NSW HSC

Physics

Study Notes

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5. Mechanics

Projectile motion is the motion of a thrown/launched object.

Assumptions:

1. Air resistance is negligible.
2. Acceleration due to gravity is constant (and $-9.8ms^{-1}$)

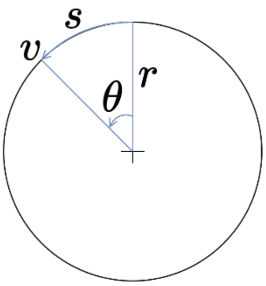
1D: object propelled vertically upwards and travels back down.
2D: object traces out (or a portion of a) shape of a parabola.

- Horizontal acceleration (a_x) is constant.
- Vertical acceleration (a_y) is constant.

Quick equation for projectile range: $s_x = \frac{u^2 \sin 2\theta}{g}$

Usual format: $v_y = u_y + at$ then $s_x = u_x t$

Uniform circular motion: motion in circular path at a constant speed.
Speed: $v = \frac{2\pi r}{T}$, Acceleration (towards centre): $a_c = \frac{v^2}{r}$, Force (towards centre): $F_c = \frac{mv^2}{r} = F_{net}$



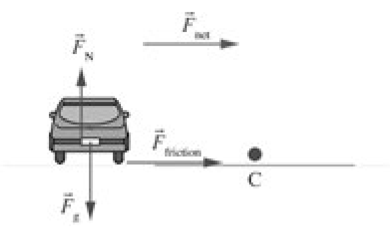
Angular velocity: $\Delta\theta = \frac{\Delta s}{r} = \frac{\text{arc length}}{\text{radius}}$ (radians), angular velocity: $\omega = \frac{\Delta\theta}{\Delta t} = \frac{v}{r}$, (rad s^{-1})

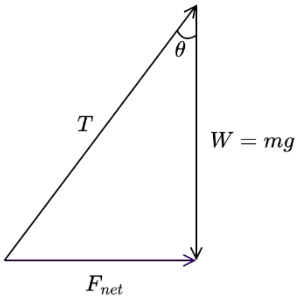
For an object in uniform circular motion: $v^2 \propto r$, orbital velocity (speed): $v = \frac{2\pi r}{T}$

When you increase the tension in a string rotating a mass around, it increases the velocity due to the increased force pulling the mass inwards.

For a mass on a string which is experiencing uniform circular motion:

$$F_c = F_{net} = \frac{mv^2}{r} = mg \tan\theta$$





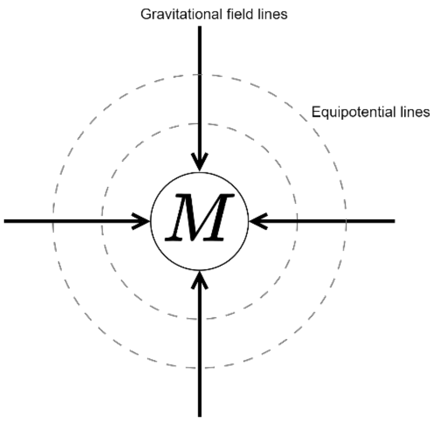
For an object travelling on a banked surface:
$v = \sqrt{rg \tan\theta}$, $N = \frac{mg}{\cos\theta}$, $F_c = mg \tan\theta$

Derivation:

$$\begin{aligned} \tan\theta &= \frac{F_c}{W} \\ &= \frac{\frac{mv^2}{r}}{mg} \\ &= \frac{v^2}{rg} \\ v^2 &= rg \tan\theta \end{aligned}$$

Use work equations for uniformly curved tracks: $K + U = W$

For a system in uniform circular motion, there is no work done.



Torque is a measure of rotational energy, $\tau\ (Nm)$, $\tau = r_\perp F = rF \sin\theta$, with r being the perpendicular distance from pivot to line of action and θ being angle between the force and perpendicular ray.

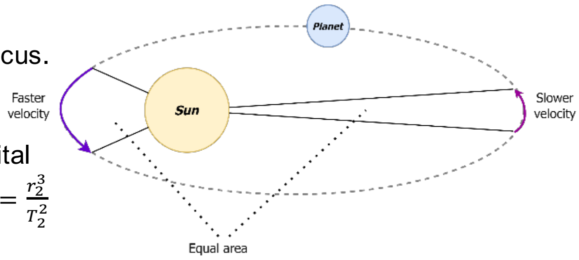
Newton's Law of Universal Gravitation: $F = \frac{GMm}{r^2}$, with $G = 6.67 \times 10^{-11}$ and r being distance between centre of objects

Due to Newton's 3rd law two bodies will exert the same gravitational force on one another, yet one will probably experience a greater acceleration due $F = ma$

Gravitational force: $F_g = \frac{GMm}{r^2}$, gravitational field strength $g = \frac{GM}{r^2}$

Kepler's laws of Planetary Motion:

1. The planets move in elliptical orbits with the sun at one focus.
2. The line connecting a planet to the sun sweeps out equal areas in equal intervals of time.
3. For every planet, the ratio of the cube of the average orbital radius, r, to the square of the period, T, i.e., $\frac{r^3}{T^2} = k$ or $\frac{r_1^3}{T_1^2} = \frac{r_2^3}{T_2^2}$



To find the constant for Kepler's 3rd law: $k = \frac{GM}{4\pi^2}$, therefore $\frac{GM}{4\pi^2} = \frac{r^3}{T^2}$

Orbital velocity: $v = \sqrt{\frac{GM}{r}}$

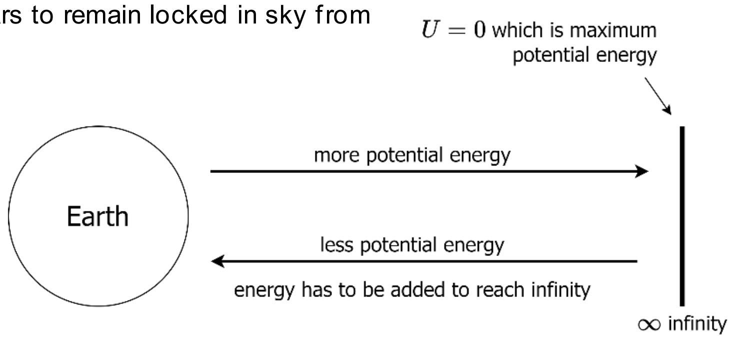
Derivation:

$$F_G = \frac{GMm}{r^2}$$
$$F_{net} = F_G = F_c$$
$$F_c = \frac{mv^2}{r}$$
$$\frac{GMm}{r^2} = \frac{mv^2}{r}$$
$$\frac{GM}{r} = v^2$$
$$v = \sqrt{\frac{GM}{r}}$$

Types of orbits:
Low-earth: 180 – 2000km altitude
Medium: 2000 – 3600km altitude
High: >3600km altitude, includes geostationary (appears to remain locked in sky from the ground)

Escape velocity: $v_{\text{escape}} = \sqrt{\frac{2GM}{r}}$

Gravitational potential energy measures the amount of energy generated by moving within a gravitational field. $U = -\frac{GMm}{r}$



Total work done: $\sum E = -\frac{GMm}{2r}$

Derivation of velocity of object:

$$F_c = F_g$$
$$\frac{mv^2}{r} = \frac{GMm}{r^2}$$
$$v^2 = \frac{GM}{r}$$

Then derivation of energies of an object in orbit:

$$\begin{aligned} K &= \frac{1}{2}mv^2 \\ &= \frac{1}{2}m\left(\frac{GM}{r}\right) \\ &= \frac{GMm}{2r} \end{aligned}$$

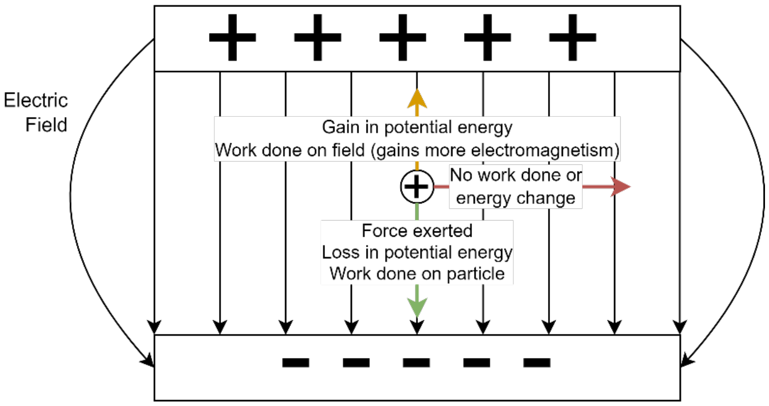
Total energy of an object in orbit:

$$\begin{aligned} \sum E &= K + U \\ &= \frac{GMm}{2r} - \frac{GMm}{r} \\ &= -\frac{GMm}{2r} \\ \text{i.e., } \sum E &= \frac{U}{2} \end{aligned}$$

Escape velocity is: $v_{\text{esc}} = \sqrt{\frac{2GM}{r}}$

$$\begin{aligned} E_{\text{before}} &= E_{\text{after}} = 0 \\ E_{\text{before}} &= U + K \\ &= -\frac{GMm}{r} + \frac{1}{2}mv^2 \\ \frac{1}{2}mv^2 &= \frac{GMm}{r} \\ v^2 &= \frac{2GM}{r} \\ v &= \sqrt{\frac{2GM}{r}} \end{aligned}$$

6. Electromagnetism



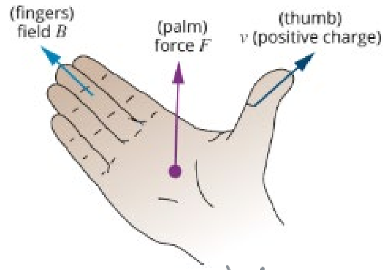
Electric field strength (E) given in NC^{-1}

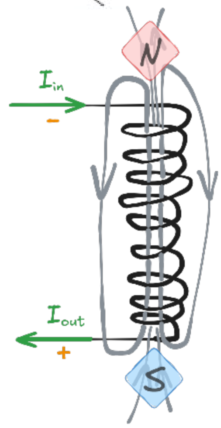
Electric field is constant between two charged plates.

Potential difference in volts ΔV

Electric charge (q) in C

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





Forces on a moving charge: $F = qv_{\perp}B$, with v being velocity perpendicular to the magnetic field, B.

Use the right-hand rule to determine the direction of a charge and force on a charge.

With charged particle enters a magnetic field perpendicular to the field, it may begin to exhibit circular motion as the force is towards the centre of a point. Magnetic fields always produce a force **perpendicular** to the field.

$$F_B = F_C$$
$$qv_{\perp}B = \frac{mv^2}{r}$$
$$r = \frac{mv}{qB}$$

If F_B is constant, hence motion will be uniform circular motion.

Within an electric field: $F = qv_{\perp}B$, this is from:

$$I = \frac{q}{t} \Rightarrow q = It$$
$$v = \frac{d}{t} = \frac{l}{t}$$
$$F = qvB$$
$$= (It) \times \frac{l}{t} \times B$$
$$= lI_{\perp}B = lIB\sin\theta$$

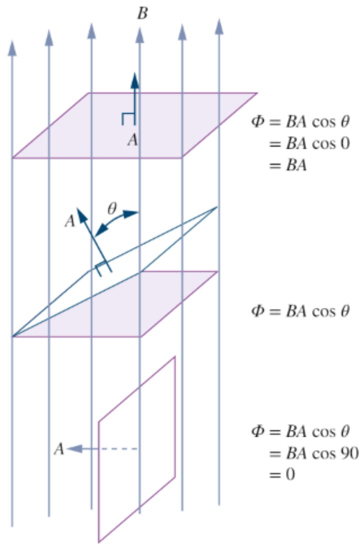
Between two force carrying plates there will be a magnetic force. If the current is parallel (like currents) the plates will attract while if the current is opposite the plates will repel.

Force (per unit length) between plates is derived with:

$$F = lI_{\perp}B$$
$$F = lI \times \frac{\mu_0 I}{2\pi r}$$
$$\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi r}$$

Moving a magnet around a solenoid induces a current.

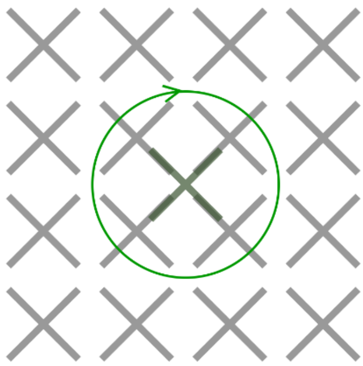
Electromotive force (emf): source of energy that can cause a current to flow in an electric circuit/device. Not a force, more like a voltage. When a battery is open it is the voltage between the terminals.
Magnetic flux: strength of a field in a given area expressed as a product of area and the component of field strength at right angles to the area.
Magnetic flux density: the amount of magnetic flux per unit area, same as magnetic field strength.



$\phi = \vec{B}_{\parallel}\vec{A} = BA\cos\theta$, where the angle is between the perpendicular vector off the area and the magnetic field lines.

Faraday's law describes how induced emf is equal to the rate of change of magnetic flux in the circuit.
$\varepsilon = N\frac{\Delta\phi}{\Delta t}$, with N being the number of turns, ϕ being the flux and ε is electro-motive force (volts).

Field diminishes



Field 'increases' out of the page

Lenz's law describes how the induced current is a direction to oppose the change that caused it.
Resulting in: $\varepsilon = -N\frac{\Delta\phi}{\Delta t}$

e.g., if a coil of wire were to be on top of a magnetic field going into a page, and that field would diminish. The coil would produce a current such it creates a magnetic field going into the page, to try and resist the change.

Eddy currents are generated to try and counteract the magnetic flux.

Transformers are a highly efficient mechanism at changing voltage, they utilise the conversion of an electric field into a magnetic field and back using coils.
With N being the numbers of turns in the coil: $\frac{V_p}{V_s} = \frac{N_p}{N_s}$. p iis primary and s is secondary.
This is derived by:

$$V_p = -N_p\frac{\Delta\phi}{\Delta t}$$
$$\frac{\Delta\phi}{\Delta t} = -\frac{V_p}{N_p}$$
$$V_s = -N_s\frac{\Delta\phi}{\Delta t}$$
$$V_s = -N_s\left(-\frac{V_p}{N_p}\right)$$
$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

If a transformer is 100% efficient, power is conserved: $V_p I_p = V_s I_s$

In reality, transformers aren't 100% efficient: $P_{\text{input}} > P_{\text{output}}$

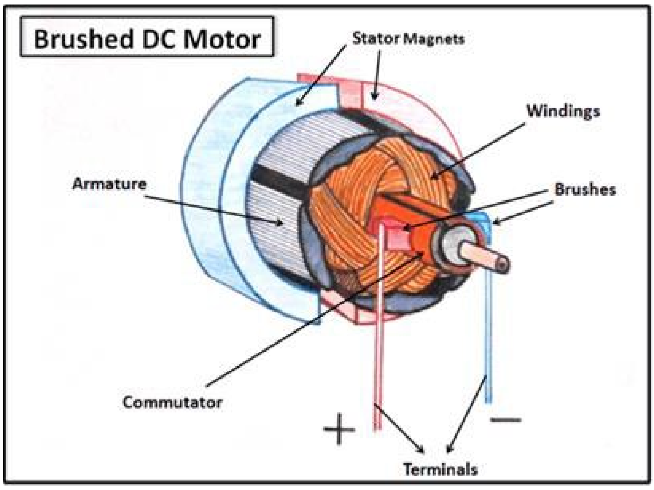
Power loss occurs from:

Name	Cause	Prevention
Incomplete flux linkage	The magnetic field from the primary coil doesn't pass entirely through secondary coil.	Place the coils close to each other. Use a ferromagnetic coil.
Resistive heat production	When current passes through the wires energy will be lost as heat due to the resistance in the coils.	Decrease resistance in coils
Eddy currents	Magnetic currents form in the iron core due to changing flux losing energy as heat.	Create laminated cores, reduces the number of flux contact areas. Use ferritic material, conduct magnetic field good and electricity poorly.

Transmission lines transmit at a high voltage as there is less current and therefore less voltage to lose $V_{\text{drop}} = IR$

To calculate current in transmission wires use: $P = VI$

To calculate losses in wires, use $V_{\text{drop}} = IR$ and $P_{\text{loss}} = I^2R$



DC motor allows for DC current to create rotational motion.
The commutator allows for the current to switch in the armature (making continuous motion). The stator is the permanent magnets creating the magnetic force within the armature – turning the rotor/axle.

To calculate the torque in a motor:

$$\tau = F \times w$$
$$= lIB \times w$$
$$= nIA_{\perp}B = nIAB\,\sin\theta$$

With A representing the area enclosed by the coils and n being the number of coils.

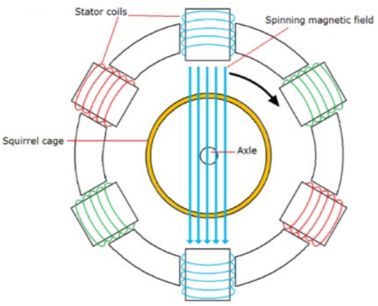
Back EMF opposes the current through a motor, due to the changing flux within the motor. This creates an upper limit on how fast a motor can spin (self-regulated). If the motor is loaded, the back EMF decreases so it increases the torque.

$$I = \frac{V_s - V_B}{R}$$

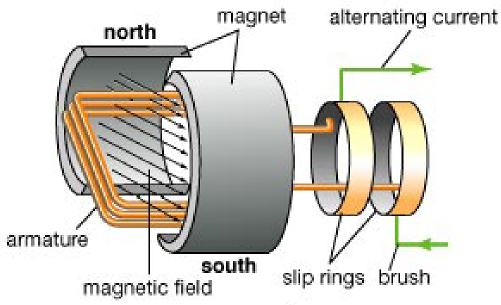
AC motor use the alternating nature of the AC current to create a rotating magnetic field due to 3 phases, which rotates the coils within the stator. AC motors are less efficient but have higher power than a DC motor.

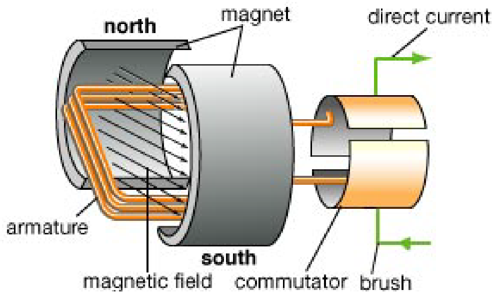
This rotating field induces a magnetic field in the squirrel cage causing it to turn and following this field.

A generator converts kinetic energy into electrical energy.



A DC motors uses a **split** ring commutator create a constant stream of current.
An AC motors uses a **slip** ring commutator to create an alternating current.





Higher rotation speed increases the voltage and the frequency of the current.

RMS is a way of averaging the voltage given by a power source. As AC/DC peaks and troughs, you have to use the average voltage value.

$$V_{\mathrm{RMS}} = \frac{V_{\mathrm{peak}}}{\sqrt{2}}$$

$$I_{\mathrm{RMS}} = \frac{I_{\mathrm{peak}}}{\sqrt{2}}$$

Maxwell’s equations:
Gauss’ law of electricity: magnetic flux can be measured for any closed surface.
Gauss’ law of magnetism: magnetic flux through any closed surface is equal to zero. Meaning that magnetic monopoles are impossible.
Faraday’s law: electric fields can be induced by changing magnetic fields.
Ampère’s law: magnetic fields can be induced by changing electric fields.

7. The nature of light

Maxwell found that EM waves oscillate in perpendicular planes to one another and are in sinusoidal phase. Also, that EM waves did not have just to be (visible) light and that there was a constant speed to light.

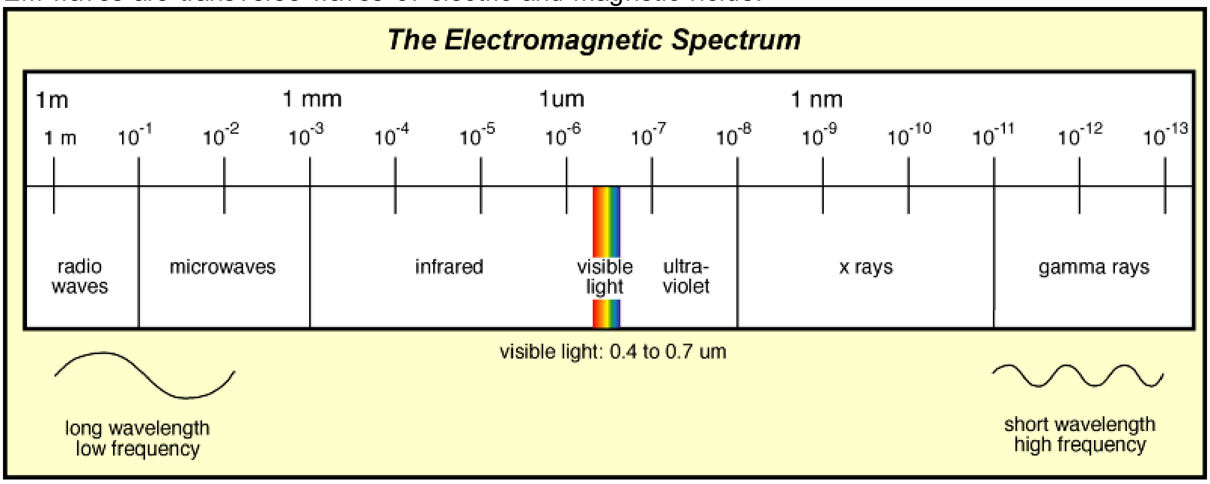
Heindrich Hertz discovered radio waves ('invisible' EM waves), using high voltages to induce sparks in disconnected circuits.

$$v = f\lambda$$

v = speed of wave (ms^{-1})
f = frenquency of wave (Hz)
λ = wavelength (m)

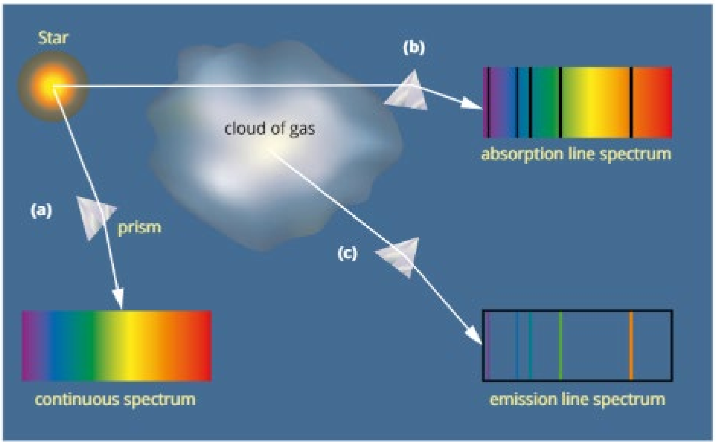
Galileo used two people on hilltops to measure light, the time was so short it was hard to get any accurate measurements especially with human reaction times.
Ole Rømer measured the movements of Jupiter's moon Io and saw a difference in the time taken for an Io orbit when Earth was travelling towards and away from Jupiter – due to light taking extra time to get here.
James Bradely used measurements of distance stars using known values the velocity of earth round the sun and the angular difference in recordings.
Hippolyte Fizeau used a rotating cog, where he adjusted so the light emitted from one gap and passed into the adjacent gap.
Léon Foucault and Michelson both used rotating mirrors to estimate the speed of light over a known distance and rotational speed.
Rosa & Dorsey analytically solved it using Maxwell's equation: $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$
Louis Essen and Gordon Smith used crystals which vibrated at a set amount to measure the speed of light with $c = f\lambda$
Lasers have been used recently by splitting it down multiple arms and making them align perfectly to combine to give a final speed.

EM waves are transverse waves of electric and magnetic fields.



Continuous spectrum is white light from a hot glowing object (which has all the colours of light).

Type of spectra	Example of emitter
Continuous	Incandescent bulb
Single	Laser light
Emission	Sulphur bulb



Spectral lines are due to atoms absorbing or emitting light after electrons move between shells.

Absorption spectra is due the gas absorbing certain wavelengths of light in the quantum interactions between the atoms and electrons.

While emission is the 'same electrons which were absorbed' being emitted.

All these spectra require the light to pass through a diffraction grating or prism to spread out the light.

Spectroscopy can be used to classify and identify the various properties of stars.

	Property	**Measurement gained**
	*Position of the lines*	Composition of the star
	*Intensity distribution (wavelength of highest intensity)*	Temperature
	*Sharpness/fuzziness of the lines*	Density (of the photosphere)
	*Thickness of the lines*	Rotational speed of the star
	*Shift (left or right)*	Velocity of the star • Towards blue → star moving toward observer • Towards red → star moving away from observer

Newton thought that light was particles, which led to problems with diffraction (as Newton could not explain it) and couldn't explain refraction properly (though light sped up in a denser material due to an attractive force).
While Huygen thought that light acted like a wave, which correctly explain diffraction and refraction.

The single slit experiment showed that wave diffract and interfere when passing through a slit creating an interference pattern.
The double slit experiment showed that waves create a pattern yet with consistent intensity of light throughout.
$d = \frac{\lambda L}{x}$, with d being distance between slits, λ being wavelength of light, L distance from grating to screen and x being distance between bands.

To find the gap between gaps of light within the double split experiment, $d\sin\theta = m\lambda$ can be used.

With d being distance between slits, λ being wavelength of light, L distance from grating to screen, x being distance between bands, m the order number of the band (0 is centreline), θ being angle between bands.

Or $d = \frac{\lambda L}{x}$ can also be used to find the distance between bands.

Light is polarised as it travels in two wave directions as a transverse wave. Polarisation occurs when this transverse wave is limited to vibrating in one direction only.
A polarising filter on non-polarised light, will reduce the intensity of light by 50%.

Malus' law describes the drop in intensity of polarised light as it passes through another polarising filter:

$$I = I_{\max}\cos^2\theta$$

Where $I_{\max}$ is intensity of light before filter and I is intensity after filter. Then θ is the angle of the polarised light compared to the filter.

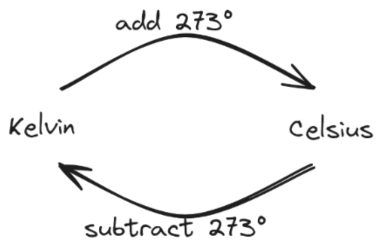
Light can both be described as a wave and particle, and both these models are needed to full explain all these observations.

Support for wave model:	Support for particle model:
- Diffraction	- Black Body Radiation (UV catastrophe)
- Dispersion	- Emission spectra
- Double slit experiment	- Photoelectric effect
- Interference	- Photons
- Polarisation	- Threshold frequency
- Refraction	

A black body is a perfect emitter, so all light emitted is from the body and none is reflected light.
Wien's Law describes the relationship between the temperature of a black body (in Kelvin):

$$\lambda_{\max} = \frac{b}{T}$$

$b = 2.898 \times 10^{-3} m\,K$, which is Wien's displacement constant, T is the temperature and $\lambda_{\max}$ is peak wavelength.



Max Planck discovered that light was quantised, meaning that its radiation fell into discrete categories which correctly explained the blackbody curve (which Wien could not).

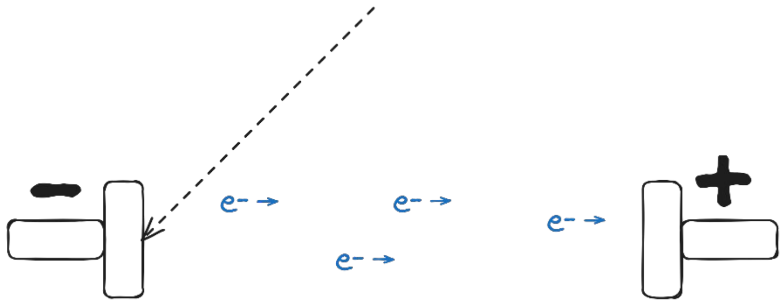
$$E = hf$$

Where E is the energy of the particle in J, h is Planck's constant (6.626×10^{-34}) and f is frequency.

Can be rewritten as $E = \frac{hc}{\lambda}$, with c being speed of light and λ is wavelength.

Then to convert from Joules to electron volts use $V = \frac{W}{q_e}$, with W being Joules and q_e being 1.602×10^{-19}.

Photoelectric effect is when electrons are released from a metal when an incident ray of light is above a certain frequency.



The **threshold frequency** (f_0) is the frequency needed for the metal to release photoelectrons.
Stopping voltage is the voltage required for no photoelectrons to reach the photo collector.
Photocurrent is the flow of photoelectrons.

There is no time delay between the light striking the metal and the release of electrons. The higher the intensity of incident light (the number of incident light rays) determines the current of the photocurrent (not amplitude).

Work function of a metal, ϕ, is the amount of energy required to eject a photoelectron.

The energy of a photon: $E = hf$, with h being Planck's constant and E being energy in $Js\ or\ eV\ s$

While $K_{\max} = hf - \phi$, with max amount of kinetic energy from a photoelectron for a given frequency.

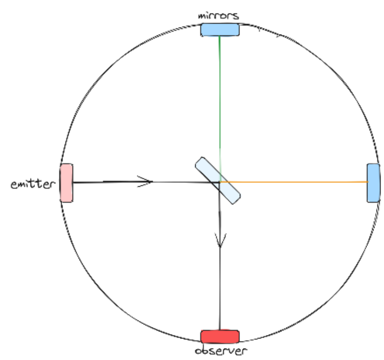
Increasing intensity of light, increases current.
Increasing frequency of light, increases kinetic energy does NOT affect current.

The stopping voltage, is the minimum voltage required to stop the photoelectrons from reaching the collector plates, given V_0

$$V_0 = \frac{K_{\max}}{q}$$

Frames of reference refers to the object with respect to which measurements are taken.
An **inertial frame** of reference is either at rest or moving at a constant velocity, which means that Newton's laws of motion are obeyed.
A **non-internal frame** of reference is where the frame is accelerating, which leads to fictious forces acting and Newton's law appearing not to be obeyed.

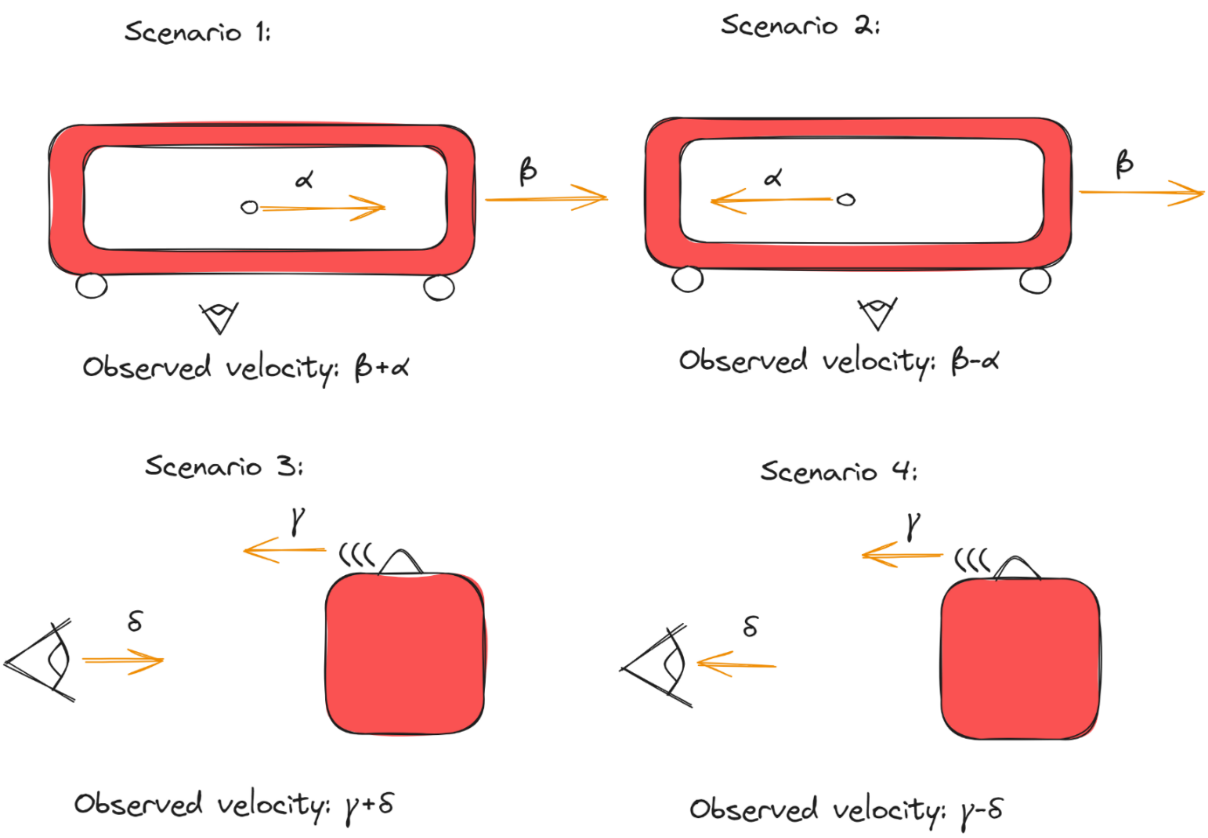
The Michelson-Morley experiment sought to establish whether there was an aether. That is whether there a medium for the waves of light to travel through. By changing the environment that this circular apparatus was exposed to, they hoped to discover that the two beams of light arrived at different times (proving that there was an aether that was a having a kinetic effect on the light).



Yet, when the experiment was run, the speed of light was found to be constant throughout all the trials. Meaning it was a "failed experiment" to prove the existence of the aether.

Einstein had two postulates of special relativity:

- The laws of physics are the same in all inertial (non-accelerated) frame of reference. Meaning that there is no absolute rest.
- The speed of light in a vacuum has a constant value for all observers regardless of their motion of the source.



The speed of light is the same for all observers in all frames of reference.

Evidence to support that c is constant:

- Maxwell equations: predicted the speed of light to be same ($\frac{1}{\mu_0 \varepsilon_0}$)
- The 'failed' result of the Michelson-Morely experiment.

Evidence that all inertial frames are equivalent:

- The 'failed' result of the Michelson-Morley experiment, showed that there is no experiment to be done to detect motion that doesn't use an outside point in an inertial frame of reference meaning that there is no privileged reference frame.

When object travels different speeds, the length of time may dilate to keep c as a constant. Meaning that time travels slower for people travelling faster, leading to different experiences of time.

For time, there is a dilation formula of: $t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$ where t_0 is time at the event, t is time at observer, v speed of vehicle where event occurs.

Which gives the Lorenz factor: $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$.

When an object travels at relativistic speeds, when observed from a stationary observer, it appears to contract in length.

$$l = l_0\sqrt{1-\left[\frac{v}{c}\right]^2}$$

With l_0 being the proper length (measured from an internal observer at rest, in the event's frame of reference).
With l being the length measured by an **external** observer.

Evidence for special relativity: experimental results which proved Einstein's theory.

Hafele-Keating experiment used highly accurate atomic clocks on fast moving airplanes to measure and prove the effects of time dilation.

Cosmic origin muons at Earth, muons normally have a lifetime of 2.2µs. Yet, due to the relativistic speeds they travel at, they can last for much longer.

With particle accelerators, scientists have measured the jumping of electrons in fast moving particles where the ones which move faster experience less jumping due to 'slower' speeds.

Supermassive black holes emit 'relativistic jets' of hot plasma that stays together because of time dilation.

For objects travelling at fast speeds, they experience relativistic momentum and mass, defined by: $p_v = \gamma m_0 v = \frac{m_0 v}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$
Where: p_v is the relativistic momentum in the inertial frame measured by the observer.

This means that objects with mass cannot reach or exceed the speed of light, as they would require an infinitely large force, work and its length would contract to zero (as measured from an observer).

When an object releases energy, it loses some of its mass, as demonstrated in the equation: $E = mc^2$, with E being energy in J and m being mass in kg

4. From the Universe to the Atom

Nucleosynthesis is the process in which new atoms are created:

- Big bang, created hydrogen and helium (basically the only source of hydrogen and helium in the universe)
- Stellar, created all the atoms up to iron
- Supernova, created all other atoms

The Big Bang was at $10^{32}\,K$, any higher and no mass could exist beyond this temperature. The big bang started with packets of energy (photons) to subatomic particles to fundamental particles to atoms.

Evidence for the big bang:

Evidence	**Summary**
Transformation of radiation into matter, making Hydrogen and Helium	The levels of Hydrogen in the universe can only be explained by the Big Bang which allowed for mass fusion of H into He
Expansion of the universe	Observed red shift of far away galaxies which are due to the Doppler effect, signalling that the galaxies are moving away from us.
Cosmic Microwave Background (CMBR)	CMBR is constant from every direction of the sky and is due to the heat radiation from the evaporation of early cosmic particles into photons.

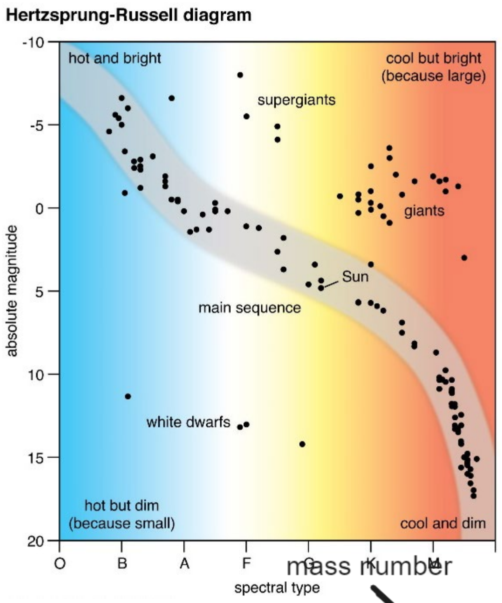
An absorption spectrum is due to certain photons being absorbed by the gas, this leads to distinct black lines on the diagram.
An emission spectrum is when this energy is then re-released as light, so it is distinct lines.

This is due to the element's atoms absorbing energy allowing the electrons to jump from one energy level to another. If an atom is given enough energy, the electrons will just escape.

The different types of stars can be classified by their temperature and main elemental characteristics leading to certain colours.

Spectral type	*Temperature (K)*
O	50 000-28 000
B	28 000-10 000
A	10 000-7500
F	7500-6000
G	6000-4900
K	4900-3500
M	3500-2000

Hertzsprung-Rusell Diagram plots luminosity versus surface temperature to get an idea of the characteristics of stars.



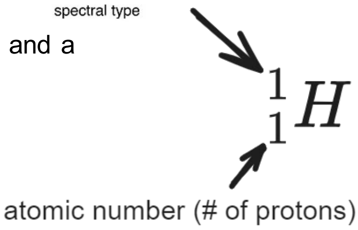
Absolute magnitude measures how bright a star would be if it were a standard distance from Earth (10 parsecs).

Main sequence stars are those which mainly convert Hydrogen into Helium.

White dwarfs have lost their nuclear reactions.

Blue giants fuse up to iron in their core.

1 amu (atomic mass unit)/Dolton is equal to $\frac{1}{12}$ of the mass of a carbon-12 atom $= 1.661 \times 10^{-27}\text{kg}$
Energy from one amu is $1.49 \times 10^{-10} J = 931.5 \times 10^{6}\, MeV$
An isotope is where the number of neutrons differs from the amount of neutrons, and a radioisotope is where the isotope releases radiation due to its unstable nature.
Nucleons are protons and neutrons.



Reactions occurring in stars:

Proton-proton chain: occurs in lower mass stars (<1.5 solar masses) and cooler stars:

$$^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{2}_{1}H + e^{+} + v$$
$$^{2}_{1}H + {}^{1}_{1}H \rightarrow {}^{3}_{2}He + \gamma$$
$$^{3}_{2}He + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + {}^{1}_{1}H + {}^{1}_{1}H$$

Net reaction: $4\,{}^{1}_{1}H \rightarrow {}^{4}_{2}He + 2e^{+} + 2v + 2\gamma$

CNO (carbon-nitrogen-oxygen) cycle: occurs in massive stars (>1.5 solar masses), hotter than sequence stars (>$18 \times 10^{6}K$)

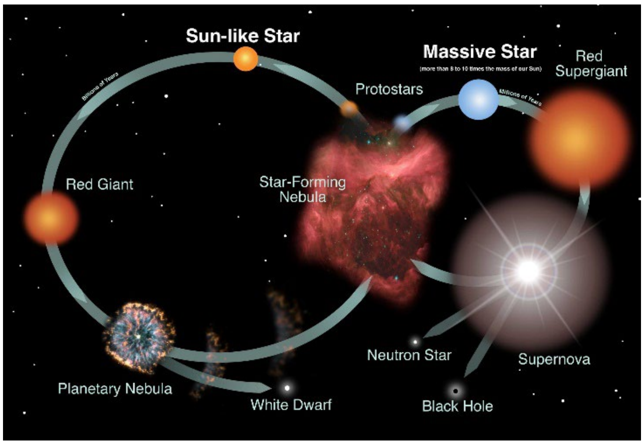
$$^{12}_{6}C + {}^{1}_{1}H \rightarrow {}^{13}_{7}N + \gamma$$
$$^{13}_{7}N \rightarrow {}^{13}_{6}C + e^{+} + v$$
$$^{13}_{6}C + {}^{1}_{1}H \rightarrow {}^{14}_{7}N + \gamma$$
$$^{14}_{7}N + {}^{1}_{1}H \rightarrow {}^{15}_{8}O + \gamma$$
$$^{15}_{8}O \rightarrow {}^{15}_{7}N + e^{+} + v$$
$$^{15}_{7}N + {}^{1}_{1}H \rightarrow {}^{12}_{6}C + {}^{4}_{2}He$$

Net reaction: $4\,{}^{1}_{1}H \rightarrow {}^{4}_{2}He + 2e^{+} + 2v + 3\gamma$ (more radiation due to higher energy in star)

Triple alpha process: occurs in red giants which have used up all their hydrogen and have temperatures of $10^{8}K$.

$$^{4}_{2}He + {}^{4}_{2}He \rightarrow \gamma + {}^{8}_{4}Be$$
$$^{8}_{4}Be + {}^{4}_{2}He \rightarrow \gamma + {}^{12}_{6}C$$

Net reaction: $3\,{}^{4}_{2}He \rightarrow 2\gamma + {}^{12}_{6}C$



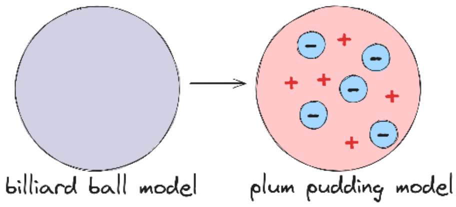
Cathode rays are beam of electrons which are able to excite molecules upon contact releasing radiation (including visible light), through the use of a variety of experiments it was able to proven that:

Experiment:	Cathode rays are:
Vacuum tube, with potential difference between electrodes.	a. Something is in the tube completing the circuit b. Something is being given out by the electrodes.
A cathode is placed in front of a Maltese cross which casts a shadow.	a. Something is being emitted from the cathode which casts a shadow. b. Which is being emitted in a straight line.
Tube with a fluorescent display and an applied magnetic field.	a. That the thing being emitted is negatively charged.
Tube with the display and an applied electric field.	a. The cathode ray accelerates in the presence of the electric field (parabolic motion)
Tube with paddle wheel.	a. Ray has momentum which is transfers to the wheel. b. Ray is made of particles with mass.

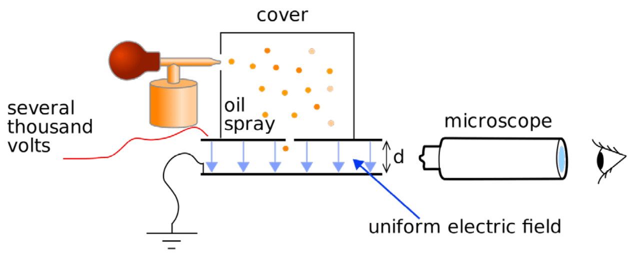
JJ Thompson used a cathode ray experiment to prove the properties of an electron and to demonstrate the properties of the atom.

He discovered that instead of the popular billiard ball model of the atom, that the atom was more like a plum pudding (made of a positive ‘dough’ and negative parts):

- Cathode rays are made of negatively charged particles
- Particles which make up these rays are smaller than hydrogen atoms
- All metals give off cathode rays



Oil drop experiment was used to find the charge of a negatively charged oil droplet, which was always found to be a multiple of -1.6×10^{-19}



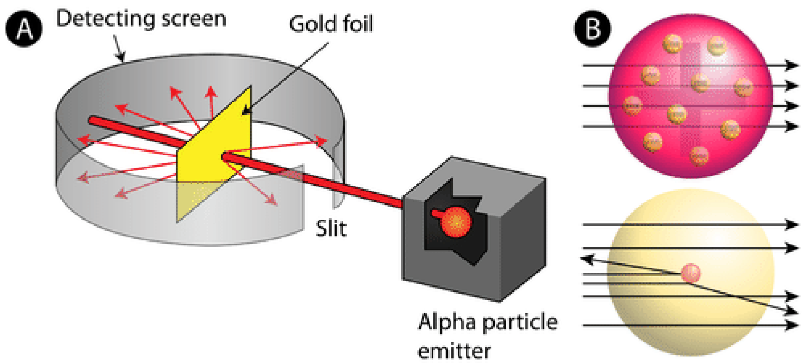
The oil drops acquired their charge from the ionised air which provide a

Using,

$$F_E = F_g$$
$$qE = mg$$
$$q = \frac{mgd}{V}$$

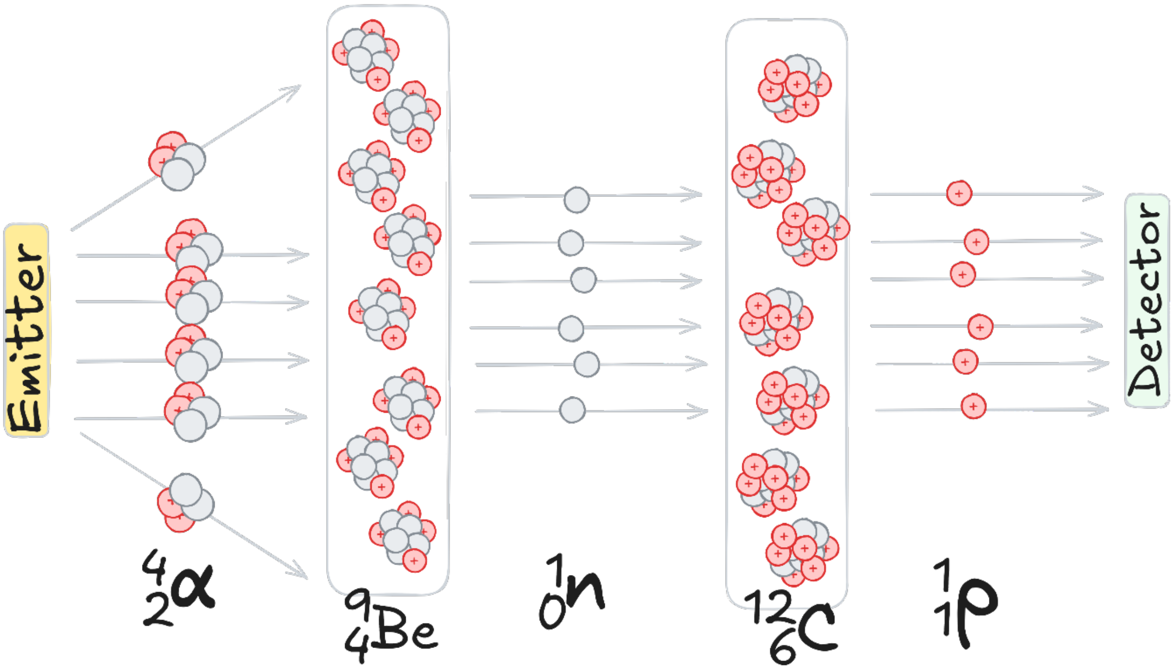
Also $K = qV$, where q is charge and V is electron-volts.

The nucleus was discovered by Gieger-Marsden as they realised that as the α particles impacted the gold leaf, that some being deflected by a heavy, tiny positively charged mass.



This allowed them to infer the properties of the nucleus.

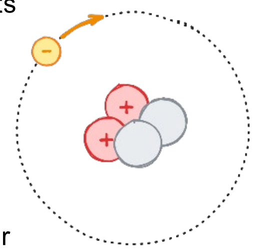
The discovery of the neutron was found by Chadwick as he realised that as a Beryllium atom was impacted by alpha particles it admitted a neutral particle (as it was displaced by electric fields, which explained how atoms can ionise – they can lose their electrons or have too many).



Bohr realised that there were some issues with Rutherford's model of the atom, as it could not account for:

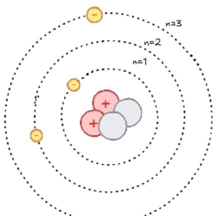
- Composition of the nucleus
- As electrons orbit they should lose energy in the form of EM radiation due to the *conservation of energy*, which should mean the electron spirals into the atom (totally destroying the atom).

Bohr proposed a model which properly defined the behaviour of electrons in elements (only effectively proved hydrogen):



Postulate 1

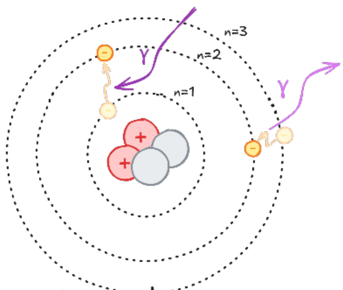
Postulate 1: an electron in an atom moves in a circular orbit due to electrostatic attraction from the positive nucleus.



Postulate 2

Postulate 2: electrons can only occupy certain energy levels, and no energy is emitted when the electron is in its 'stationary' or resting state.

Postulate 3: when an electron drops from a higher energy level to a lower one it emits a photon, while if it jumps to a higher level, it emits a photon.
This behaviour can be described with: $E_{\text{photon}} = E_1 - E_2 = hf$



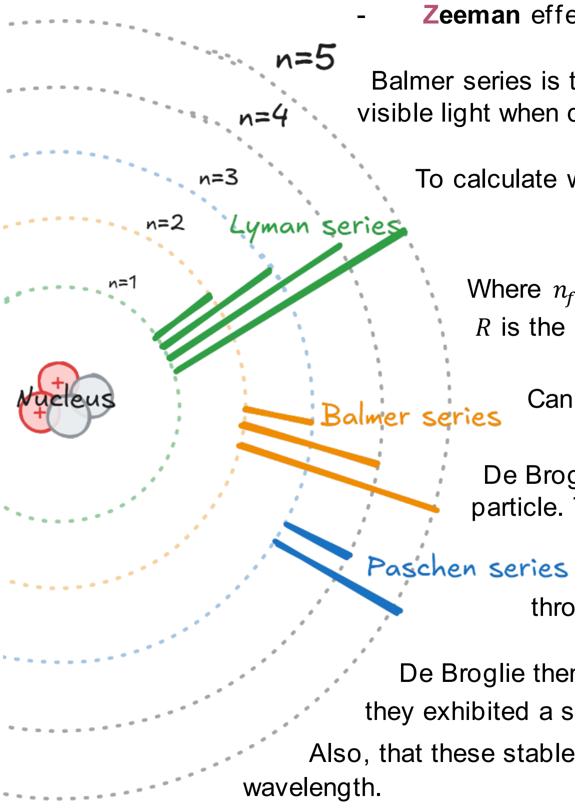
Postulate 3

Postulate 4: electrons have a particular angular momentum while 'stationary' described with $L_n = \frac{nh}{2\pi}$, as angular momentum is quantised.

Bohr model has a series of limitations:

- Atomic spectra of **multi-electron atoms** couldn't be accounted for under Bohr's simplified electrostatic model
- Variance in **line intensity** in hydrogen
- Line **splitting** both fine and hyperfine

- **Stability** of quantum states
    - **Zeeman** effect, splitting of spectral lines under a magnetic field.



Balmer series is the movement of electrons to lower shells, and how they emit visible light when doing so.

To calculate wavelength of the dropped electrons, use:

$$\frac{1}{\lambda} = R\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$$

Where n_f is the final energy level and n_i is the initial energy level.
R is the Rydberg constant, which is $1.079 \times 10^7\, m^{-1}$.

Can also calculate energy drop with $E_i - E_f = hf = \frac{hc}{\lambda}$

De Broglie realised that electrons and matter, was both a wave and particle. That they exhibited a quantum nature.

Through Davisson and Germer's experiment which shot through graphite and produced an interference pattern.

De Broglie then realised that electrons would have a steady energy value when they exhibited a standing wave. $\lambda = \frac{h}{mv}$
Also, that these stable orbits occur when the circumference is exactly equal to electron wavelength.

Schrodinger realised that electrons have a wave nature and 'orbit' around the electron in a circular standing wave. This explains the discrete energy levels that they occupy.

The position of subatomic particles can never be accurately known, so instead it is expressed as a wave function of probability of certain locations.
The diffraction pattern is proof of this probability distribution.
Energy also exists in these quantised states and the wave equation accurately describes this relationship.

Radioactivity is the tendency of an atom to spontaneously emit radiation from its nucleus (particularly is the nucleus is unstable).
Nucleon is a particle in the nucleus, while a nuclide is a distinct nucleus configuration.
Radioisotope is an element configuration which is prone to decay.
Types of decay:

Name	Typical	Example
Alpha decay (${}^{4}_{2}He$)	Heavy unstable nucleus undergoes decay	${}^{238}_{92}U \to {}^{234}_{90}Th + {}^{4}_{2}He$
Beta minus decay (${}_{-1}^{0}\beta$) *electron*	Nucleus has too many neutrons	${}^{1}_{0}n \to {}^{0}_{1}p + {}_{-1}^{0}\beta + \bar{\nu}$
Beta plus decay (${}^{0}_{1}\beta$) *positron*	Nucleus has too many protons	${}^{0}_{1}p \to {}^{1}_{0}n + {}_{-1}^{0}\beta + \bar{\nu}$
Gamma decay (γ)	When a nucleus has too much energy after splitting.	${}^{238}_{92}Xe^* \to {}^{238}_{92}Xe + \gamma$

Name	Ionising ability	Penetrating power	Usage
Alpha decay (${}^{4}_{2}He$)	Very high	Low	Smoke detectors
Beta minus decay (${}_{-1}^{0}\beta$) *electron*	Moderate	Moderate	PET scans
Beta plus decay (${}^{0}_{1}\beta$) *positron*	Moderate	Moderate	Radiotherapy
Gamma decay (γ)	Low	High	Bone scans

Most elements after ${}^{83}Bi$ are unstable in all isotopes.

Gamma radiation is high energy and is able to pass through more surfaces.

Half-life is the time for half of a radioisotope to decay.
It is spontaneous, uncontrollable/independent and predictable.

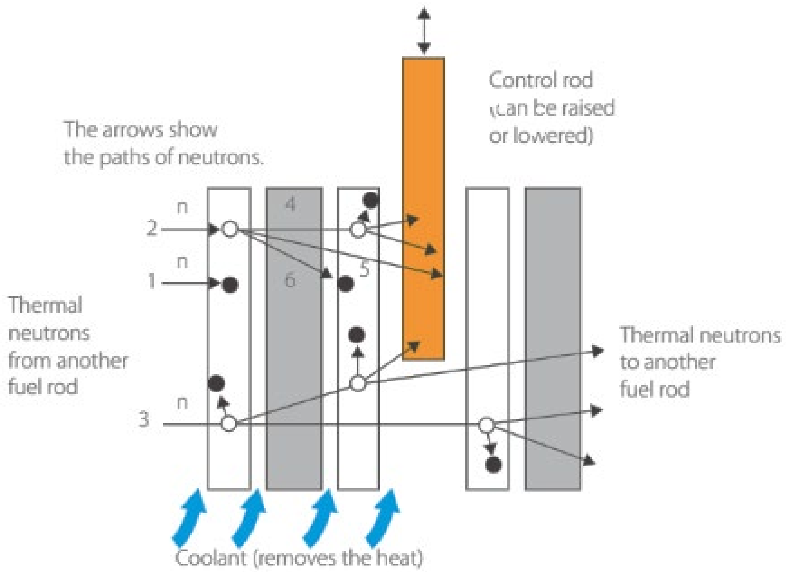
Equations of decay: $N_t = N_o e^{-\lambda t}$ and $\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$, with N_t being the number of particles at t, N_0 being the number of particles at $t = 0$, λ being the decay constant and $t_{\frac{1}{2}}$ being time taken for half the particles to decay. Also have $n = \frac{t}{t_{\frac{1}{2}}}$, with n being number of half-lives elapsed in time t and $N_t = N_0 \left(\frac{1}{2}\right)^n$

Other units for remaining atoms: number of atoms, becquerels (rate of emission) or quantity-mass.

Nuclear fission is where an atomic nucleus splits into two or more pieces.

Nuclear reactors use a variety of rods within a nuclear reaction, the fuel rods provide the fuel (usually ${}^{236}_{92}U$), moderator (water or graphite) slows/moderates the reaction and control rod stops the reaction (boron steel or cadmium).

The moderator increases the chance of the reaction due to collision theory, therefore if the moderator were to be removed the energy released would decrease.

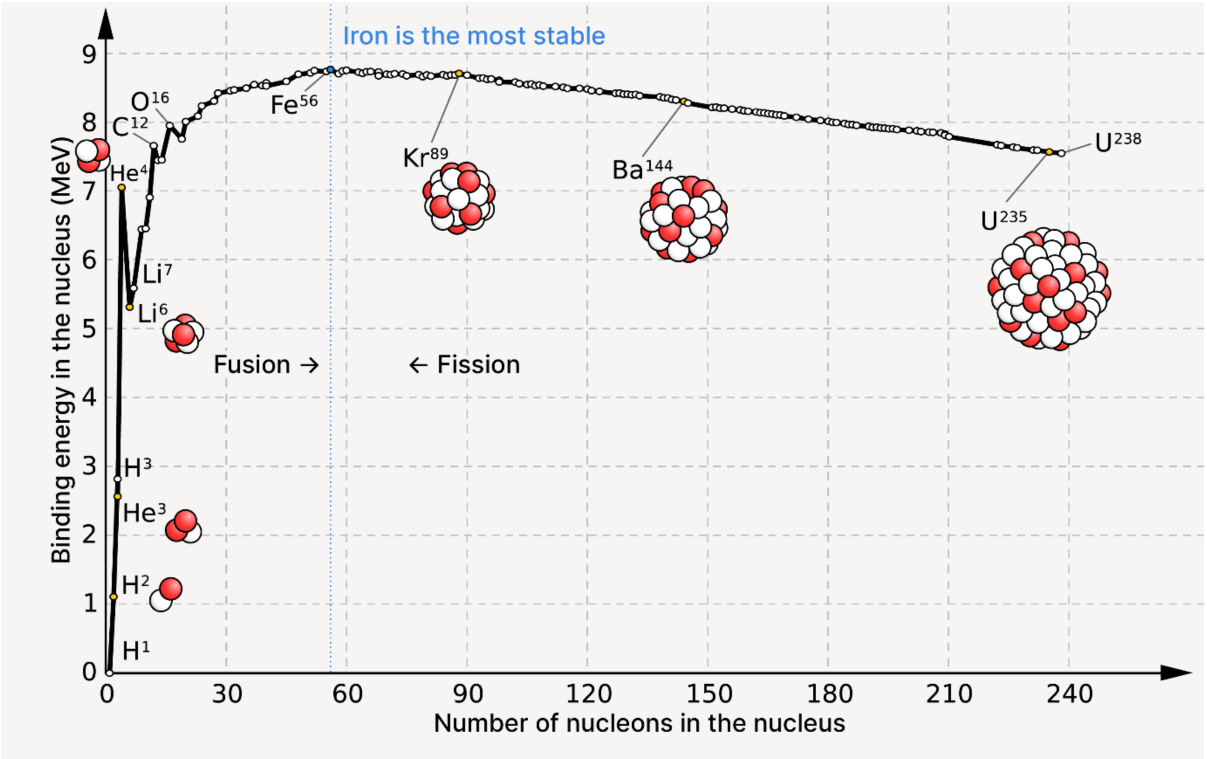


Mass defect is the mass ‘lost’ within a reaction.
When dealing with chemical reactions balance out the mass numbers and charges.

Nuclear fusion is the process of fusing 2 nuclei together to form a new atom, with an accompanying energy release. It requires a large amount of kinetic energy in the first place, to cause nuclei which have repelling electrostatic forces.
Fusion is clean, as there are no radioactive products released.

Binding energy is the total energy holding a nucleus together.
A nuclear reaction releases energy as the products are more stable (have higher binding energy overall than the reactants).

When nucleons (protons & neutrons) are brought together to form a nucleus, the mass of the nucleus is less than the sum of the masses of individual nucleons – this is called the mass defect.



This means that elements below Iron-56 will tend to undergo fusion, releasing energy as they achieve a more relaxed state. While elements above Iron-56 tend to undergo fission, which as releases energy as well.

There has been a range of experimental evidence pointing to protons and neutrons not being fundamental particles, through using colliders scientists were able to see that collisions of elementary particles (neutrons and protons) released constituent components.

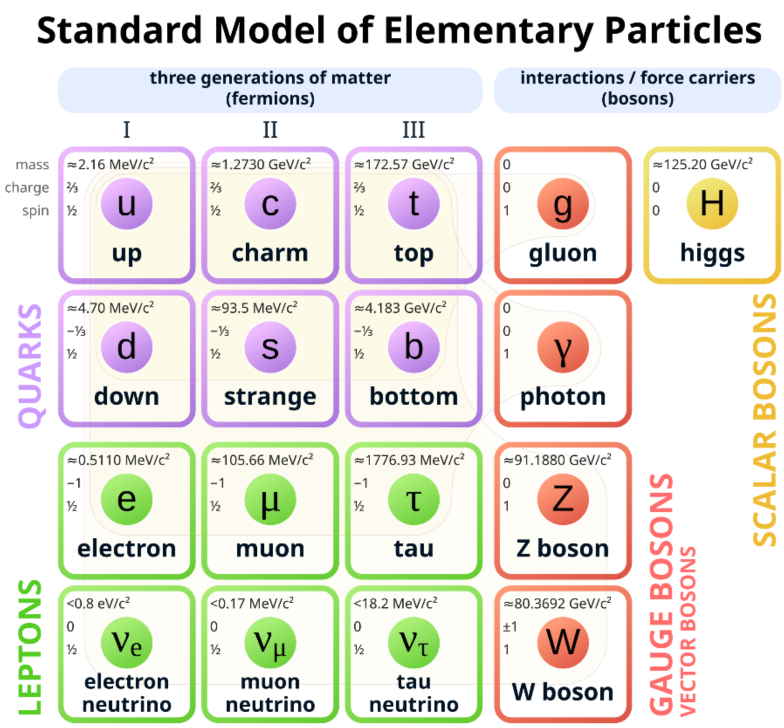
Every particle has an *anti*-particle version, which has opposite spin and charge to its regular variant.

A cloud chamber allows for the observation of radiation (i.e., α, β^-/β^+, γ, e^+/e^-) by looking at the trails it forms in the supersaturated vapour.

Rutherford was able to prove that an atom is mostly empty space by firing radiation through a thin gold sheet.

A model is a construct or representation of an idea that best expresses the world around us.

The standard model represents how subatomic particles are made up of many individual elementary particles, which fall into broad categories.

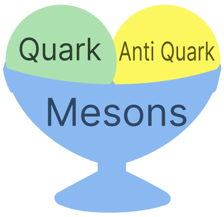


Fermions are any matter particles, which are either elementary particles like an electron or composite particles like a proton.

A **quark** is one of the 6 fundamental particles, they cannot be found individually and exist tightly bound by strong forces in hadrons.

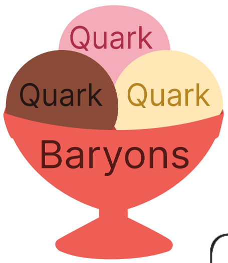
A **lepton** is something that doesn't take part in interactions with the strong nuclear force and don't like to combine with one another and can exist on their own. They interact by exchanging Z and W bosons, mediating the weak nuclear force.

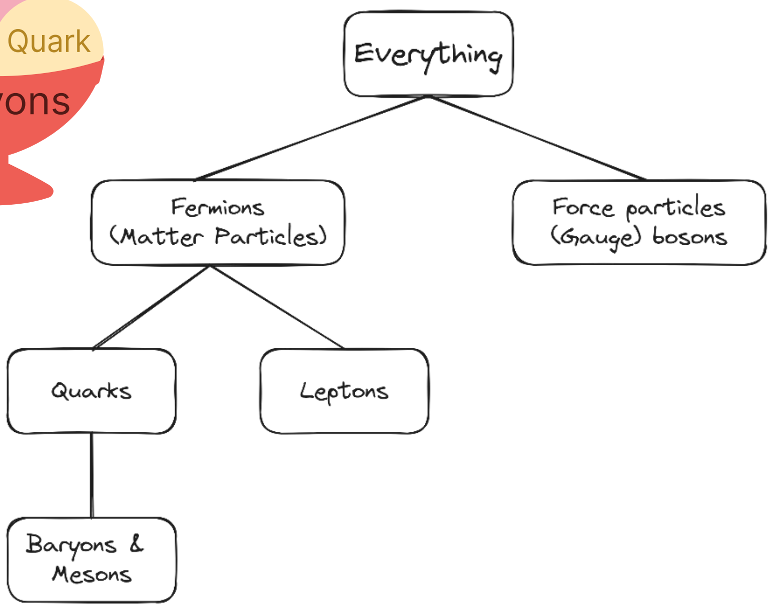
A **hadron** is a composite particle which contains quarks held together by the strong nuclear force.



A **meson** is a hadron with 2 quarks one quark and one anti-quark.

A **baryon** is a hadron made up of 3 quarks or 3 anti-quarks.



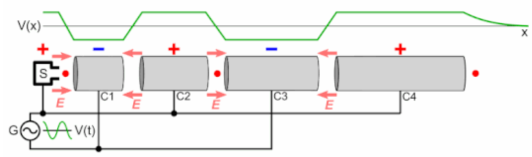


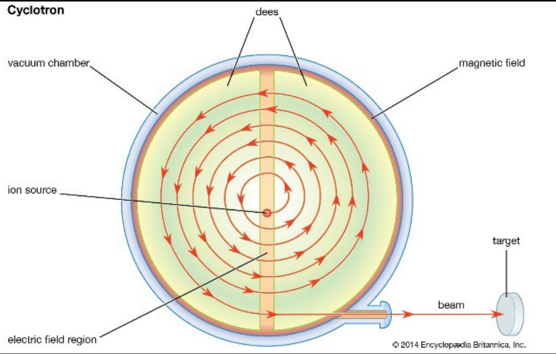
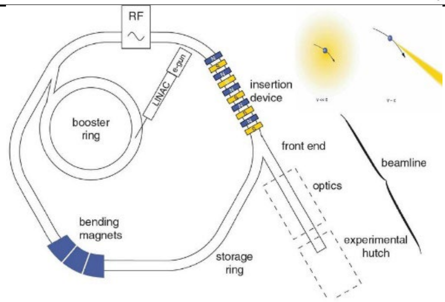
A **boson** is particular which allows for the mediate of the three fundamental forces:

- Electromagnetic
- Weak nuclear force
- Strong nuclear force

Particle accelerators speed up small particles of matter to extremely high speeds so experiments can be performed on them.

Up quarks have a charge of ⅔, while down quarks have ⅓. This allows for the charge of +1 for a proton (2u & 1d) and 0 for a neutron (1u & 2d)

Type	Diagram	Workings	Example
Linear		This uses an alternating current to accelerate a charged particle along a path.	SLAC

Cyclotron		Release particles at the centre of a circle then using alternating currents to accelerate charged particles in a 'vortex' shape.	Hospitals
Synchrotrons		Use a series of rings to accelerate particles to high speeds with electric field and magnetic field. Take samples of the beam to run experiments.	LHC

The Large Hadron Collider (LHC) is governed by CERN and was used to discover the Higgs boson and pentaquarks.

Scientific Principles

Types of Variables

Independent – the part of the experiment which is changed.
Dependent – what is measured/observed within the experiment and is drawn on for results.
Controlled – things that are kept the same.

Scientific principles:

Validity

Whether the investigation is only ensuring one variable is being changed at a time, and keeping the other variables controlled.

Validity has to be ensured in the experiment, the method and the analysis.

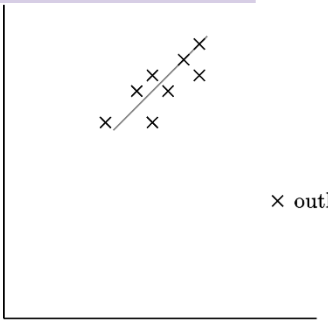
Also, be aware of any assumptions being made over the course of the experiment and evaluate whether the values yielded are appropriate.

Reliability

The alignment of the measurements/observations made during the course of the investigation.
Generally, the reliability is improved with increased repetition of the experiment.

Making sure to use the same steps and expecting the same value (or very close to it).

It also involves minimisation of outliers, by analysing the patterns and looking for ones which are obviously wrong.



Accuracy

The 'closeness' of the measured/observed result to the expected/calculated value.

Involves ensuring that equipment is calibrated and right precision for the job.
(i.e., not using a kitchen scale to measure mg differences)

Accuracy can be impeded by systemic, equipment and random errors.

- Systemic errors: are faults within the experiment or method itself leading to incorrect conclusions being drawn (predictable errors).
- Equipment errors: the equipment is not calibrated or precise enough for measurements.
- Random errors: unpredictable errors, which can be minimised through multiple methods.

Bias can be due to incorrect assumptions and procedures being used in an experiment.

Use consistent decimal places (1.23) or significant figures (1230) within answers, and don't usually round answer until the end.

Discrete data: separate portions of data (i.e., colours)
Continuous data: continuous flow of data (i.e., temperature)

Can manipulate non-linear data with $B = k\frac{1}{d}$, with B and d being two separate quantities

Uncertainty is the maximum variance from the mean (±) also expressed in a percentage form.

Summary of Theory/Experiments

Topic 5 - Mechanics

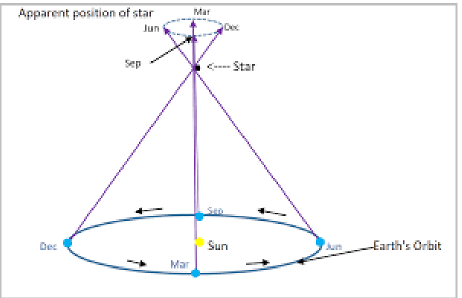
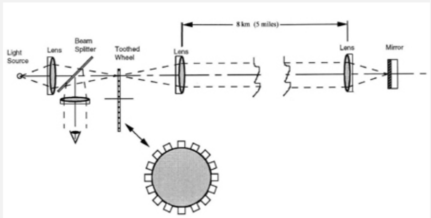
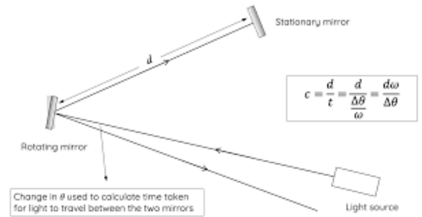
Year	Name	Scientist(s)	Description	Diagrams/Formula
1609	Laws of Planetary Motion	**Kepler**	1. Bodies move in elliptical orbits, with the orbited body at one focus. 2. As the body traces out the same area in its orbit, it travels with the same time. 3. $\frac{r_1^3}{T_1^2} = \frac{r_2^3}{T_2^2}$, for bodies orbiting in the same system.	
1687	Law of Universal Gravitation	**Newton**	That all gravitational bodies exert <u>equal</u> forces on one another.	$F = \frac{GMm}{r^2}$

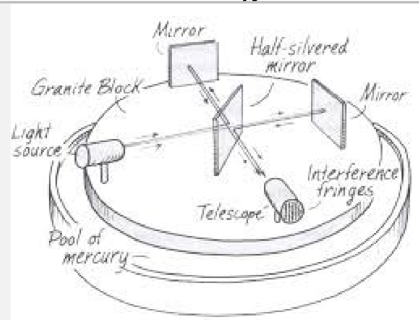
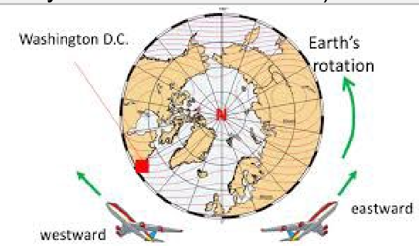
Topic 6 – Electromagnetism

Year	Name	Scientist(s)	Description	Diagrams/Formula
1831	Faraday's law	**Faraday**	A change in magnetic field leads to induced emf (V).	$\varepsilon = N\frac{\Delta\phi}{\Delta t}$
1834	Lenz's law	**Lenz**	The current induced due to changing magnetic field, works to oppose the change and to bring the system back to its original state.	$\varepsilon = -N\frac{\Delta\phi}{\Delta t}$
1865	Maxwell's equations	**Maxwell**	Maxwell unified the theories of electric and magnetic waves to realise that all EM waves were self-propagating and acted at right angles to one another. Maxwell formulated four equations which described the properties of both oscillating electric and magnetic waves.	$v = \frac{1}{\sqrt{\varepsilon_0\mu_0}}$

Topic 7 – Nature of Light

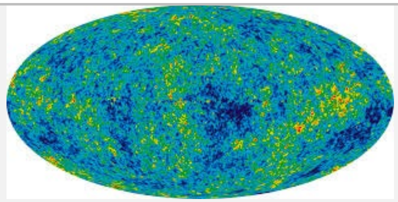
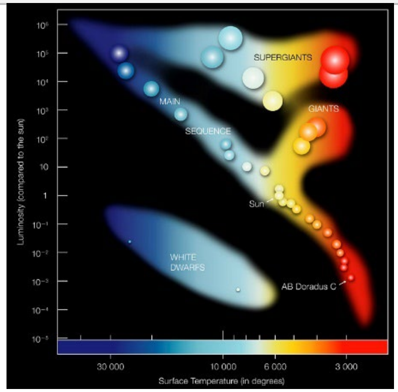
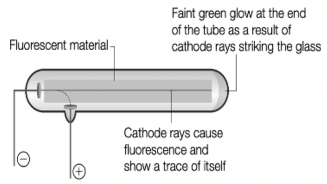
Year	Name	Scientist(s)	Description	Diagrams/Formula
1865	Propagating EM waves	**Maxwell**	That EM waves oscillate in perpendicularly to one another, and in a sinusoidal phase.	
1887	Radio wave discovery	**Hertz**	Hertz discovered radio waves after passing voltage through a gap, and seeing sparks fly.	$v = f\lambda$
		Brief summary of speed of light discoveries		
1728	Stellar aberration	**Bradely**	Bradely measured the apparent displacement of stars as the Earth moved around the sun, by measuring these displacements over the course of a year. Found the speed at which light travelled from this.	$301\ 000 km\ s^{-1}$

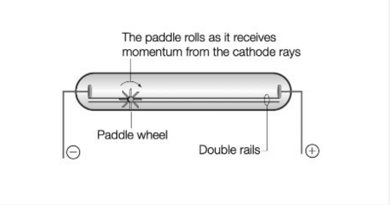
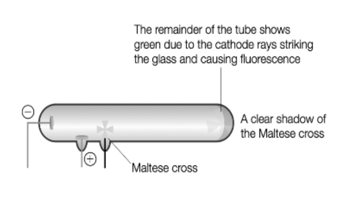
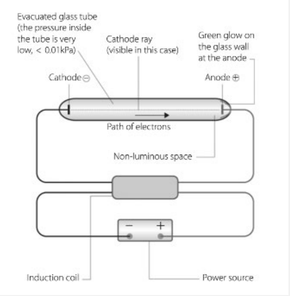
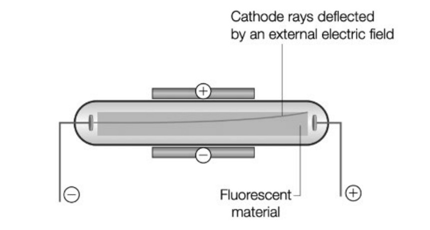
				
1849	Rotating cog	**Fizeau**	Through using a cog rotating at a set speed in such a condition that the light goes in one tooth and comes back in the next set.	$315\ 000 km\ s^{-1}$ 
1862	Rotating mirror	**Foucault**	With a rapidly rotating mirror, Foucault was able to determine the angle which the light made when completing its journey.	$298\ 000 km\ s^{-1}$ 
		Theories of the nature of light		
1678	Wave model	**Huygens**	Theorised that light acted like a wave, leading to the diffraction and refraction being explained.	
1718	Corpuscular model	**Newton**	Theorised that light was particles, and that when it entered a denser medium it sped up due to an attraction to the material.	
1809	Malus' Law	**Malus**	There is a drop in intensity of light as it passes through a polarising filter. (Unpolarised light always loses half of its intensity through its first filter)	$I = I_{\max} \cos^2\theta$
1893	Wien's Law	**Wien**	The relationship between the temperature of a black body and its most 'frequent' wavelength.	$\lambda_{\max} = \frac{b}{T}$

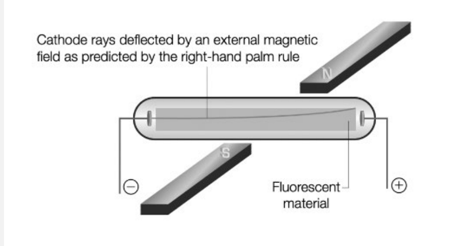
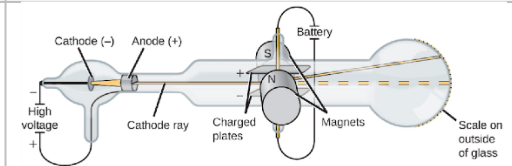
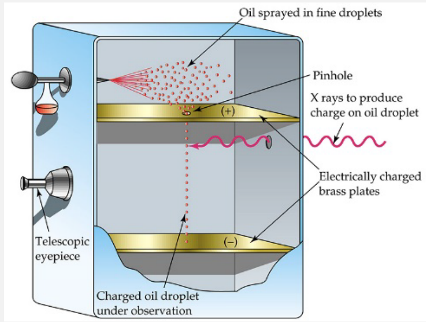
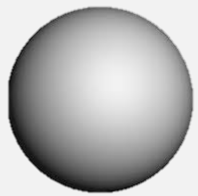
				$K = °C + 273$
1900	Quantisation of light	**Planck**	Planck realised that energy is quantised especially to do with the photoelectric effect.	$E = hf = \frac{hc}{\lambda}$
1887	Michelson-Morely experiment	**Michelson-Morely**	They sort to establish whether an aether existed which light transited through, yet it was a *failed* experiment as they were not able to prove the aether existence.	
1907	Einstein's thought experiments	**Einstein**	Einstein postulated that if a train car were to move very fast (at *relativistic* speeds) and a light pulse would be placed at the centre of the train, the observer on the platform would see the light pulse reach the front of the moving train before the rear. However, for the train itself it sees the light reach the front and rear at the same time. This led to the conclusion for time and length dilation, as they change to keep the speed of light *consistent* for all observers.	$t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}}$ $l = l_0\sqrt{1 - \frac{v^2}{c^2}}$
1940	Detection of cosmic muons		Cosmic muons travel at such high speeds, that they begin to experience time dilation allowing them to be detected on the Earth's surface (when due to their short lifespan they should not be able to).	
1971	Hafele-Keating experiment	**Hafele-Keating**	Highly accurate atomic clocks when flown on clocks around the Earth and their measurements compared to 'stationary' clocks at the US Naval Observatory. The clocks flying Eastwood lost time, as they were going faster compared to Earth. While the clocks travelling west gained time.	

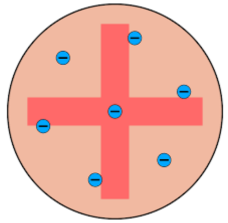
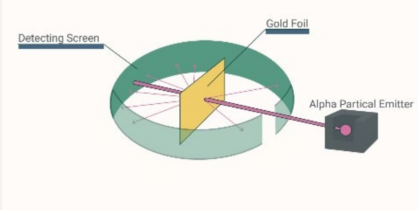
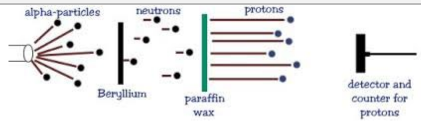
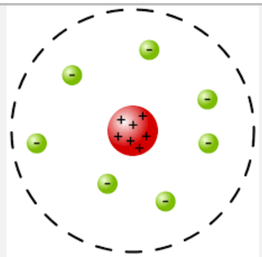
Topic 8 – Universe to the Atom

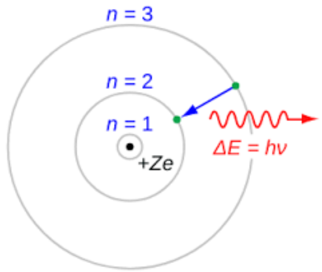
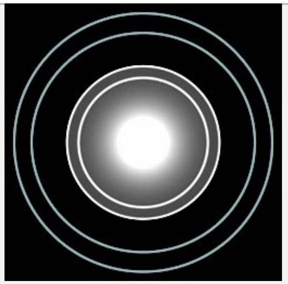
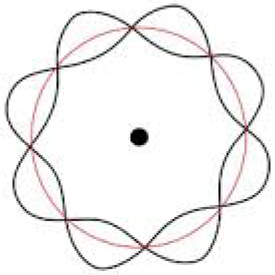
Year	**Name**	**Scientist(s)**	**Description**	**Diagrams/Formula**
13.7 billion	Big Bang		A high energy event at the start of the Universe, at $10^{32}\,K$, created subatomic particles.	

years ago				
1929	Red shift of distance galaxies	**Hubble**	By observing the light from distant galaxies, Hubble noticed that a large portion of this light had been redshifted leading to the observation that the universe was expanding.	
1965	Cosmic microwave background	**Penzias and Wilson**	The cosmic microwave background is due to the large release of energy at the Big Bang (specifically evaporation of cosmic particles) and is present in all the measurement of microwave radiation.	
1913	Hertzsprung–Russell Diagram	**Hertzsprung–Russell**	This diagram allows the measurement of relative luminosity, temperature, colour and evolutionary stage.	
Cathode Ray Experiments				
1859	CRT fluorescence	**Plücker**	Cathode rays can be used to incite a fluorescence in a fluorescent material, allowing for the path to be traced. └ Proves that cathode rays contain **energy**	

1879	CRT momentum	**Crookes**	Cathode rays when fired at a light paddle wheel causes it to move and spin. └ Proves that cathode rays have **momentum**	
1880	CRT Maltese Cross	**Crookes**	Cathode rays created a shadow of a Maltese in a tube from the cathode to the anode. └ Proves that cathode rays had a **negative** charge and travelled in **straight lines**	
1895	CR charge	**Perrin**	Perrin proved that the movement of cathode rays through an evacuated chamber leads to the creation of a charge. └ Proves that cathode rays had **charge**	
1897	CRT electric fields	**Thomson**	Cathode rays can be deflected by an electric field, where the CR bends towards the positive terminal. └ Proves that cathode rays are **negatively charged**	

1897	CRT magnetic fields	**Thomson**	Cathode rays were deflected by a magnetic field, according to the right-hand rule. └ Proves that cathode rays were **magnetic**	
1897	Charge-to-Mass	**Thomson**	Measured the charge to mass ratio of an electron through balancing the electric and magnetic forces.	
1909	Oil Drop Experiment	**Millikan**	Balanced the forces of the electric field and gravity to determine the charge of an ionised negatively charged oil drop.	1.6×10^{-19} 
		Atomic Models		
1800	Billard Ball Model	**Dalton**	That an atom is a single particle of one singular charge.	

1904	Plum Pudding Model	**Thomson**	An atom is a positively charged 'dough' with negatively charged constituents.	
1908	Discovery of the Nucleus	**Geiger-Marsden**	Through their experiment of passing alpha particles through gold foil most passed straight through, some deflected (impacting electrons) and some reflected (hitting the nucleus).	
1932	Discovery of the neutron	**Chadwick**	By firing alpha particles into a Beryllium sheet, Chadwick found that it emitted a neutral particle (which had no charge as it wasn't displaced by electric fields).	
1909	Rutherford Model	**Rutherford**	Rutherford proposed a model where the electrons orbited around the positive nucleus like how planets orbit around the Sun.	
1913	Bohr Model	**Bohr**	Bohr proposed that electrons orbit in quantised circular orbits around the nucleus and can jump between levels.	$E_{\text{photon}} = E_1 - E_2 = hf$ $L_n = \frac{nh}{2\pi}$

				
1923	Matter Waves	**Davisson and Germer**	After shooting electrons through graphite these scientists observed an interference pattern pointing to a wave nature of particles.	
1924	Matter Waves	**De Broglie**	All particles exhibit wave properties. Electron's stable orbit occur when they have a standing wave, meaning they are balanced.	$\lambda = \frac{h}{mv}$ 

1926	Schrödinger Model	**Schrödinger**	Particles orbit an electron in circular volume-based orbitals, and their position and velocity can never be truly known.