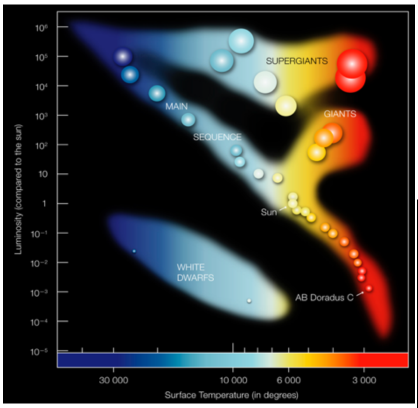
From The Universe to The Atom

Hertzsprung Russel Diagram



Main Sequence → Giant/Supergiant → White Dwarf

The Hertzsprung Russel is a fundamental tool in physics that helps study the attributes of stars such as characteristics and evolutionary stage, surface temperature, colour, and luminosity. This is done by plotting the luminosity of the star against the surface temperature.

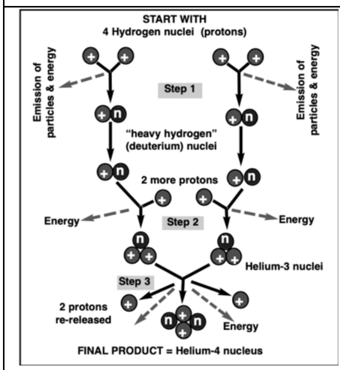
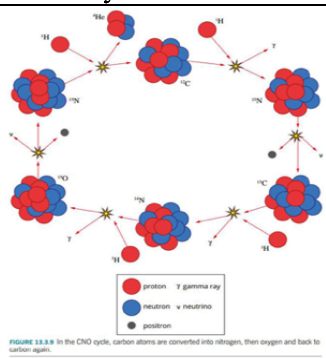
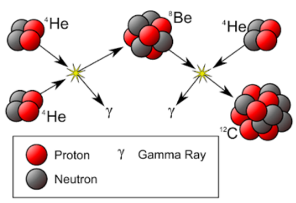
Main Sequence	Giants & Supergiants	White Dwarfs
These stars which are shown from the lower right to top left of the diagram. These stars are similar to our sun and have a core composed primarily of hydrogen. After burning through their hydrogen cores, they become Giant/Supergiants.	These stars are located on the top right/middle of the diagram. They are significantly larger than main sequence stars and contain a heavy iron core.	Located from the lower left to middle of the diagram. They are known to be fainter and cooler. They are remnants of giants (smaller main sequence) after they exhaust their nuclear fuel.

Surface Temperature – Represented by the horizontal axis of the diagram. This is measured unconventionally as the higher surface temperature stars are on the left and as it moves to the right surface temperature decreases. It is derived by the formula: $Intensity = \frac{Power}{Surface\ Area}$

Colour – The surface temperature of a star helps determine its colour. As we move towards the cooler stars the colours start to become warmer (such as yellow, orange, red). Inversely as we move towards the warmer stars the colours become cooler (such as light and dark blue)

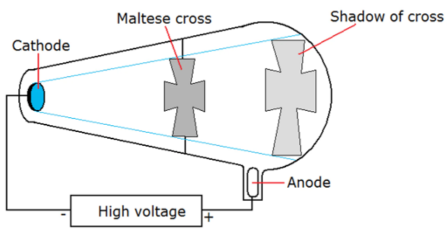
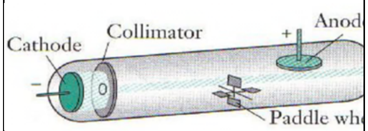
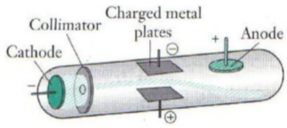
Luminosity - Represented by the vertical axis of the diagram. Luminosity is a measure of the total amount of energy radiated by a star over time. This is measured as an order of magnitude of the sun's luminosity.

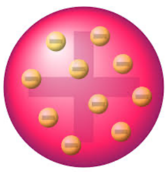
Nucleosynthesis Reactions in main-sequence and post-main-sequence stars

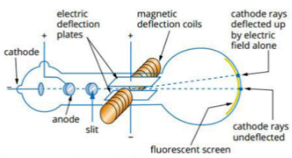
Proton-Proton Chain	CNO Cycle	Triple αlpha Process
 The proton-proton chain is the simplest form of nuclear fusion occurring during main sequence. This involves fusion between 4 ^{1}H (hydrogen nuclei) weighing 4.032u to form a	 The carbon-nitrogen-oxygen cycle occurs in medium to large main sequence alongside the previous chain. While still producing a ^{4}He (although higher energy) nucleus it goes through a more sophisticated	 This process occurs primarily in post-main-sequence stars. In this sequence ^{4}He has accumulated and thus undergoes further nuclear fusion to become even larger elements such as Beryllium. This provides enough kinetic energy to combat the star's greater electrostatic

lighter ^4He nucleus as lost mass is converted to energy. $4{}^1_1H \rightarrow {}^4_2He + 2{}^0_0\nu_e + 2{}^0_1\bar{e} + 2{}^0_0\gamma$	catalytic loop which involves beta decay and isotopes.	repulsion. The final result of this process is ^{26}Fe.

Experimental Evidence Supporting the Existence and Properties of the Electron

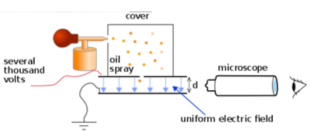
Cathode Ray Experiments – Discovery of the Electron		
Maltese Cross Experiment	Padded Wheel Experiment	Deflection by Fields
 In this experiment a Maltese cross is placed within the path of a cathode ray casting a shadow and travelling in a straight line. Thus, drawing similarities to light. Cathode rays are usually of wave nature; however, this hinted at a particle nature.	 A tiny paddle wheel is placed within the path of a cathode ray causing the paddle wheel to be pushed and rotated towards the anode. This indicated that cathode rays had momentum further hinting at its particle nature.	 In the presence of an electric field the cathode ray is deflected towards the positive plate. However, when encountering a magnetic field it was deflected in the same direction as negatively charged masses. This proved cathode rays are streams of negatively charged particles





Thomson's Charge-to-Mass Experiment

Building on previous studies JJ Thomson passed cathode rays through perpendicular electric and magnetic fields, adjusting the field strength so the ray travelled straight. Thomson then studied the curvature of the beam after removing the electric field and derived e/m = 1.76×10^{11}C/kg. This value was constant regardless of the cathode material or gas in the tube. Thus, he deduced an electron was 1/1800 the mass of a hydrogen ion. He then proposed the Plum Pudding Model of the atom containing a sphere of positive charge with electrons embedded.



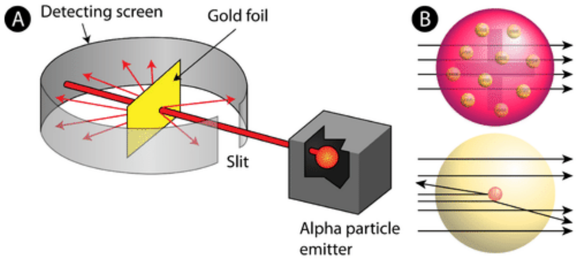
Millikan's Oil Drop Experiment

Robert Millikan used an electric field suspend oil drops against gravity. By adjusting the field and observing when the droplet was just hovering by adjusting the field. He calculated the droplet's charge (when qE = mg) and got integer multiples of -1.60×10^{-19} Coulombs. This also proved that electric charge is quantised (existing in discrete packets). Using Thomson's calculations of charge mass ratio, Millikan was able to calculate the mass of an electron: approximately 9.11×10^{-31} kg

Experimental Evidence Supporting Nuclear Model of the Atom

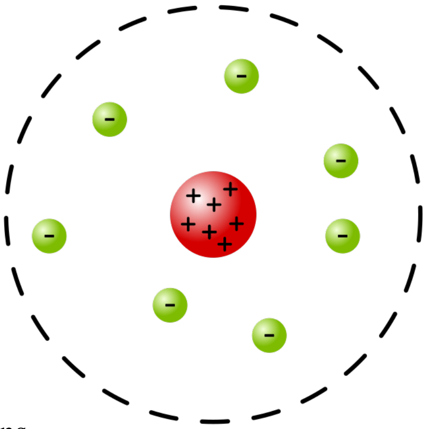
Geiger Marsden Experiment:

In the Geiger Marsden Experiment a beam of alpha particles (^{4}He nucleus) was shot at a gold foil which was surrounded by a fluorescent screen. While it was hypothesized using through Thomson's model that the alpha particles would pass through with minimal deflection, the results of the experiment showed that while most did pass through the deflected particles had extreme angles of over 90 degrees. This proved that Thomson's model of the atom was flawed as there had to be a densely packed region of mass and electric charge located in the middle of the particle.



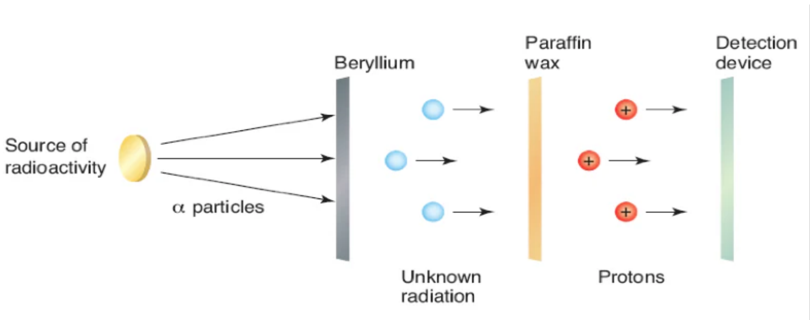
Rutherford's Atomic Model:

From the observations and results of the Geiger Marsden Experiment, Rutherford proposed and developed a new atomic model. This model consists of a positively charged center termed the nucleus surrounded by a cloud of smaller negatively charged electrons orbiting the nucleus in a vast empty space which brought stark similarities to the solar system and is sometimes referred to as Rutherford's Planetary Model.



Chadwick's Discovery of the Neutron:

Rutherford's atomic model was a breakthrough with the advent of protons, however the mass of the atom suggested there were more subatomic particles that did not contribute to the charge of the atom. In 1932, James Chadwick performed an experiment which revealed the existence of a neutral particle coined the neutron. Chadwick bombarded a beryllium foil with high energy α particles which emitted unknown neutrally charged radiation with enough kinetic energy and momentum to eject protons when passing through paraffin wax, meaning these particles had a higher mass then protons (due to the laws of conservation of momentum and energy). This 'neutron' was then added to Rutherford's existing model as part of the nucleus, and it helps in nuclear binding preventing nuclei from flying apart. This discovery was critical in the understanding of nuclear reactions, such as fusion as highlighted above.

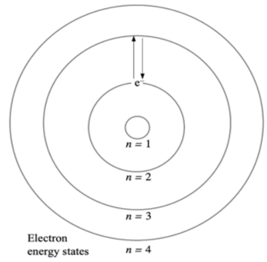


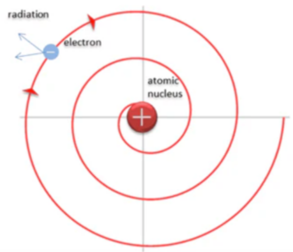
Quantum Mechanical Nature of the Atom

In 1912 Niels Bohr proposed a new model of the atom with discrete electron energy levels. He had three postulates (to suggest or assume the existence of something for the basis of discussion, reasoning, or belief):

1. Electrons revolve around the nucleus in fixed orbits or shells
2. Electrons in an atom have quantized energy
3. The angular momentum of an electron is quantized:

$$L_n = \frac{nh}{2\pi}$$



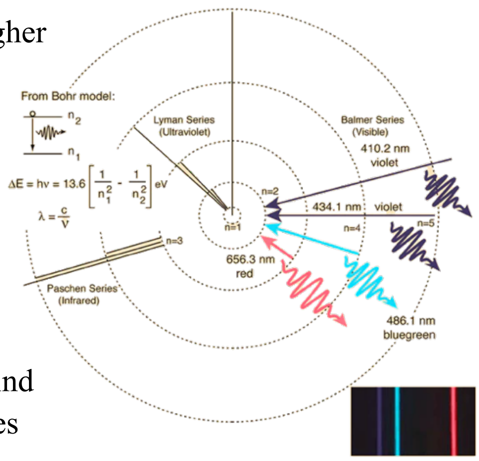
Limitations of Rutherford's Model	Limitations of Bohr's Model
Rutherford's planetary model suffered numerous shortcomings. - Rutherford's model was not able to account for the atomic mass of the atom. This was later discovered when Chadwick discovered the neutron. - Thus, according to Maxell's theory of electromagnetism an electron (in this case) orbiting a nucleus (in circular motion) should continuously radiate and spiral into the nucleus. Thus, in this model the atom collapses in seconds. - It did not explain how atoms only emit specific wavelengths light instead of continuous spectrum  	Despite being a major improvement, Bohr's model also had shortcomings. - Did not explain stationary states of electrons and why they didn't spiral into nucleus - Only accurate for single electron atoms such as hydrogen. The accuracy decreases as charge increases. - It couldn't explain the variations in thickness and intensity of spectral lines - Could not explain the wave-particle duality that came from de-Broglie's hypothesis. - Couldn't explain the continuous spectrum emitted by solids. This required a complex quantum model.

Emission Spectrum and Balmer series in relation to hydrogen

Emission lines are created due to the transition of electrons from higher to lower states. The visible emission line of hydrogen is shown in the Balmer series. In the Balmer series electrons jump from n = 2 to higher states before coming back down to n = 2. John Balmer used the equation:

$$\frac{1}{\lambda} = R_h\left(\frac{1}{{n_{final}}^2} - \frac{1}{{n_{initial}}^2}\right)$$

in which $n_{final} = 2$ as the electron jumps back to n = 2. This helped find the wavelength and showed that the wavelengths in the Balmer series matched visible light spectrum.



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