CHEMISTRY

ATOMIC STRUCTURE

EARLY DISCOVERIES AND THE MODELS

NOTES

What you will learn

- Cathode rays
- Charge to mass ratio
- Anode rays
- Discovery of neutron
- Thomson's model
- Rutherford's model
- Nucleus

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Introduction

The **existence of atoms** had been **proposed** as **early** as **400 B.C.** by Indian and Greek philosophers who were of the view that atoms were the **fundamental building blocks of matter**.

- The atomic theory of matter was first proposed on scientific basis in 1808.

Dalton's atomic theory

1. All matter is made up of atoms that are indivisible.
2. All atoms of a given element are identical in mass and properties.
3. It explained the law of conservation of mass, law of constant composition, and law of multiple proportions.
4. It regards the atom as the ultimate particle of matter.

Drawback of the theory

It **failed to explain** the **results of** many **experiments**. For example, it was known that substances like glass or ebonite, when rubbed with silk or fur, get electrically charged.

- The **experimental observations**, made by **scientists** towards the **end of the nineteenth and beginning of the twentieth century, established** that **atoms are made of subatomic particles, i.e., electrons, protons, and neutrons**—a concept that was very different from that of Dalton's atomic theory.

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Cathode rays

Experimental set-up

Discharge tube/Cathode-ray Tube/Crooke's tube/Crooke's discharge tube

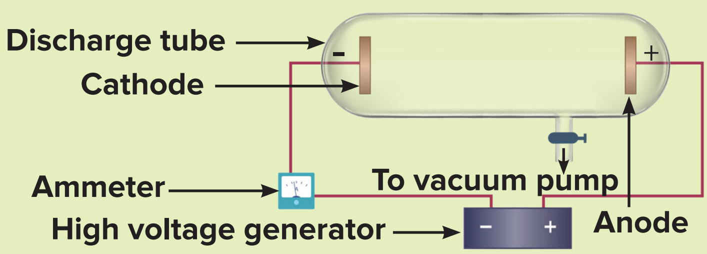

Fig. 1: Cathode-ray tube

Discharge tube: It is a **cylindrical hard glass tube** that is fitted with **two metallic electrodes** connected to the opposite poles of a battery.

The gas taken in the discharge tube was subjected to a very low pressure (~10^{-6} *atm*) maintained by a vacuum pump and high voltage (~10,000 volts) to generate the cathode rays.

Note: Why is low pressure required?

At low pressure the amount of gas within the discharge tube is less thereby electrons of the cathode ray will experience very less number of collision with the ionized gas particles. This will help electrons gain sufficient kinetic energy required to reach the anode. At high pressure, there are more number of gas molecules that would act as obstructions in the path of electrons, thereby preventing the electrons from reaching towards the anode.

Observations and Conclusions

They cast the shadow of an object on the ZnS screen placed in its path.

Cathode rays **move** from **cathode to anode**.

A sharp shadow of an object is produced on the ZnS screen in the absence of electric and magnetic fields.

Cathode rays **travel** in a **straight line.**

They rotate a light paddle wheel placed in its path

This **shows** that **cathode rays contain** material **particles** having **both mass and velocity**.

Rays are observed with the help of fluorescent or phosphorescent material.

These rays are **not visible** to the **naked eye**.

They get deflected when placed in an electric field and magnetic field.

The **direction of deflection shows** that they are **negatively charged.**

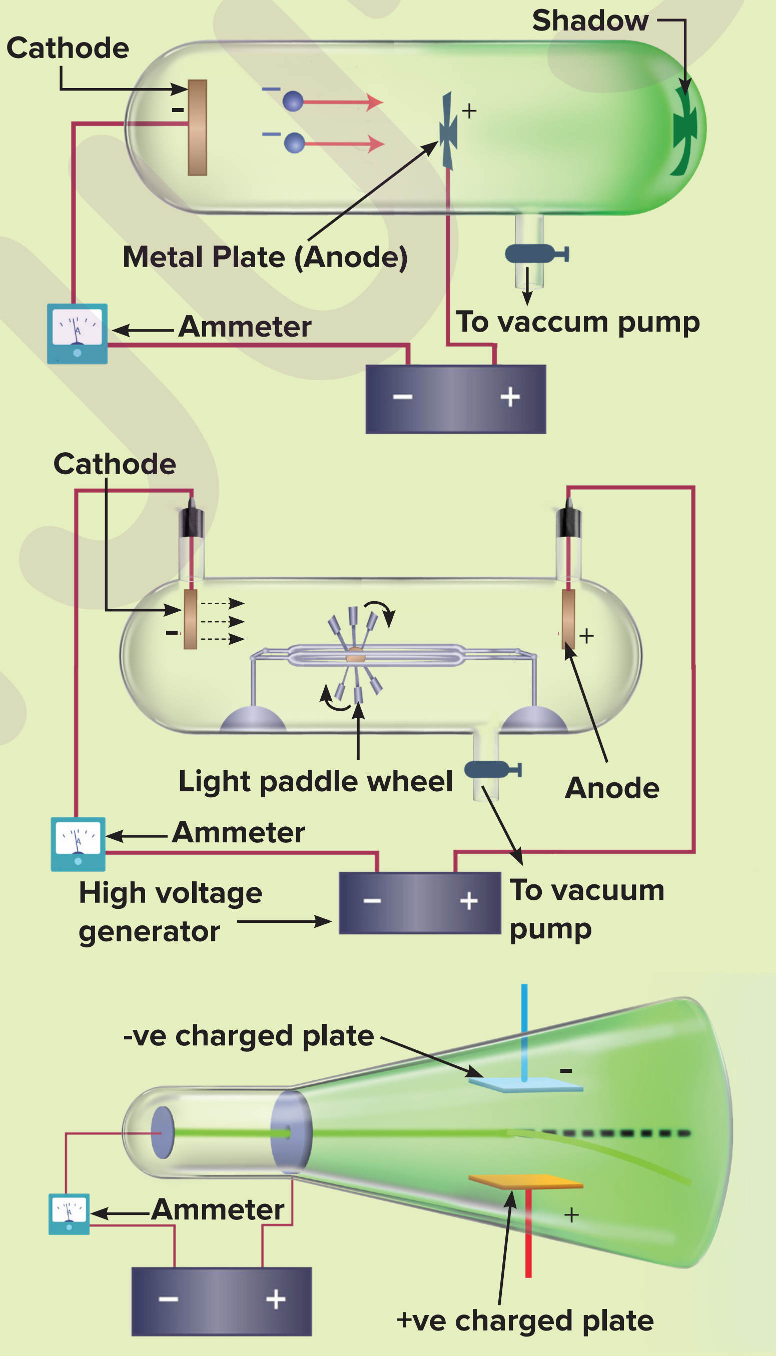

Fig. 2: Properties of Cathode rays

Conclusion

- The above observations led to the conclusion that cathode rays consist of negatively charged particles. These charged particles were identified as electrons.

Note: Irish physicist George Johnstone Stoney named the fundamental unit of electricity as 'electron' in 1891. J.J. Thomson and his team of British physicists identified it as a particle in 1897.

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Charge to mass ratio

- In 1897, J.J. Thomson measured the **charge (e)** to **mass (m) ratio** of an electron by applying electric and magnetic fields perpendicular to each other as well as to the path of electrons.

$$e/m = 1.758820 \times 10^{11}\ C\ kg^{-1} \sim 1.76 \times 10^{11}\ C\ kg^{-1}$$

- This **e/m ratio** came out to be the same, **irrespective of the nature of the gas** or **the cathode material taken**, concluding that the electrons are fundamental particles.

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Discovery of anode rays

- The **discovery of anode rays** by **Goldstein** was done on the basis of the cathode ray experiment conducted by using a perforated cathode.
- **Existence of positively charged particles** in atom was shown by E. Goldstein, using **canal rays (anode rays)**.

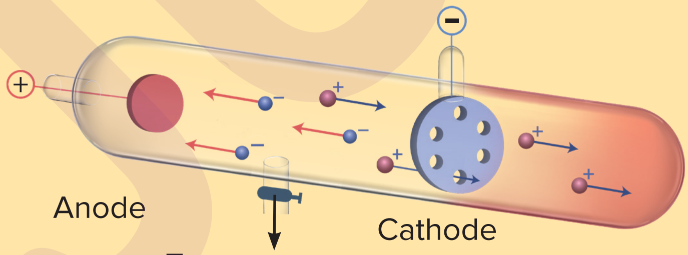

Fig. 3: Canal ray experiment

Experimental setup

The apparatus of the experiment incorporates the same apparatus as the cathode ray experiment that is made up of a **glass tube, containing two pieces of metal** at the different ends, that **acts** as an **electrode**. The two **metal pieces** are **connected** with an **external voltage**, thus completing the circuit.

Further, a **high voltage source** is **provided** between the two metal pieces **to ionise the air and make it a conductor of electricity. Air evacuation** is done to **maintain low pressure** inside the tube.

Explanation of the discharge tube experiment of anode rays

- **Positive anode pulls** out some **electrons from the gas molecules** producing **positively charged gas ions**.
- Now, as the pressure in the tube is very low, these positive gaseous ions **move** towards the **cathode** at a very **high speed** due to less obstructions.
- These high-speed positive gaseous ions **collide** with the **cathode**.
- Now, as these **electrons move** towards the **perforated anode, they** produce a **glow** behind the anode on the ZnS screen.

- After that, **when the cathode is perforated**, the **positive gaseous ions** pass through the **cathode** and produce a **pink glow** behind the cathode on the ZnS screen.

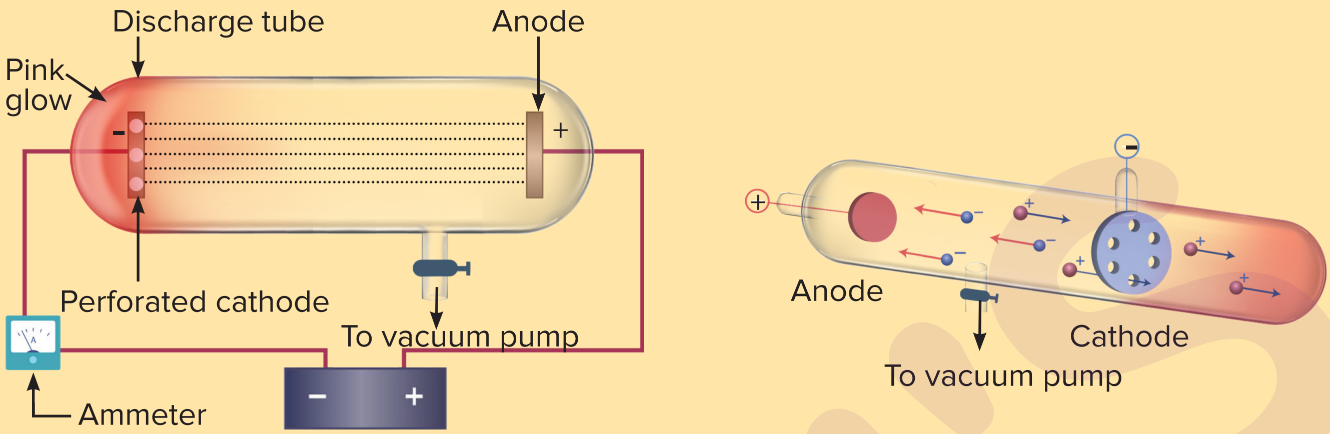

Fig. 4: Discharge tube experiment setup of Anode rays

Observations and Conclusions

S.No.	Observation	Conclusion
1.	Pink glow is observed behind the perforated cathode in the absence of electric and magnetic fields.	Anode rays travel in a straight line from anode to cathode.
2.	They get deflected when placed in the electric and magnetic fields.	The direction of deflection shows that they are positively charged.

Note:

- The **properties of anode rays**, unlike cathode rays, **depend** upon the **nature of the gas taken in the discharge tube**, as the **e/m ratio** of the positive rays is **different** for different gases and the **maximum** value of **e/m ratio** is for **hydrogen gas**.
- The **smallest** and the **lightest positive ion** was obtained from **hydrogen gas** and was known as the **proton**. This positively charged particle was characterised in 1919, by Rutherford.
- As **anode rays** pass through the **canal of the perforated cathode**, it is also known as **canal rays**.

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Discovery of neutron

- Neutron was discovered by **Chadwick** (1932).
- Chadwick bombarded a thin sheet of beryllium ($^{9}_{4}Be$) with alpha particles ($^{4}_{2}He^{2+}$). Electrically neutral particles having a mass slightly greater than that of protons were emitted.
- Chadwick named these particles as neutrons.

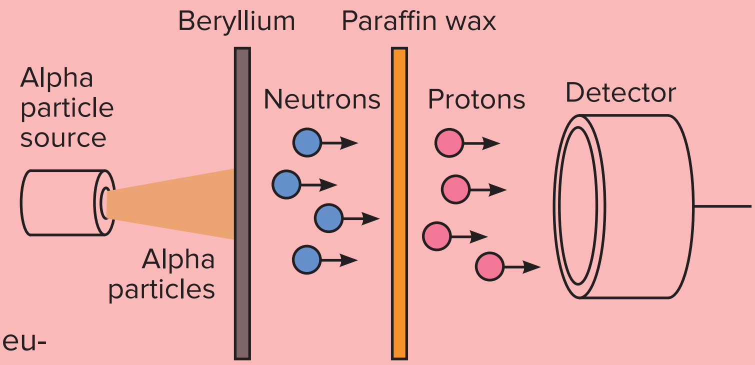

Fig. 5: Experimental setup used by Chadwick

$$^{4}_{2}He^{2+} + ^{9}_{4}Be \longrightarrow ^{12}_{6}C + ^{1}_{0}n$$

$^{4}_{2}He^{2+}$	+	$^{9}_{4}Be$	→	$^{12}_{6}C$	+	$^{1}_{0}n$
Alpha particles Atomic number = 2 Mass = 4 *u*		Atomic number = 4 Mass = 9 *u*		Atomic number = 6 Mass = 12 *u*		Neutron Charge = 0 Mass = 1 *u*

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Thomson's model of the atom

Plum Pudding Model / Raisin Pudding Model / Watermelon Model

Postulates

- An atom possesses a **spherical shape** (radius approximately 10^{-10} *m*).
- **Positive charge** is **uniformly distributed** in which **negatively charged** electrons are **embedded like raisins** in a 'plum pudding'.
- According to Thomson, the electrons are embedded in an atom in such a way that **the most stable electrostatic arrangement** is achieved (i.e., repulsion between electron-electron and proton-proton are minimised).
- **Mass** of the atom is assumed to be **uniformly distributed** all over it.

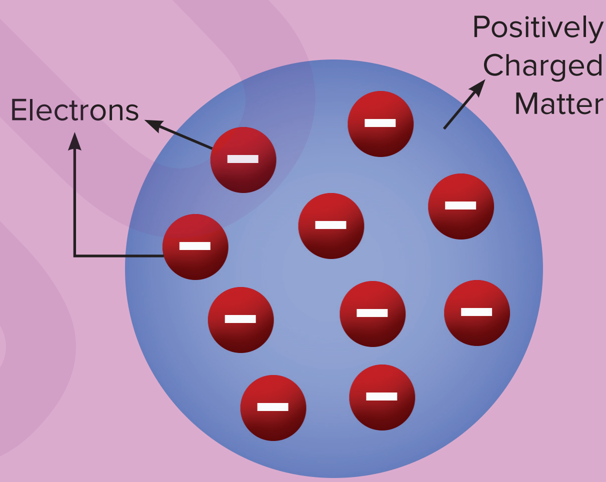

Fig. 6: Plum pudding Model

Fig. 7: Raisin pudding and Watermelon Model

Drawbacks

Although it was able to explain the **electrical neutrality** of the atom, it has some drawbacks.

- It failed to explain how the positive charge holds on the electrons inside an atom.
- It failed to explain the **stability of an atom**.
- This theory did not mention anything about the **nucleus of an atom**.
- It was not consistent with the results of later experiments.

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Rutherford's Model

α - Scattering experiment

A **stream** of **high energy** α–**particles** from a **radioactive source** was **directed on** a **thin foil** (thickness ~ 100 *nm*) of **gold** metal. The thin gold foil was **surrounded by** a **circular screen coated** with **fluorescent zinc sulphide**. Whenever an α–particle struck the screen, a tiny flash of light was produced at that point on the screen.

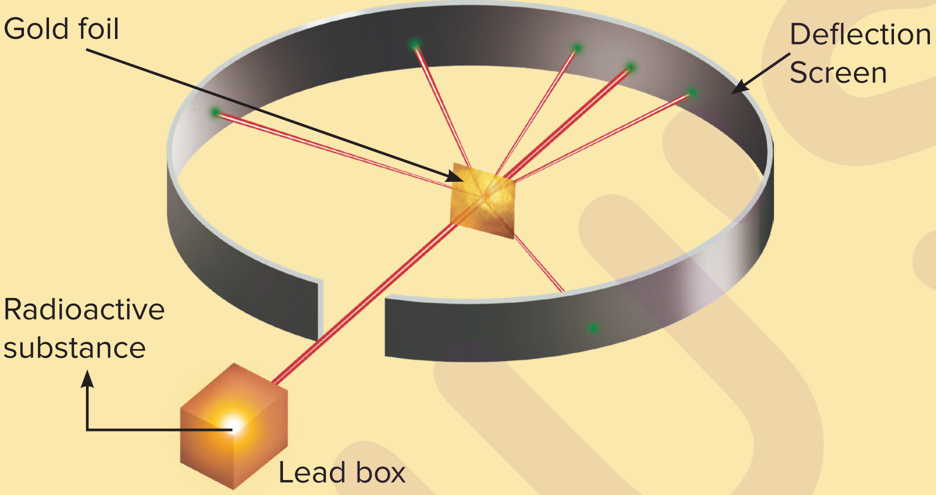

Fig. 8: Rutherford's gold foil experiment

Observations and Conclusions

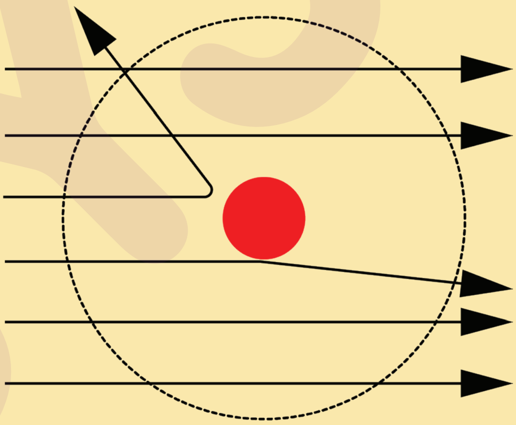

Fig. 9: Rutherford's gold foil experiment

S.No.	Observation	Conclusion
1.	**Most** of the **alpha-particles passed through** the **foil without** any **deflection**.	**Presence** of **large empty space** in the atom.
2.	**Few alpha-particles** were **deflected** by **small angles**.	**Positive charge** is **concentrated** in a very **small region** and not uniformly distributed in the whole atom.
3.	**Very few alpha-particles** (1 out of 20,000) **rebounded completely**, i.e., deflected at ~180°.	**Confirms the concentration of positive** charge in a very small region called the **nucleus**.

Nucleus

- In an atom, the mass and positive charge are centrally located in an extremely small region known as the nucleus.
- The volume of the nucleus is negligible when compared to the total volume of the atom.
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- The volume of the nucleus is negligible when compared to the total volume of the atom.
- Radius of the atom is about 10^{-10} *m*.
- Radius of the nucleus is 10^{-15} *m*.

  For example, placing a marble of 1 *mm* thickness in a stadium of radius 100 *m*.

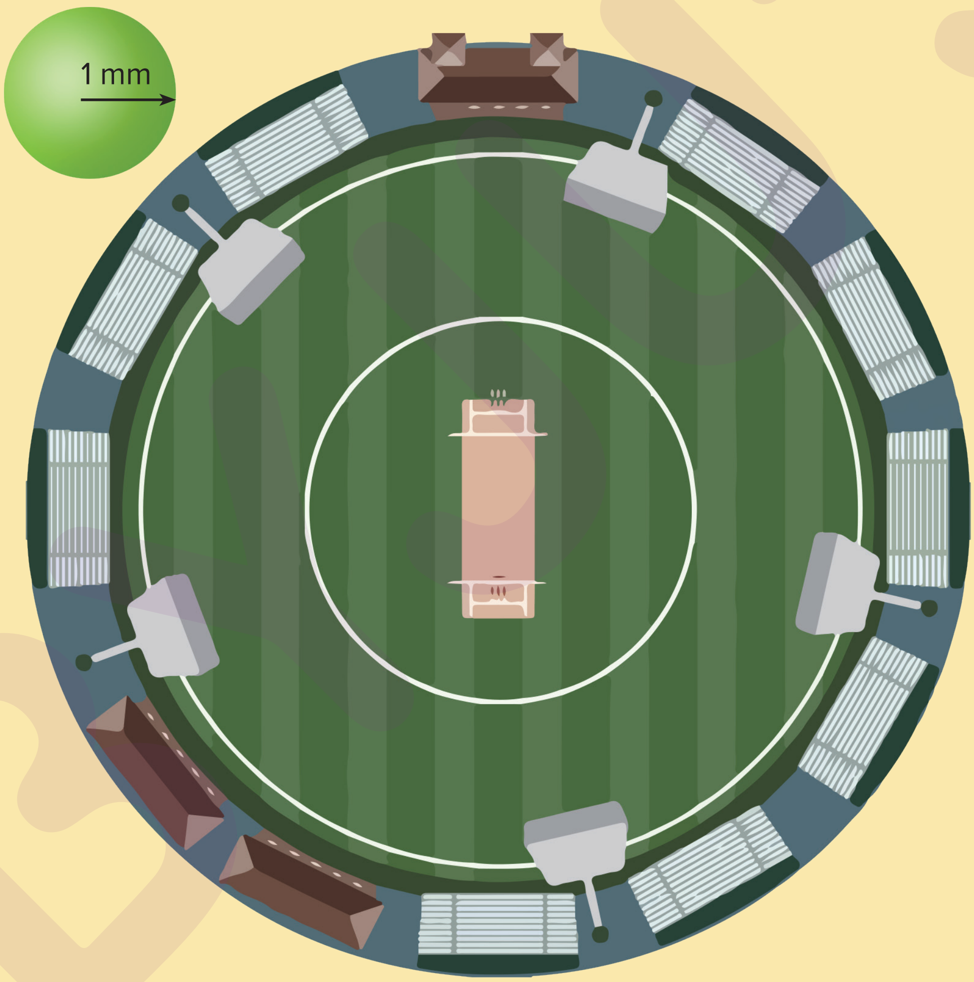

Fig. 10: Analogy showing difference in size of atom and nucleus

- The average radius of a nucleus of an element whose mass number is A, is $R = R_0A^{1/3}$

  where R_0 = 1.11 x 10^{-15} *m* to 1.44 x 10^{-15} *m*

  R = Radius of the nucleus

  A = Mass number of an element
- Both protons and neutrons present in the nucleus are collectively known as nucleons.