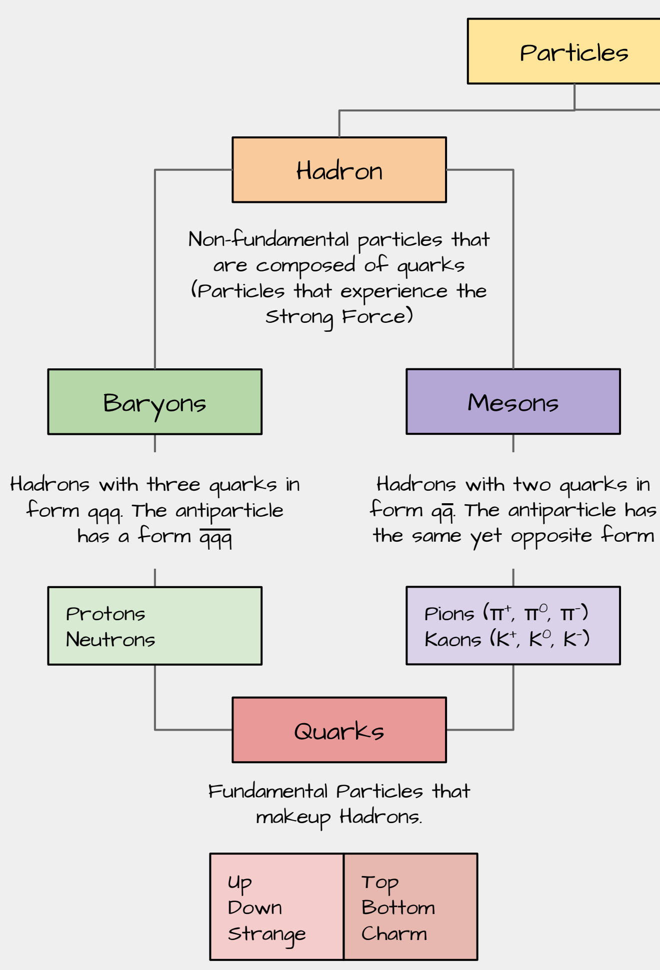
Quarks and Leptons

Fundamental Particles: A particle that cannot be further broken down to constituent parts: Quarks, and Leptons

Strangeness: Strange particles take longer to decay and hold strange quarks. Created in pairs, decays only in decrements of one

Conservation Laws: These are attributes that are conserved during an interaction:

- Charge is always conserved
- Baryon number is always conserved
- Lepton number (of the same type) is conserved
- Strangeness is conserved, except during a decay



p	uud
n	udd
π^+	$u\overline{d}$
π^0	$u\overline{u}$, $d\overline{d}$, $s\overline{s}$
π^-	$\overline{u}d$
K^+	$u\overline{s}$
K^0	$\overline{s}d$, $s\overline{d}$
K^-	$\overline{u}s$

Quantum Phenomena

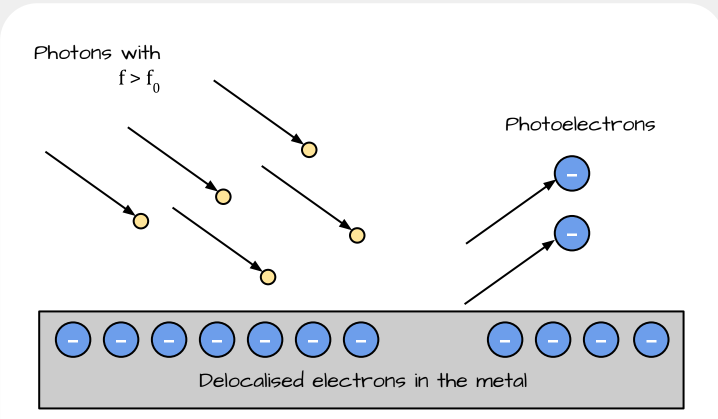
Photoelectric Effect: When light of frequency greater than the threshold frequency is incident on the surface of a metal, electrons are liberated from the surface of the metal

Threshold Frequency: Photoelectric effect only occurs if incident light has a frequency greater than this

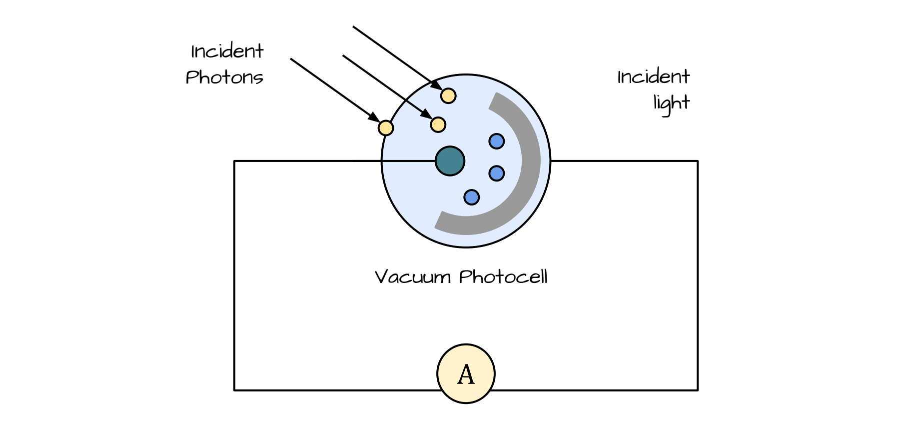
Work Function: The minimum energy required to emit an electron from a metal surface

Maximum Kinetic Energy: This is the difference between energy of the incident photons and the work function

Stopping Potential: This is the pd that needs to be induced to match E_{kmax} of the photoelectrons and halt them from being emitted. This is found by $E = e\,V_s$

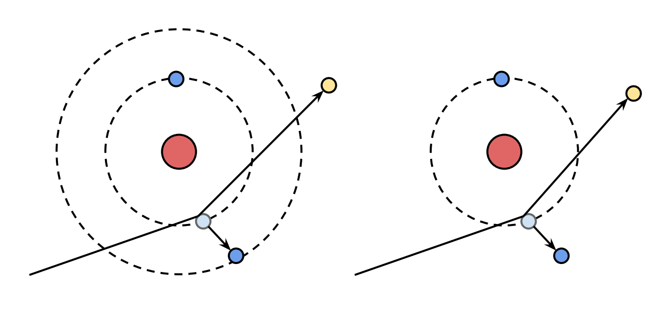


The Photoelectric Effect proves that particle nature of light as the PE effect only occurs at certain range of frequencies. If it was only caused by energy supplied, increasing the intensity of incident EMR even under the threshold frequency, PE must be liberated. However, as the energy supplied is linked to the frequency, and not intensity, a 1-1 relationship between light and electrons is shown, proving light is a particle

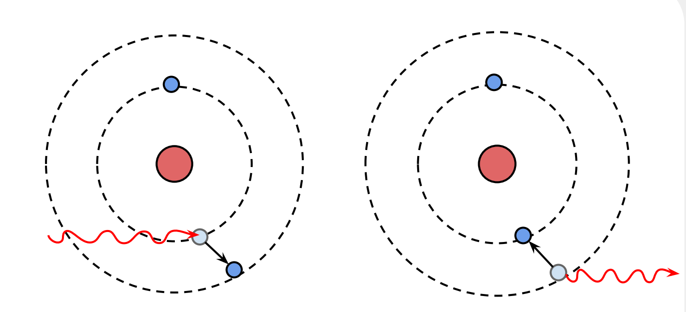


Ionisation: This is the process of which an atom gains or loses and electron resulting in a net charge.

Excitation: This is the process when an electron gains energy and 'jumps' to a higher energy level.

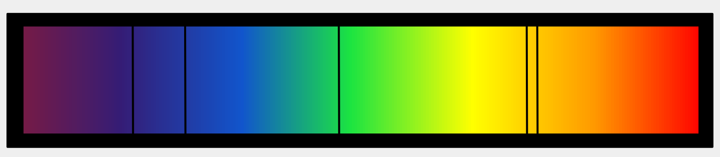


Excitation by collision *Ionisation by collision*



Excitation by photon absorption *De-excitation by photon emission*

Absorption Spectra: This is a spectrum with gaps of frequencies where light has been absorbed.

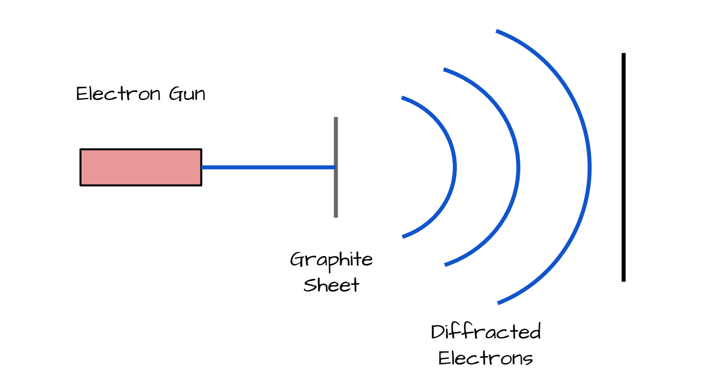


Emission Spectra: This is a spectrum of only lines from parts of the spectrum where light was emitted

It has been know for long that light has a dual-nature between waves and particles. According to De Broglie, electrons do too.

De Broglie Wavelength: This is the equation for calculating the wavelength of a moving particle to achieve wave-nature.

Electron Diffraction: Electrons travelling in their De Broglie Wavelength, can diffract when passed through atomic gaps of a crystal. This is proof of wave-particle duality in electrons

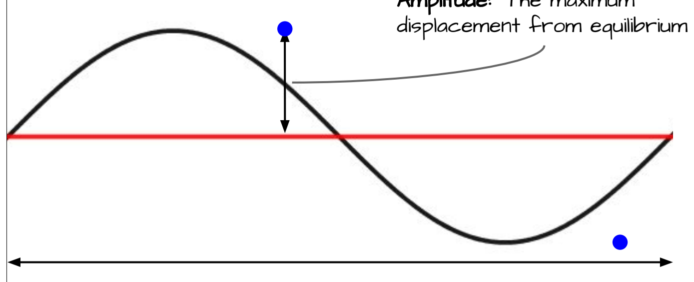


Waves and Optics

Waves

Anatomy

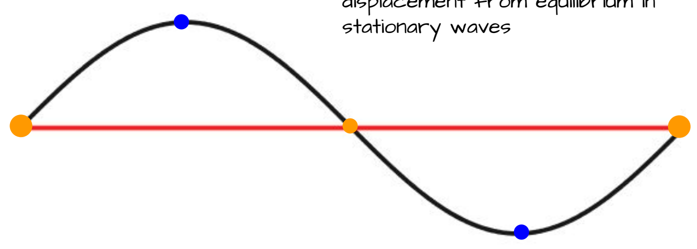
Progressive Wave



Amplitude: The maximum displacement from equilibrium

Wavelength: The distance between two identical points of two adjacent cycles

Stationary Wave

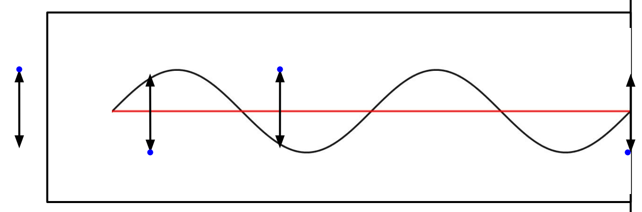


Antinode: The points of maximum displacement from equilibrium in stationary waves

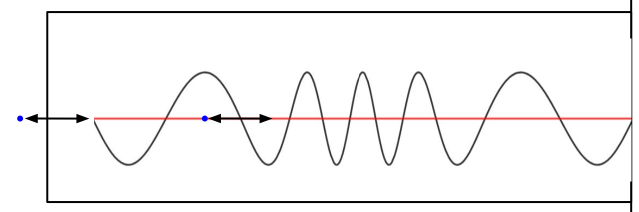
Node: The points of minimum displacement (zero) from equilibrium in stationary waves

Types by direction of oscillation

Transverse Wave: These waves oscillate particles perpendicular to path of the wave

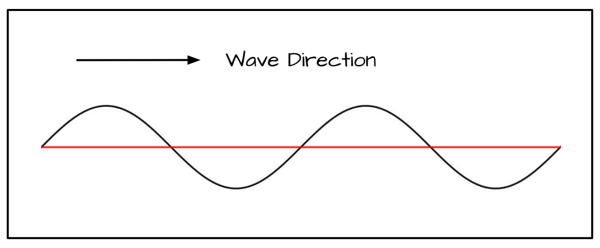


Longitudinal Wave: These waves oscillate particles parallel to path of the wave

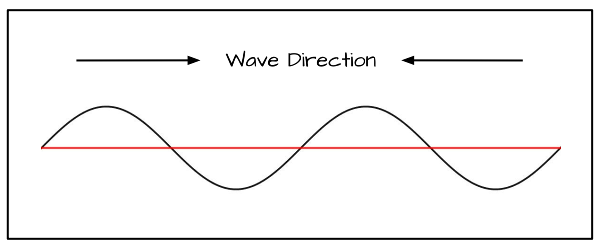


Types by energy transfer

Progressive Wave: These waves transfer energy without transferring matter and is caused by oscillating particles.



Stationary Wave: These waves are formed by the superposition of two coherent and opposite progressive waves



First Harmonic: The lowest frequency where a stationary wave forms. The distance between the nodes is ½λ

$$f = \frac{1}{2L}\sqrt{\frac{T}{\mu}}$$

Phases

Phase difference: This is the difference between two waves based on their stage in the wave cycle. Assume a cycle is a circle of radius one, hence circumference is 2π. This is the concept of radians

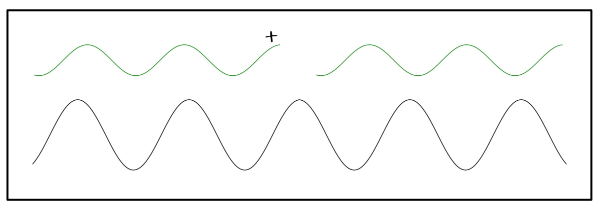
In-Phase: This is when the phase difference is 0 rad, or 0 degrees.

Out of Phase: This is when the phase difference is not 0 rad, or 0 degrees.

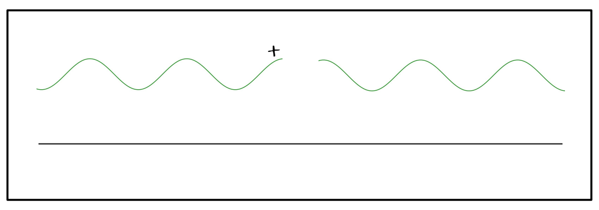
Anti-Phase: This is when the phase difference is π rad, or 180 degrees.

Superposition: This is the process of two waves combining as they pass each other, causing a resultant displacement with the vector sum of the constituent waves. This causes **Interference**.

Constructive Interference: This is the process of two waves with the same vector displacement combine.



Destructive Interference: This is the process of two waves with displacement in the opposite directions. If the displacements have an equal absolute value, total destructive interference occurs.



Polarisation: This is when a wave only oscillates in one plane. This only occurs with transverse waves

Coherent: This is a source of waves where the wavelength, frequency are the same and phase difference is constant.

Wave Speed: The speed of which a wave transfers energy. $c = f\lambda$

Frequency: The rate of completion of wave cycles. $f = {}^{1}/_{T}$

Period: The time taken by a wave to complete one full wave-cycle

Optics

Optical Fibre

Optical Core: This is the part of the cable which carries the light signal. The core often has a higher refractive index than the cladding to ensure Total Internal Reflection

Cladding: This is a coating around the optic fibre which improves its tensile strength and prevent signal transfer between fibres

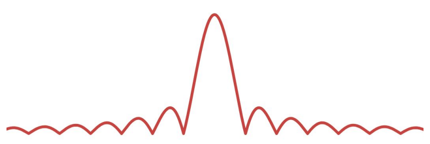
Pulse Broadening: This is the process of the signal elongating when passed down the optic cable due to dispersion.

Modal Dispersion: This is caused by waves entering the cable at slightly different angles, causing them to reach the end at slightly different times.

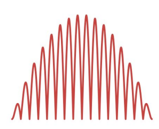
Material Dispersion: This is caused by waves of different λ travelling at slightly different speeds causing them to reach the end at slightly different times.

Diffraction

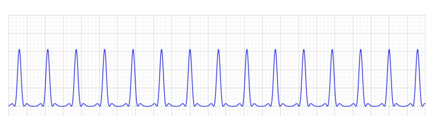
Single Slit Interference Intensity Pattern



Young's Double Slit Intensity Pattern



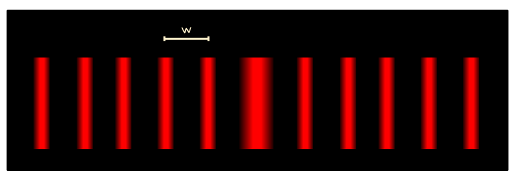
Diffraction Grating Intensity Pattern

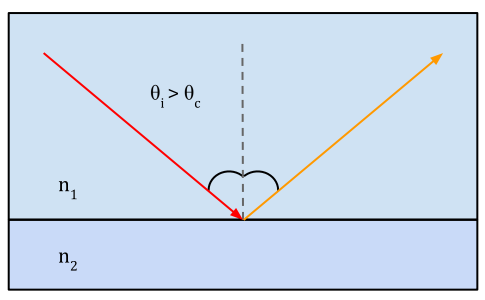


Diffraction: This is the property of waves dispersing when they pass through a slit of similar size to their wavelength

Diffraction Grating: A sheet with hundreds of slits per millimeter which results in sharper interference patterns due to $d \sin\theta = n\lambda$

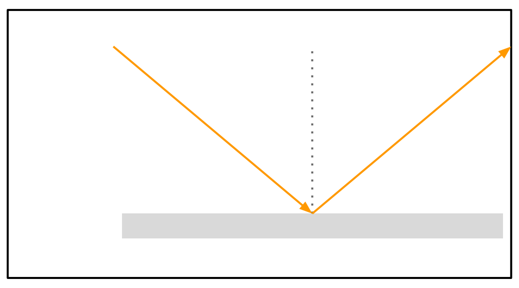
Fringe Spacing: This is the distance between two adjacent maxima or minima. Calculated using: $w = {}^{\lambda D}/_{s}$



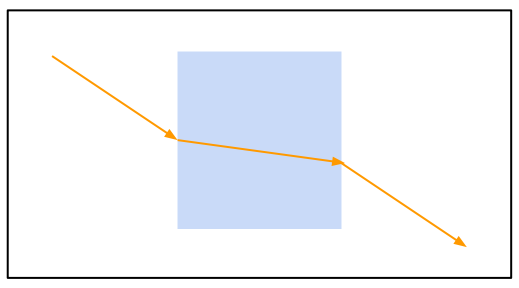


Properties of light

Reflection: This is the property of light being redirected in the same angle as it was incident to the normal.



Refraction: This is the property of light being changing direction when entering a new material to adjust to its new speed.



Refractive Index: This is the ratio between speed of light in a vacuum and the speed of light within a material. $n = {}^{c}/_{c_s}$

Snell's Law: This shows a relationship between refractive indices and angles of incidence and refraction. $n_1 \sin\theta_1 = n_2 \sin\theta_2$

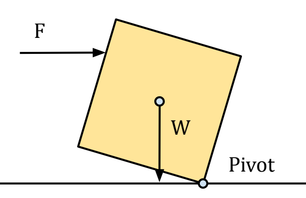
Critical Angle: This is the minimum angle of incidence where (for rays travelling from a denser medium to a lighter medium) the ray is not refracted, but reflected inwards. $\sin\theta_c = {}^{n_2}/_{n_1}$ (for $n_1 > n_2$)

Total Internal Reflection: This is the process of rays reflecting at the boundary where $n_1 > n_2$ and the angle of incidence is greater than the critical angle

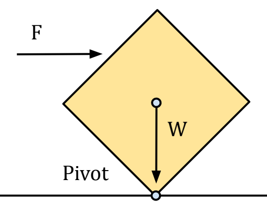
Mechanics and Materials

Forces in Equilibrium

Tilting: The process of exerting a turning force on an object about a point.



Toppling: This is when the line of action of weight (which runs through the centre of mass) passes the pivot point.



Equilibrium: This is a state of an object where the resultant forces equal to zero

Moment: This is the product of the force and the perpendicular distance from the line of action of the force to the point. (moment = $F \times d$)

Principle of Moments: For equilibrium the sum of clockwise moments equals the sum of anticlockwise moments: Σ moments (↺) = Σ moments (↻)

Centre of mass: The is point of an object where all mass is thought to be concentrated / point where no single turning force can cause a turning effect

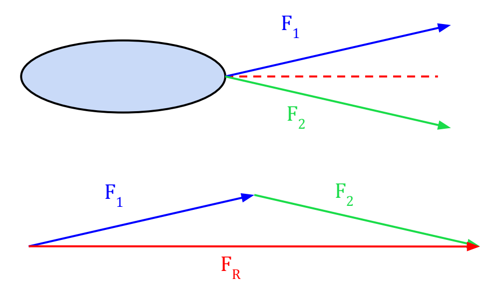
Couple: A pair of equal and opposite forces that are acting on along two distinct lines of action. These exert a turning force on the object with a total moment that is the same at any given point.

Vector: A physical quantity with magnitude and a direction. Can be represented in a column vector or i and j notation.

Scalar: A physical quantity with only a magnitude and no direction.

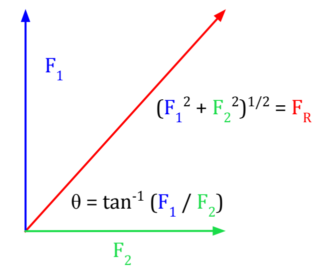
Addition

Vectors using Scale Diagrams: Draw a scale diagram conserving direction and magnitude with each arrow end linked to another arrow's head.



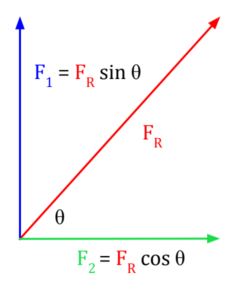
Perpendicular vectors using calculation: The magnitude of the resultant is derived using: $(F_1^2 + F_2^2)^{1/2} = F_R$

The angle $\theta = \tan^{-1}(F_1 / F_2)$



Resolving into perpendicular vectors: Draw F as a diagonal of a parallelogram and then complete it. The height is F_V and the width is F_H

This can be solved mathematically too: for the first direction from the anticlockwise, it is $\sin\theta$ and for the other it is $\cos\theta$ (where θ is angle from positive x-axis)



On the Move

Displacement: The linear distance in a given direction

Speed: The rate of change of distance: $v = \Delta d/t$

Velocity: The rate of change of displacement: $v = \Delta s/t$

Acceleration: The rate of change of velocity: $a = \Delta v/t = (v - u)/t$

Free Fall: This is when an object is released and accelerates downwards with no force except its own weight. Acceleration due to free fall on Earth is 9.81 ms^{-2}

Projectile Motion: This is the motion of an object where gravity is the only force acting on it. The vertical acceleration is g and there is no acceleration in the horizontal. The vertical and horizontal components are independent to each other.

$$v = u + at$$
$$s = \tfrac{1}{2}(u + v)t$$
$$s = ut + \tfrac{1}{2}at^2$$
$$v^2 = u^2 + 2as$$

Newton's Laws of Motion

First law: If the net force on an object is zero, it will have a constant velocity.

Second Law: The total force acting on an object is proportional to the rate of change of momentum of the said object. $F = ma = \Delta mv/t = m(v - u)/t$

Third Law: For every force exerted on a body (A) by another (B), A will exert a force equal in magnitude, type but opposite direction on B.

Weight: The force exerted by an object due to gravitational acceleration.

Inertia: This is the resistance of an object to a change in its motion.

Terminal Velocity: This is the maximum velocity an object can achieve, moving through a fluid due to its acceleration and fluid resistance being equal to each other.

Force and Momentum

Momentum: This is the product of the mass and velocity of an object. momentum = $m\,v$

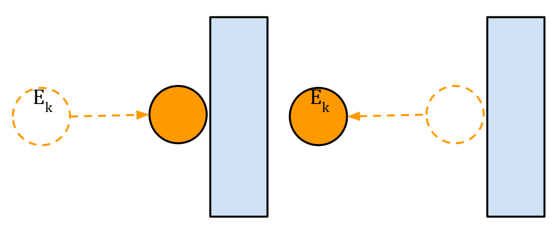
Conservation of Momentum: This principle states that for a system of interacting objects, the total momentum is constant given no external forces act on the system. $\Sigma\,\text{mom.}_i = \Sigma\,\text{mom.}_f$

Impulse: The change of momentum of an object across time. $Ft = \Delta(mv)$

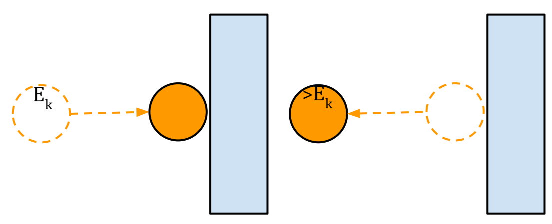
Explosion: The process where objects at rest fly apart due to some process. The vector sum of all momentum would still be equal to zero Σ momentum = 0

Collision: This is the process of two objects colliding against each other.

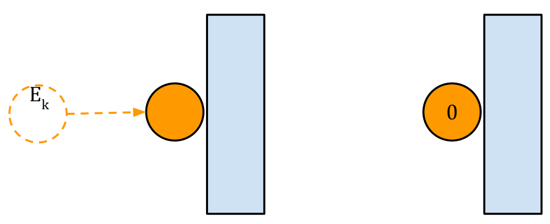
Elastic Collision: This is when there is no loss of kinetic energy during the impact and rebound. $E_{k(i)} = E_{k(f)}$



Inelastic Collision: This is when there is some loss of kinetic energy during the impact and rebound. $E_{k(i)} > E_{k(f)}$



Perfectly Inelastic Collision: This is when all the kinetic energy is lost during the impact and there is no rebound. $E_{k(f)} = 0$



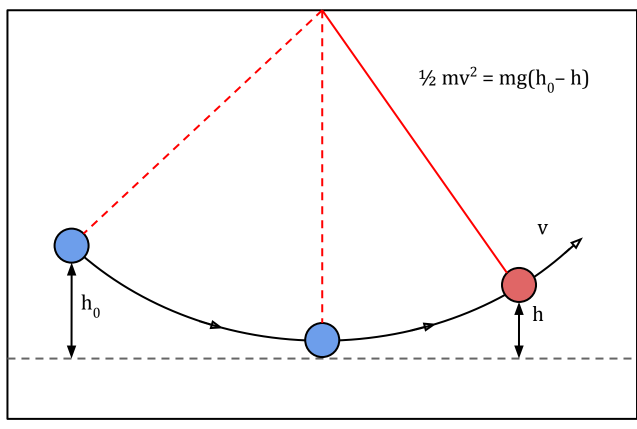
Work, Energy and Power

Conservation of Energy: This is a principal that states that energy is never created nor destroyed, only transferred.

Work: The product of force and distance travelled in direction of energy.

Kinetic Energy: The energy of an object gained via motion. $E_k = \tfrac{1}{2}mv^2$

Potential Energy: The energy of an object gained via its position. $E_p = mg\Delta h$



Power: The rate of transfer of energy. $P = \Delta E/\Delta t = \Delta W/\Delta t$

Efficiency: The ratio of useful energy output to total energy input.

Materials

Density: A physical quantity which is mass per unit volume of an object ($\rho = m/V$)

Hooke's Law: The force needed to stretch a spring is directly proportional to the extension of the spring from its natural length. ($F = k\Delta L$)

Spring Combinations

Springs in Parallel: $k = k_1 + k_2 + \ldots$

Springs in Series: $1/k = 1/k_1 + 1/k_2 + \ldots$

Elastic Potential Energy: $E_p = \tfrac{1}{2}F\Delta L = \tfrac{1}{2}k\Delta L^2$

Elasticity: The property of an object to be deformed and regain its original shape. Deformation that stretches is tensile and deformation that compresses is compressive.

Tensile Stress: The tension in the wire per unit area. $\sigma = T/A$

Tensile Strain: The ratio of the extension of the wire to the original length of the wire. $\varepsilon = \Delta L/L$

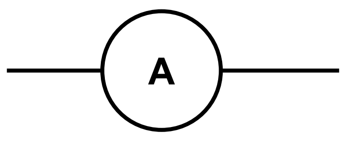
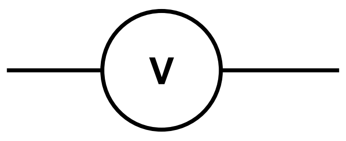
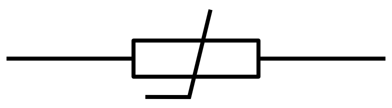
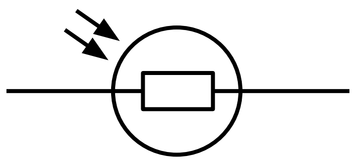
Young Modulus: This is a constant of all materials which is calculated using $E = \sigma/\varepsilon = TL/A\Delta L$

Elastic Limit: This is the maximum extension of an object before suffering plastic deformation.

Ultimate Tensile Stress (UTL)/ Breaking Stress: This is the maximum stress that can be applied on an object before it loses its strength, extends, and becomes narrower at its weakest point, eventually leading to breakage.

Electricity

Electric Current

Ammeter	This is a device which measures the current of a circuit. This is connected in series and ideally should have zero resistance	
Voltmeter	This is a device which measures the p.d of a circuit. This is connected in parallel and ideally should have infinite resistance	
Thermistor	This is a temperature sensitive resistor where the resistance reduces when temperature increases..	
Light Dependent Resistor	This is a light sensitive resistor where the resistance reduces when light intensity increases.	

Potential Difference: This is the work done per unit charge. $V = W/Q$

Electromotive Force (EMF): This is defined as the electrical energy produced per unit charge passing through the source. $\varepsilon = I\,(R + r) = E/\,Q$

Current: The rate of flow of charge in a circuit. $I = \Delta Q/\Delta t$

Power: The rate of transfer or conversion of energy. $P = I\,V = I^2\,R = V^2/R$

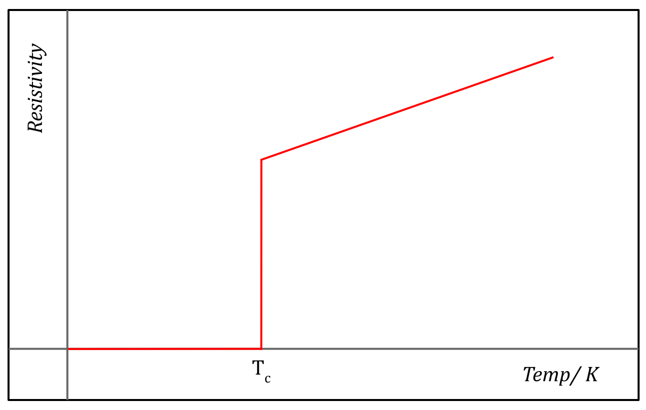
Resistance: The ratio between the potential difference and the charge (i.e. How difficult it is for current to flow). $R = V/I$

Resistivity: A material-specific constant which is the resistance across a cross-sectional area of a wire per unit length. $\rho = {}^{RA}/_{L}$

Ohm's Law: A principle that that states that the pd across a conductor is directly proportional to its current given it's held in constant physical conditions. The constant being resistance.

Ohmic Conductor: This is a conductor which obeys Ohm's law

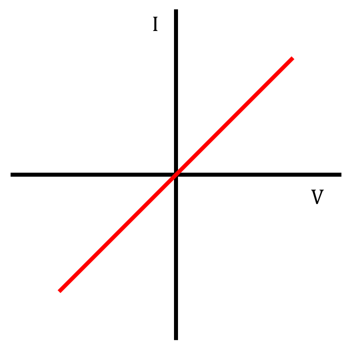
Superconductor: This is a material which, under its Critical Temperature, can conduct electricity with zero resistance. Superconductors are used in MagLev and MRI machines.



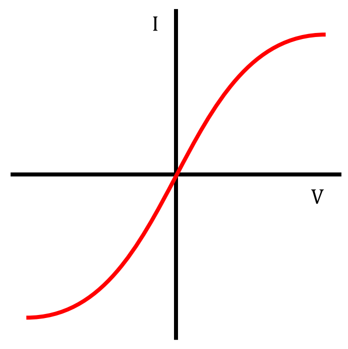
Semiconductor: This is a material where its conductivity increases with temperature.

I-V Diagrams

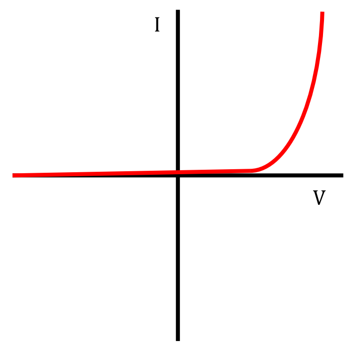
Ohmic Conductor



Filament Lamp



Diode

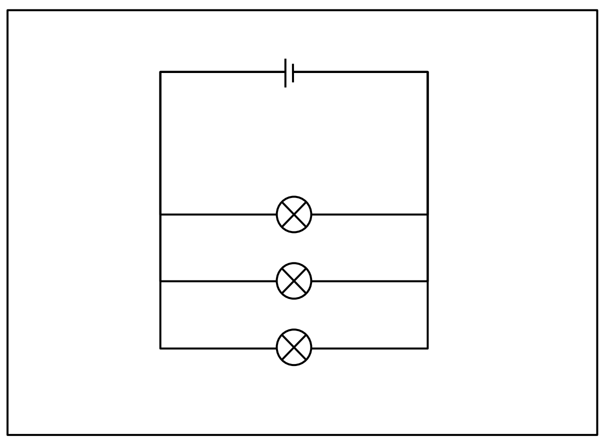


DC Circuits

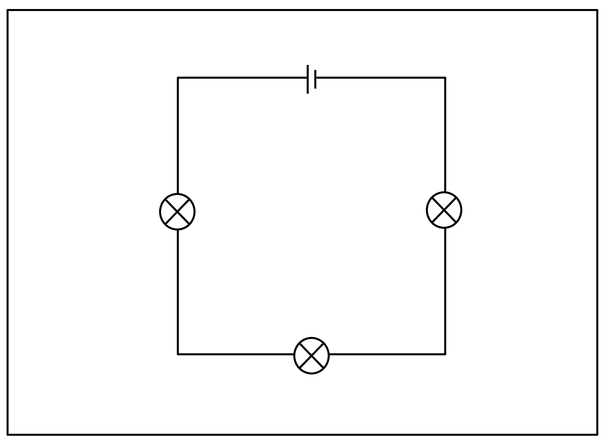
	Series	Parallel
Potential Difference	$V_\Sigma = V_1 + V_2 + V_3 + \ldots$	$V_\Sigma = V_1 = V_2 = V_3 = \ldots$
Current	$I_\Sigma = I_1 = I_2 = I_3 = \ldots$	$I_\Sigma = I_1 + I_2 + I_3 + \ldots$
Resistance	$R_\Sigma = R_1 + R_2 + R_3 + \ldots$	$1/R_\Sigma = 1/R_1 + 1/R_2 + 1/R_3 + \ldots$

Potential Divider: This is a method of splitting the potential difference by connecting two resistors in series. The total potential difference is split in the ratio of their resistances

Parallel Circuits: Components are connected in parallel loops which gets them in separate loops.



Series Circuits: Components are connected in series, within one loop.



Terminal Potential Difference: This is the p.d across the power source. $\varepsilon = V = Ir$

Internal Resistance: This is the resistance of the power source.