Chapter 13

Atomic Model

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INTRODUCTION TO ATOMIC MODELS

500 BC Maharishi Kanada

Paramanu (atom) is the smallest, indivisible particle of matter, considered indestructible.

As we break down matter into smaller particles, we eventually reach a point where it cannot be subdivided any further.

442 BC Democritus

Democritus proposed that matter is composed of imperceptible particles known as Atoms, interspersed within void or empty space.

Atoms are considered immutable and indestructible.

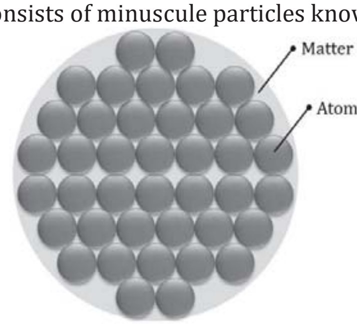
The properties of a material are contingent upon the specific type of atoms from which it is composed.

Dalton's Atomic MODEL

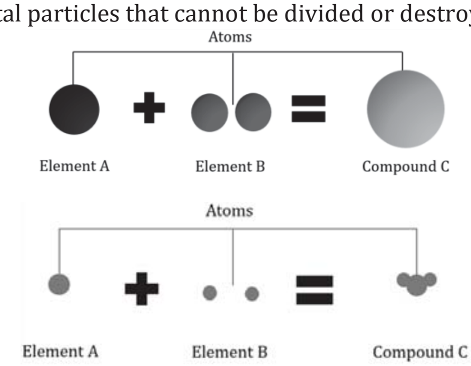
Postulates

1803 AD John Dalton

All matter consists of minuscule particles known as atoms.

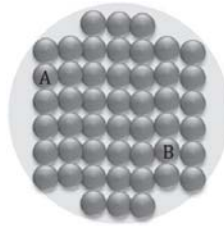


Atoms are fundamental particles that cannot be divided or destroyed during a chemical reaction.



No new atom is formed. No atom is destroyed.

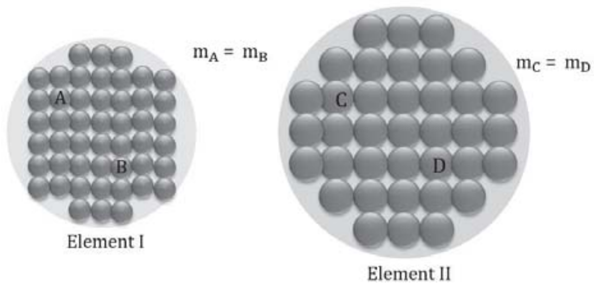
Atoms belonging to a particular element share identical mass and chemical properties.
Mass of atom A = Mass of atom B



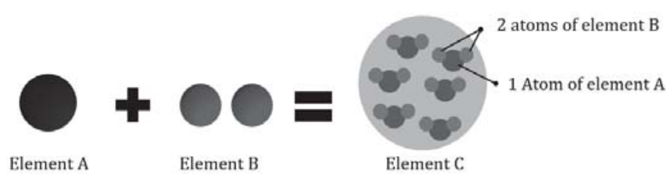
Element I

Atoms of distinct elements exhibit varying masses and chemical properties.
Mass of atoms from element I is not same as mass of atoms from element II.

$$m_a \neq m_c$$

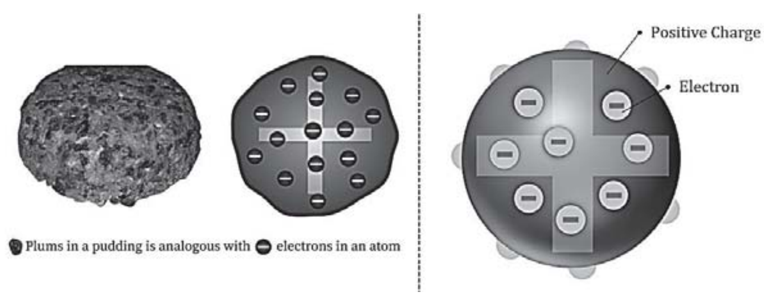


Atoms combine to form compounds in ratios that are small whole numbers.



1897 AD J. J. Thomson

In a given compound, the type and quantity of atoms remain consistent.
An atom comprises a positively charged sphere containing embedded electrons.
As a whole, an atom is electrically neutral due to the equal magnitude of its negative and positive charges.



Thomson's atomic model, alternatively known as the "plum-pudding" model, depicted the positive charge as uniformly distributed throughout the atom, akin to the distribution of pudding, with electrons embedded within it, resembling plums in a pudding.
Thomson proposed that since the positive charge forms a spherical shape and the electrons are contained within this positive sphere, only electrons can be emitted from the metal upon heating.

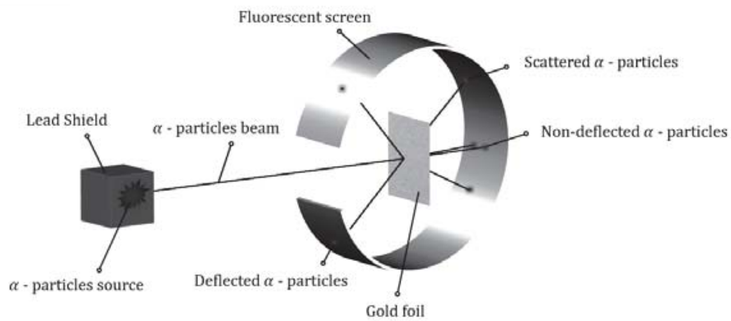
Thomson's Atomic Model

Limitations

Failed to provide an explanation for why cathode rays would pass largely unaffected through thin materials.

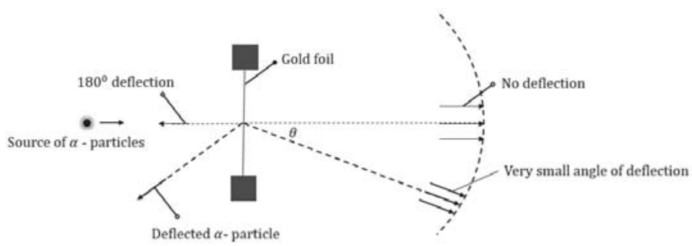
Lenard proposed that atoms contain substantial empty space and are composed of electrons and similarly minuscule positively charged particles.
Lenard's proposition failed to account for the selective ejection of only electrons when metals are heated.

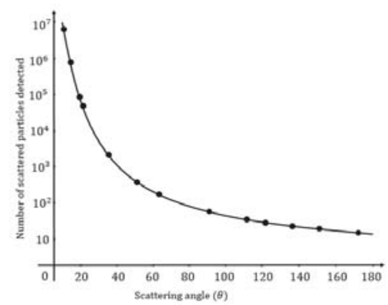
Rutherford's Atomic model
Gold foil Experiment
1911 AD Ernest Rutherford



The α - particles (He^{2+}) Alpha particles emitted by a radioactive source were directed into a focused beam by passing through lead bricks. This beam was directed onto a thin gold foil. Observations of the scattered alpha particles were made using a rotatable fluorescent screen and a microscope. The impact of the scattered alpha particles on the screen resulted in brief flashes of light.

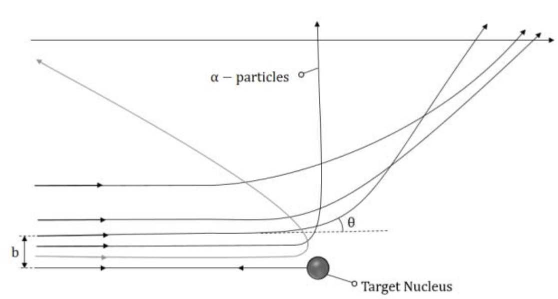
Observations





The trajectory was forecasted by applying Coulomb's law and Newton's laws, assuming the presence of a dense, small particle positioned at the atom's center, carrying a positive charge.
Most of the α- particles pass straight through the gold foil.
Only about 0.14% of the incident α-particles scatter by more than 1°
1 in 8000 alpha particles were deflected by more than 90°
The anticipated path is depicted by the curve, while the actual observed values are represented by dots.

Alpha –Particle trajectory



The impact parameter (b) represents the perpendicular distance from the initial velocity vector of the alpha particle to the nucleus's center.
The paths followed by alpha particles depend on the impact parameter (b) of the collision.

For small impact parameters (b), the collision led to significant scattering.

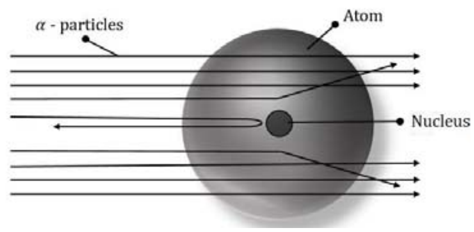
For large impact parameter (b), the α – particle goes nearly un-deviated and has a small deflection ($\theta \cong 0$)

In the case of a head-on collision, the impact parameter (b) is minimum, and the α – particle rebounds ($\theta \cong \pi$).

Conclusions

The majority of the space within an atom is vacant.

A small region inside the atom is occupied by a positive charge.

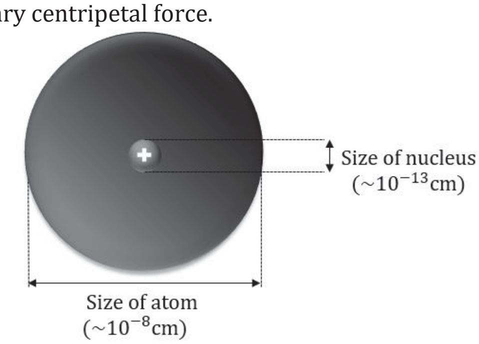


Nuclear model

Inside an atom, there exists a positively charged center known as the nucleus, which contains nearly all of the atom's mass.

Electrons orbit the nucleus in circular pathways.

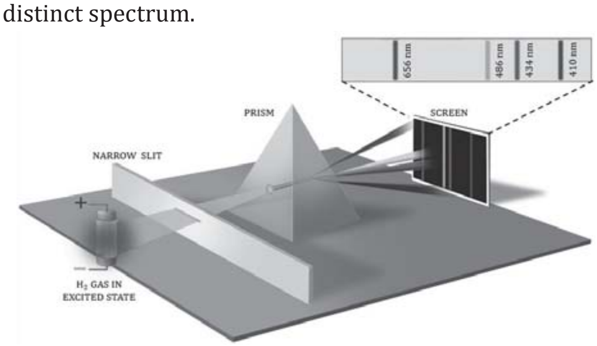
If the electron were stationary, it would be drawn straight into the nucleus by the Coulomb attraction. Therefore, the electron must move in circular orbits, where only its velocity vector changes, ensuring that the Coulomb force provides the necessary centripetal force.



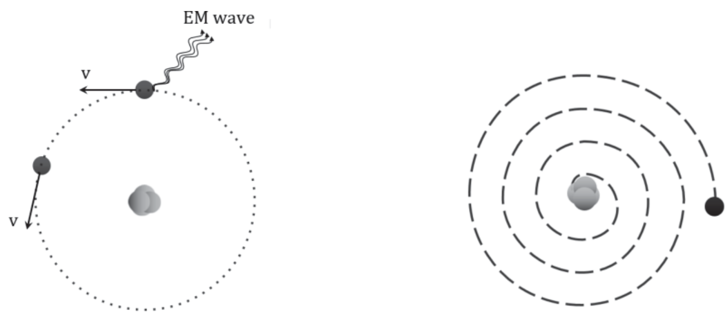
The nucleus is significantly smaller in size compared to the overall size of the atom.

Hydrogen Spectra

When hydrogen gas is excited at low pressure through the passage of an electric current, it emits radiation. This radiation is directed through a prism, resulting in the observation of a discrete spectrum on a screen. The spectrum displays specific wavelengths against a dark background. Such a spectrum is referred to as an emission line spectrum. The Rutherford atomic model fails to account for this distinct spectrum.



Failure of Rutherford Model



This model failed to explain stability of an atom.

As an electron undergoes acceleration, it continuously emits electromagnetic radiation, making it impossible to observe a discrete spectrum.

The electron's continuous production of electromagnetic radiation implies a continuous loss of energy.

The orbital radius ought to diminish, leading the electron to eventually collapse into the nucleus.

This model failed to explain discrete wavelengths in Hydrogen spectra.

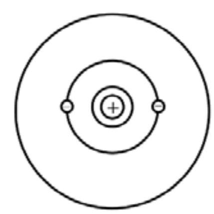
The orbiting electron is expected to emit radiation at any temperature.

The wavelength of radiation should correlate with the frequency of the electron's revolution, resulting in the emission of radiation with a continuously changing wavelength.

Bohr's Model of AN atom

Bohr's postulates

1. **Bohr's first postulate**



The electron orbits the nucleus in circular paths.

The electron's orbit around the nucleus is restricted to specific radii values.

Within these special orbits, the electron does not emit energy as predicted by Maxwell's laws.

These orbits are referred to as stationary orbits.

2. **Bohr's second postulate**

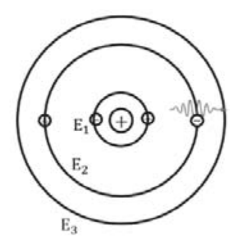
Within stationary orbits, the angular momentum (L) of the orbiting electron is quantized.

The angular momentum (L) of the electron in stationary orbits around the nucleus is a multiple of an integer. $h/2\pi$.

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

h = Planck's constant n = any +ve integer

3. **Bohr's third postulate**



An electron may transition from one of its designated non-radiating orbits to another with lower energy.

If it jumps from an orbit of higher energy E_2 to an orbit of lower energy E_1, it emits a photon of energy ΔE. $\Delta E = E_2 - E_1 = \frac{hc}{\lambda}$

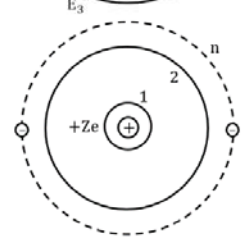
The electron can also acquire energy from a source and transition from a lower energy orbit to a higher one.

Hydrogen like atoms

A hydrogen-like atom or ion (hydro genic atom) is characterized by having a solitary electron.

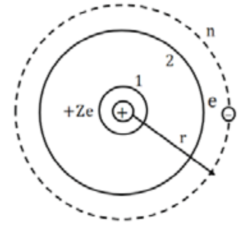
Bohr's atomic model applies to hydrogen-like atoms.

Example: $He^+, Li^{2+}, Be^{3+}, B^{4+}$



Representation of H-like atom

Radius of the nth orbit



Let Z represent the atomic number of the atom. Therefore, the total charge of the nucleus is +Ze.

The centripetal force is provided by the electrostatic attraction between the positively charged nucleus and the negatively charged electron.

$$F = \frac{1}{4\pi\varepsilon_0}\frac{2e^2}{r^2} = \frac{mv^2}{r}$$

$$\frac{2e^2}{4\pi\varepsilon_0} = mv^2r$$

Multiplying both sides by mr $\Rightarrow \frac{2e^2}{4\pi\varepsilon_0}mr = (mvr)^2$

As, angular momentum of electron, $L = mvr = \frac{nh}{2\pi}$

$$\frac{2e^2}{4\pi\varepsilon_0}mr = (\frac{nh}{2\pi})^2$$

$$\frac{2e^2mr}{4\pi\varepsilon_0} = \frac{n^2h^2}{41\pi^2}$$

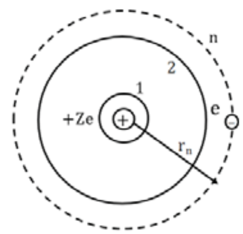
$$r = \frac{n^2h^2\varepsilon_0}{\pi 2e^2m}$$

$$r_n = \frac{h^2\varepsilon_0 n^2}{\pi me^2 Z}$$

$$r_n = 0.529 \times \frac{n^2}{Z}\text{Å}$$

Speed of electron in nth orbit $\quad \frac{1}{4\pi\varepsilon_0}\frac{2e^2}{r^2} = \frac{mv^2}{r}$

$$v^2 = \frac{2e^2}{4\pi\varepsilon_0 m\gamma}$$



Putting value of r, we get : $v_n = \frac{e^2Z}{2h\varepsilon_0 n}$

$$v_n \approx 2.18 \times 10^6 \times \frac{Z}{n} m/s$$

Time period of electron in nth orbit

$$T = \frac{2\pi r}{v}$$

Putting value of r and v, we get $\quad T_n = \frac{4h^3\varepsilon_0{}^2n^3}{me^4Z^2}$

$$T_n \propto \frac{n^3}{Z^2}$$

Frequency of electron in nth orbit $\quad f = \frac{1}{T}$

Putting value of T, we get $\quad f_n = \frac{me^4Z^2}{4n^3h^3\varepsilon_0^2}$

$$f_n \propto \frac{Z^2}{n^3}$$

Kinetic energy of electron in nth orbit

$$K = \frac{1}{2}mv^2$$

Putting value of v, we get $\quad K = \frac{me^4Z^2}{8h^2\varepsilon_0 n^2}$

Potential energy of electron in nth orbit

$$U = \frac{-2e^2}{4\pi\varepsilon_0 r}$$

Putting value of r, we get $\quad U = -\frac{me^4Z^2}{4h^2\varepsilon_0 n^2}$

Total energy of electron in nth orbit

$$E = V + U$$

$$E = -\frac{me^4Z^2}{8h^2\varepsilon_0 n^2}$$

$$E = -13.6 \times \frac{Z^2}{n^2}eV$$

$$K = -E = -\frac{U}{2}$$

As, the total energy of the system is negative i.e. $E < 0$

Hence, this system is bound, implying that energy must be supplied to separate the particles.