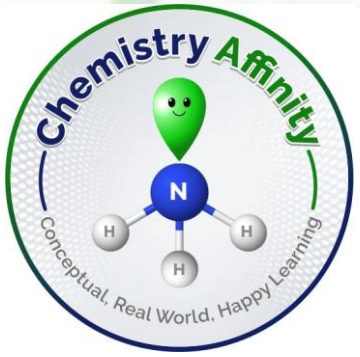
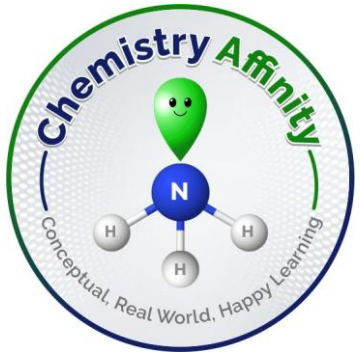


Structure of Atom

Designed by Dr. Anuradha Mukherjee

Chemistry Affinity
Conceptual, Real World, Happy Learning



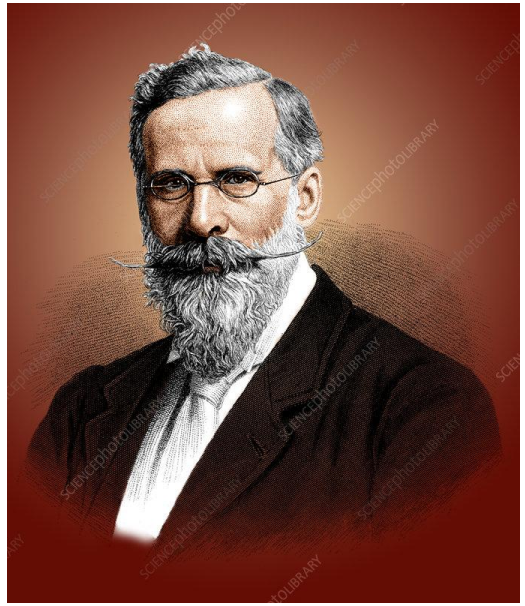
Discoveries of sub-atomic particles is an interesting and fascinating journey in the world of science

Let's Explore it.....

Discovery of sub atomic particles

The study of atomic structure was initiated by the experiments using discharge tube

Experiments on the discharge tube were first conducted in 1878 by an English physicist, William Crookes



Cathode Ray experiments

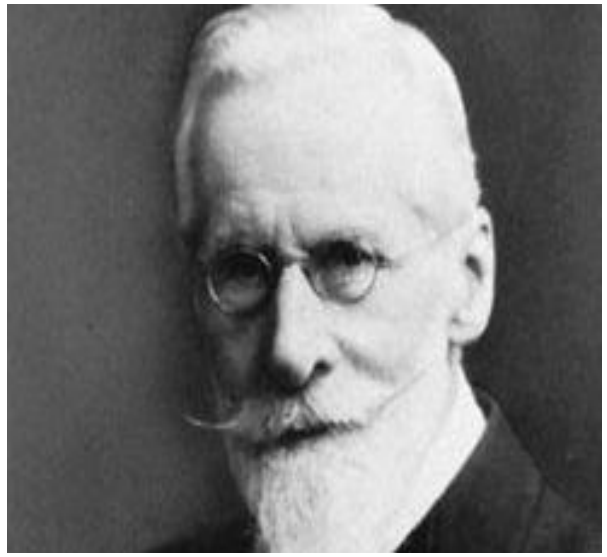
Anode Ray experiments

Sir William Crookes

In 1861, he discovered the element thallium

In 1873, he find out the atomic weight of thallium

He worked on cathode ray experiment and demonstrated that cathode rays travel in straight lines and produce phosphorescence when they strike certain materials in a discharge tube which is known as Crooke's tube



Sir William Crookes
British chemist

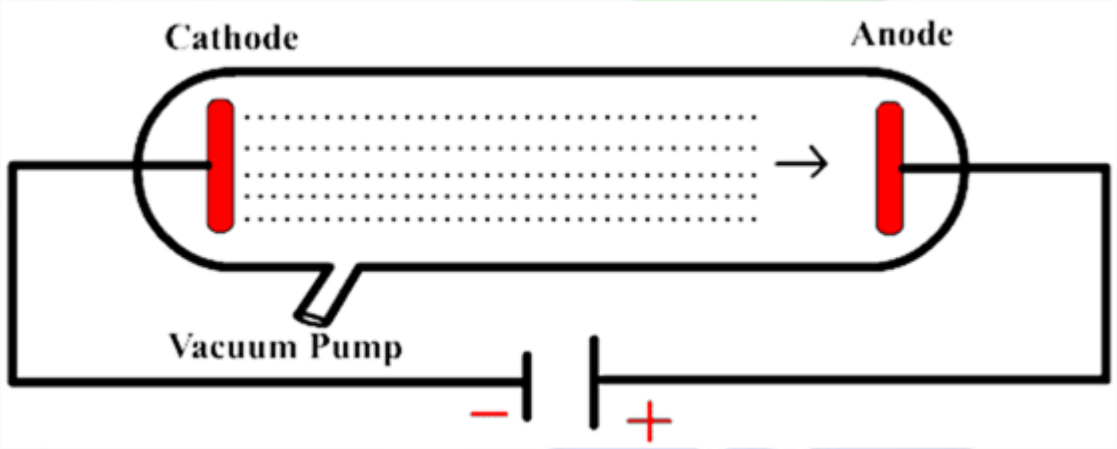
Discharge Tube

Or

Crooke's Tube

Note: Picture is taken from this link https://bit.ly/dischargetube

Crookes tubes or discharge tubes are glass vacuum chambers that contain a positive electrode (anode) and a negative electrode (cathode)



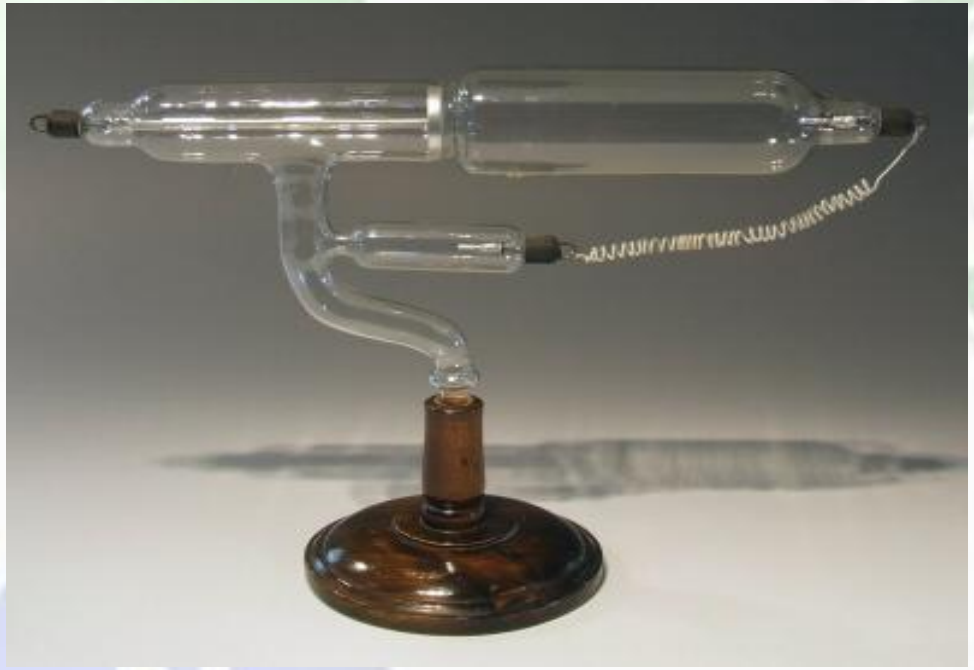
When an electrical current is passed between the electrodes of the tubes, a glow can be observed in the chamber

Now we know that the glow is due to the interaction of electrons, which travel from the cathode to the anode, with residual gas present in the device

Anode Ray Experiment

Using

Discharge Tube

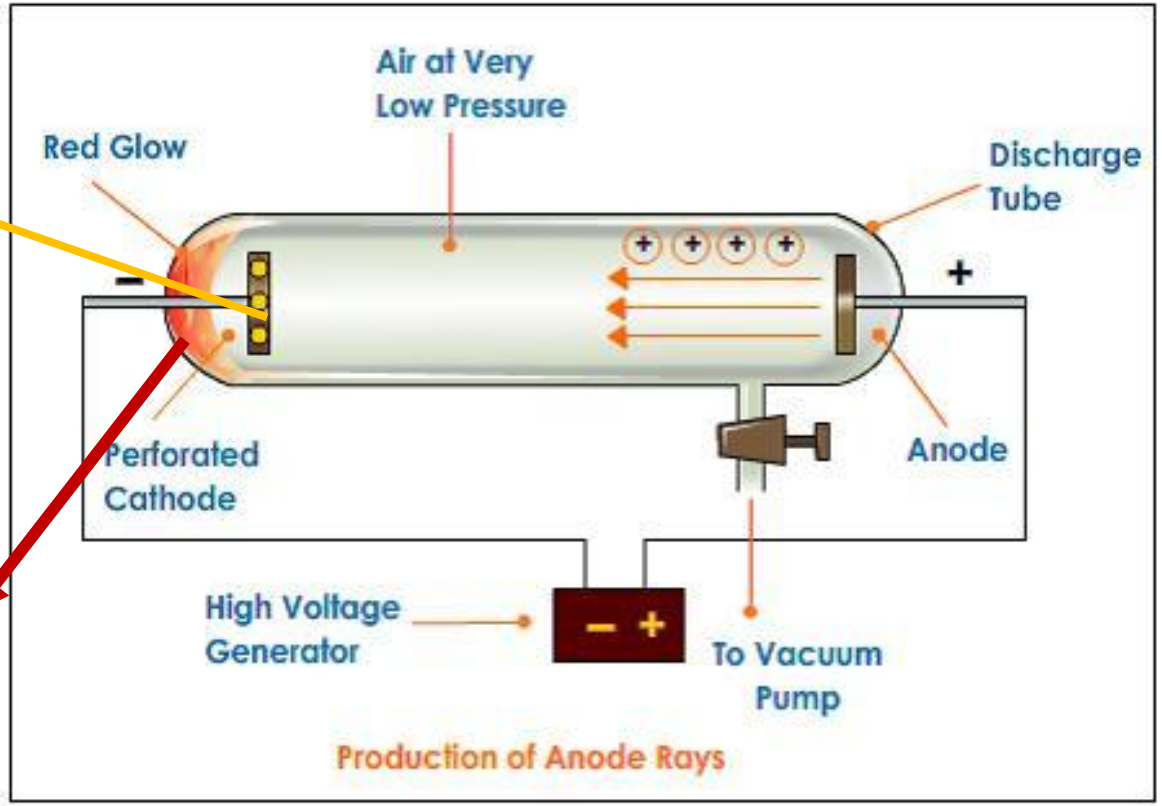


Original form of a Goldstein tube

In 1886 Eugen Goldstein discovered anode ray which is famous as "canal rays“ which led to discovery of protons

Anode Ray

Cathode is porous. so it is called perforate cathode



On applying a high voltage under low pressure, he observed a faint red glow on the wall behind the cathode. Since these rays originated from the anode, they were called anode rays or canal rays or positive rays

Anode rays were found as a stream of positively charged particles

Note: Picture is taken from Internet source

Anode Ray

When very high voltage is applied, it ionizes the gas which is present in tube

These are positive ions of gas that constitutes the anode ray or canal ray

Anode ray is made of positive ions but cathode rays are made up of electrons

Properties of Anode Ray

1. Anode rays travel in straight lines

2. Anode rays consist of material particles because the rays can rotate the light paddle wheel placed in their path

3. Anode rays are deflected by both electric and magnetic field since they deflect towards negatively charged plate. It indicates that anode rays consist of positively charged particles

4. The anode rays' properties depend upon the nature of gas taken in the discharge tube

5. The mass of the particle is the same as the atomic mass of the gas inside the discharge tube

Out comings of Anode Ray

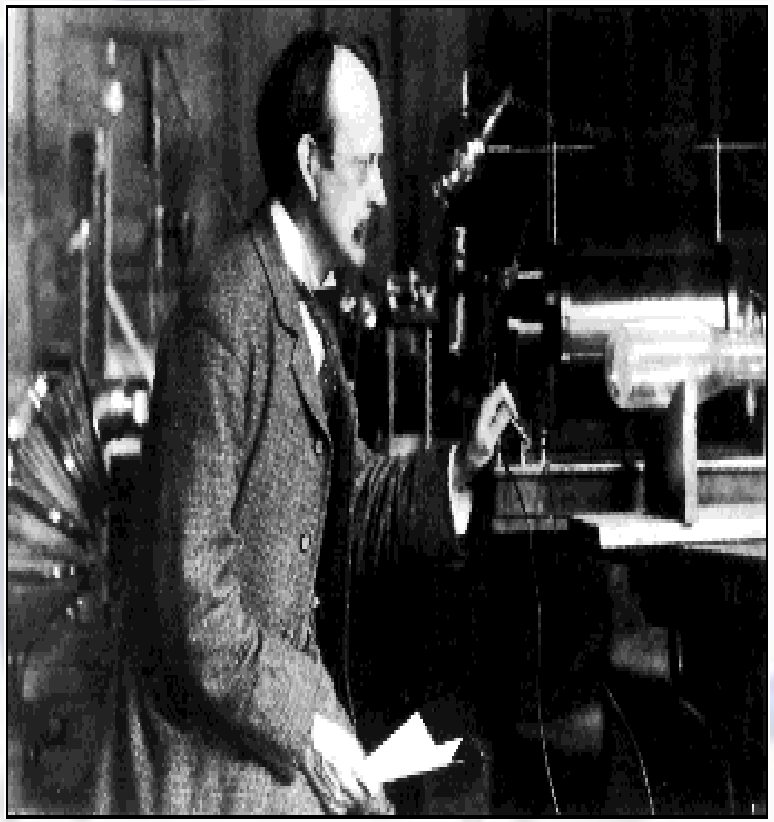
Goldstein could not explain the anode ray, it took 12 years to explain that anode ray is positively charged nucleus or proton

On the basis of Goldstein's results Dr J. J Thomson predicted his atomic model, Plum pudding model

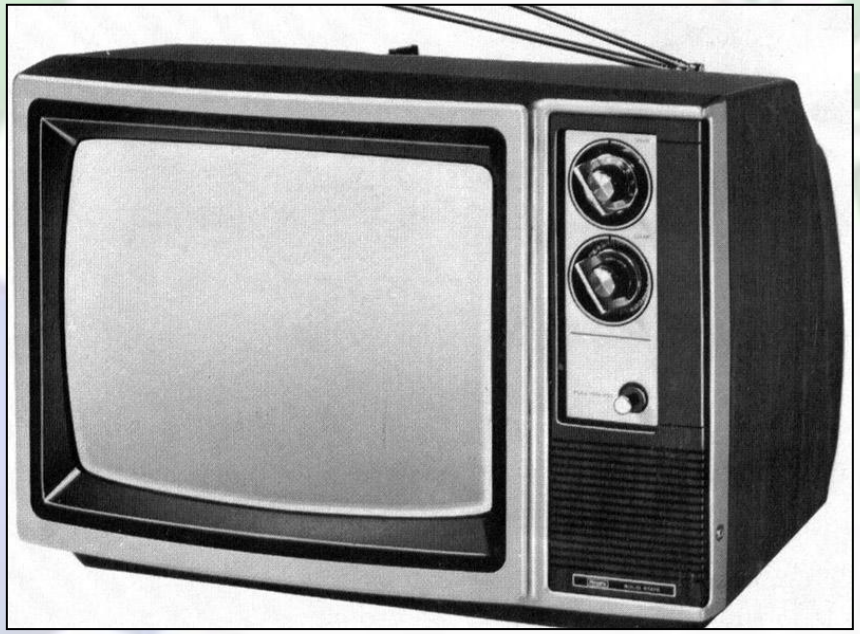
Let's explore the discovery of "Plum Pudding Model" by J. J. Thomson

"Plum Pudding Model" Discovered "Electrons", the fundamental particles of atom

Discovery of Electrons (1897)



J.J. Thomson, discovered electrons by cathode ray tube experiment



Cathode ray tube at home

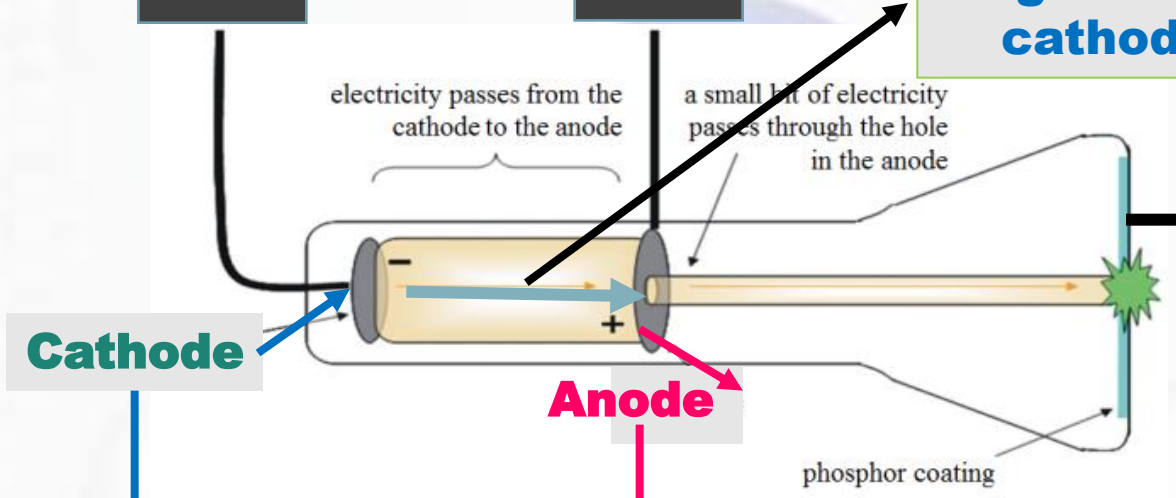
J .J. Thomson's discovery of electrons didn't happen all at once

Instead, it was a result that was slowly built over the course of different experiments in different conditions

Cathode Ray

It causes a beam of particles to flow from the cathode to the anode

High voltage Applied here



Cathode ray Originates at cathode

Cathode ray is detected

Emit light When impacted by cathode ray

Cathode

Negatively charged electrode

Anode

Positively charged electrode

Cathode Ray: Experiment No 1

Before Thomson's experiments, it had already been discovered that the *cathode rays deposit an electric charge*

An electrometer was placed at the opposite end of cathode ray

When cathode ray hit the electrometer, it measured an electric charge

Cathode Ray: Experiment No 2

First experiment raised a question cathode rays and electric charge are same or different?

To get answer of this question J. J. Thomson used a *magnet to bend the cathode rays away from the electrometers*

When he did this, he discovered that the electrometers stopped measuring electric charge

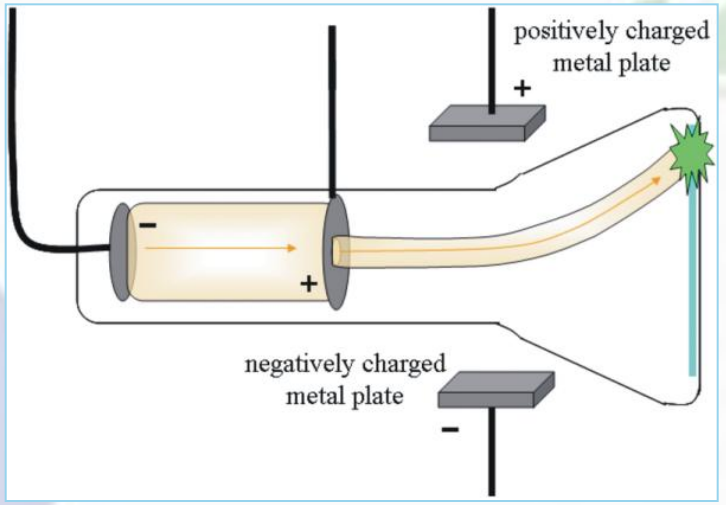
From this he deduced that the *electric charge and the cathode rays are same. They are not separate entities*

Cathode Ray: Experiment No 3

After the two experiments it was proved that cathode rays carry charge

Is that charge positive or negative?

To find out it J. J. Thomson put a negatively charged metal plate on one side of the cathode rays and a positively charged metal plate on the other side



cathode rays bent toward the positive plate and away from the negative plate

This experiment proved that cathode ray carries negative charge

Conclusion Made by J. J Thomson

1. The cathode ray is composed of negatively-charged particles

2. Cathode ray particles are part of the atom

3. These subatomic particles are fundamental particles of all the elements

Eventually, the cathode ray particles were given a more familiar name: *electrons*

Cathode Ray Experiment proved the presence of sub-atomic particles electrons, which disproved the part of Dalton's atomic theory that assumed the atoms were indivisible

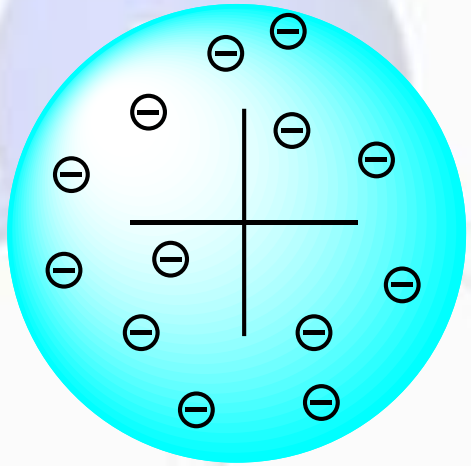
A new Atomic Model was proposed, known as "Plum Pudding Model"

Thomson Atomic Model

Thomson's atomic model was proposed in 1904. It was known plum pudding model

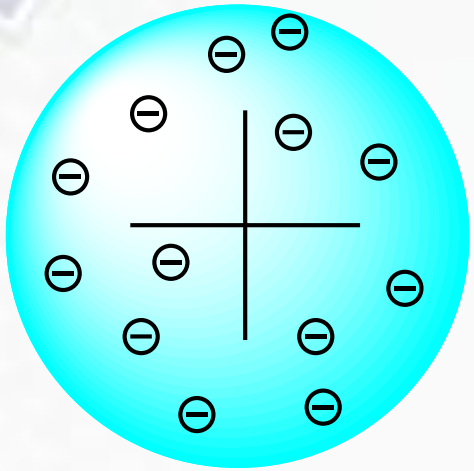
He Proposed this model after the conclusion of cathode ray experiment

The radius of the sphere is in the order of 10^{-10}m



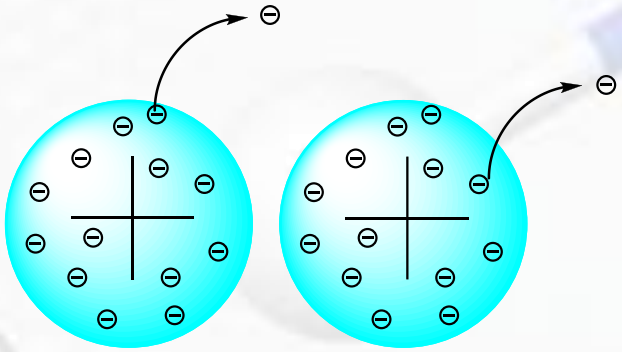
The negative and positive charges are equal in magnitude

Thomson's atomic model explained some properties of atoms

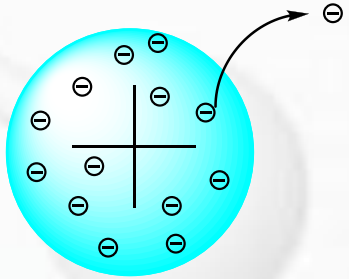


Electrical neutrality

Total positive charge of the sphere is cancelled by the negative charge

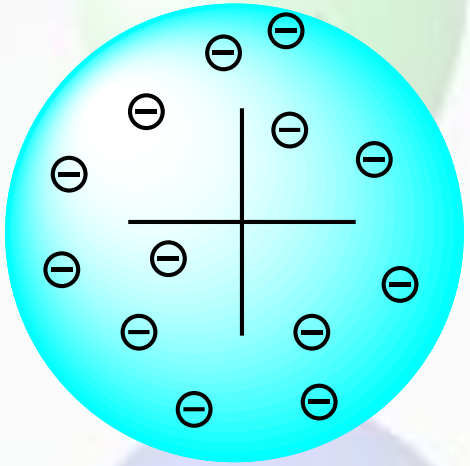


Electrical conductivity



Formation of ions

Knowledge of Atoms in 1900



1. **Electrons carry the negative charge (discovered in 1897)**

2. **Electrons are very light compare to the atom**

3. **Protons had not yet been discovered. It took 20 years to conclude the consequence of anode ray experiment. It was clear that positive charge should be present in atom to achieve charge neutrality**

Check your learning On Cathode Rays and Anode Rays

Why Goldstein used perforated cathode in proton discovery?

Ans: Perforated cathode was used so that Canal Rays (Anode Rays) could pass through it.

Actually, these positively charged constituents of the anode rays are nothing but the positively charged atoms of the gas that form due to removal of electrons

Anode rays are positively charged nucleus and cathode rays are just electrons

non perforated cathode would not allow their passage, hence perforated cathodes for production of anode rays

Why did Thomson conclude that electrons could be found in atoms of *all* elements?

Ans: Thomson used the different material for cathode which was the source of the particles.

Every time the same particles were emitted irrespective of the cathode materials.

Thus, Thomson concluded that the particle was a fundamental part of all atoms.

Differentiate between anode ray and cathode ray.

Ans: Anode ray is positive and cathode ray is negative

Why anodes are used in cathode ray tube?

Ans: If there was no anode, the electrons emitted from the cathode would simply hang around it in a cloud, all mutually repelled. By introducing the anode which is positive in nature, the " cathode rays" encounters with anode follow a straight line to stuck on fluorescent wall and create a bright spot

When hydrogen gas is taken in discharge tube, what you may expect anode ray experiment?

Ans: When hydrogen gas is taken in a discharge tube, the positively charged particles form. We know positive charged hydrogens are called PROTONS. Each of these protons is produced when one electron is removed from one hydrogen atom.

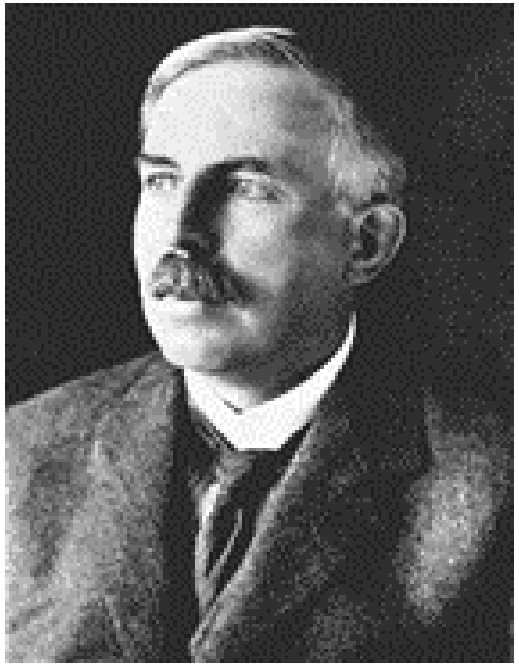
$$H \longrightarrow H^+ + e^-$$

What will happen if you are using the same metal as anode and cathode for cathode ray experiment?

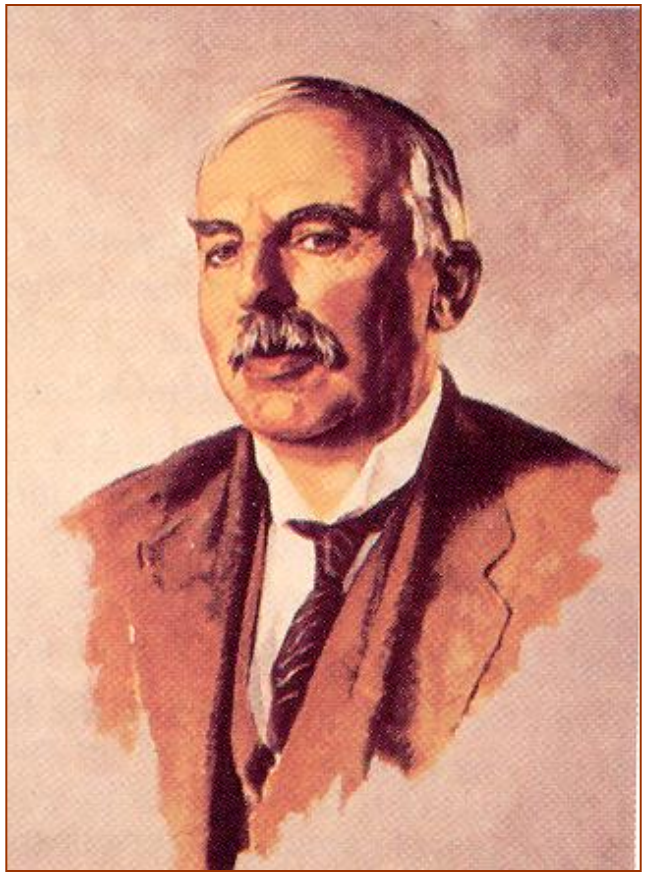
Ans: nothing will happen.
Cathode ray is flow of electrons which are fundamental particles
Any elements

Anode ray the flow of positively charged gas ions which depends on
Which gas in used in the discharge tube not the materials used
as cathode or abode

Let's Explore Rutherford Atomic Model which was proposed after famous "Gold Foil Experiment"

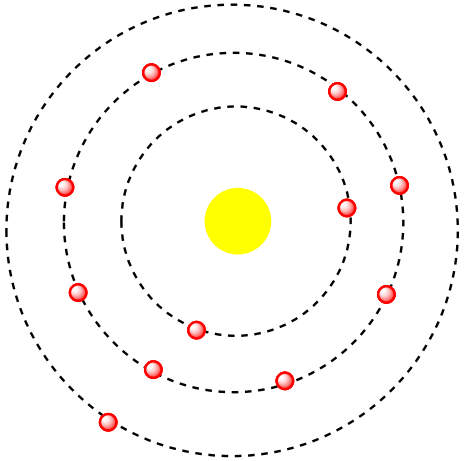


Rutherford's Atomic Model



1. Gold-foil experiment

2. Gold Foil Experimental results were not consistent with Thomson's atomic model



3. Rutherford proposed that an atom has a positively charged core surrounded by the negative electrons

5. Geiger and Marsden confirmed the idea in 1913

Rutherford's Gold Foil Experiment

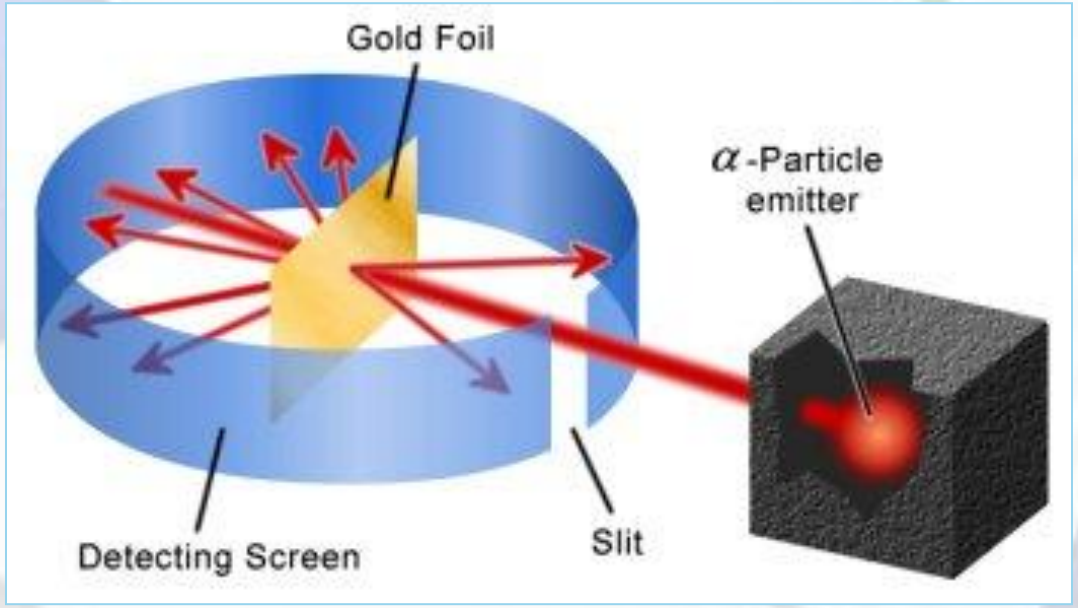
Before this experiment, It has been assumed atomic model as plum pudding model

1. The atom is a solid sphere

2. It contains negative electrons

Rutherford fired α-particles at gold foil

α-particles are small, fast moving and positively charged



What is alpha (α) particle?

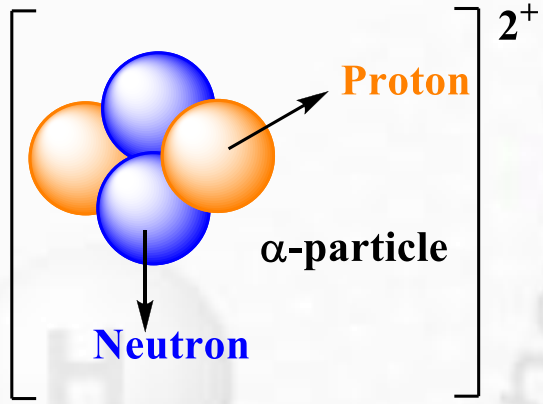
Alpha particles consist of two protons and two neutrons which are tightly bound together

$^{4}He_{2}$ —(2 electrons removed)→ He^{2+}

Helium

Doubly ionized helium
cotains two neutrons and two protons
in its nucleus.

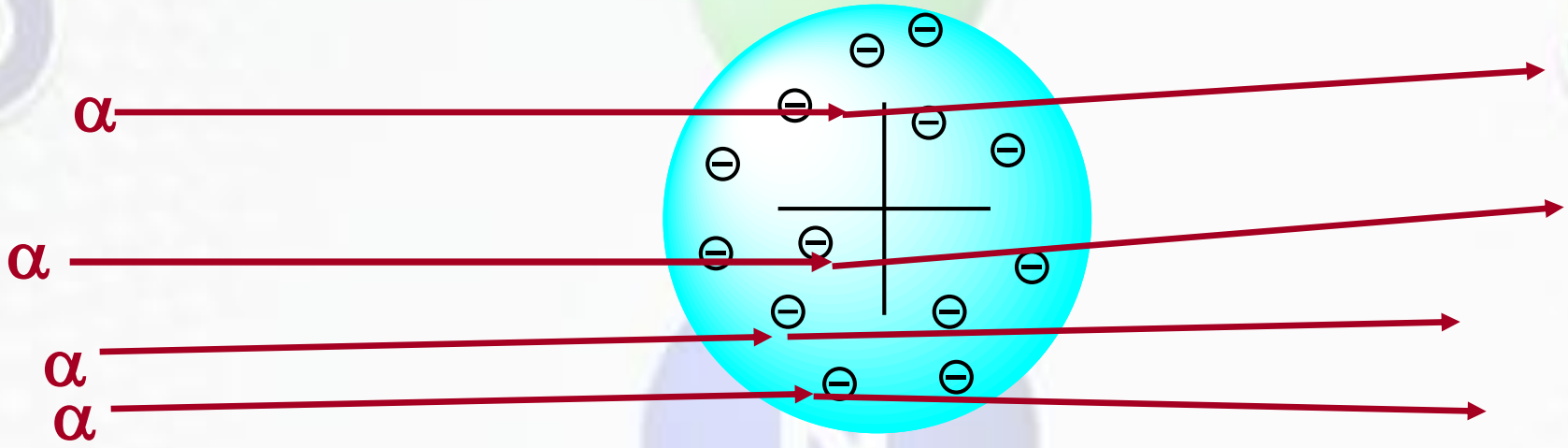
They are emitted from the nucleus of some radioactive compounds. It is known as radioactive decay or alpha-decay



Alpha particles are highly ionizing because they have large mass

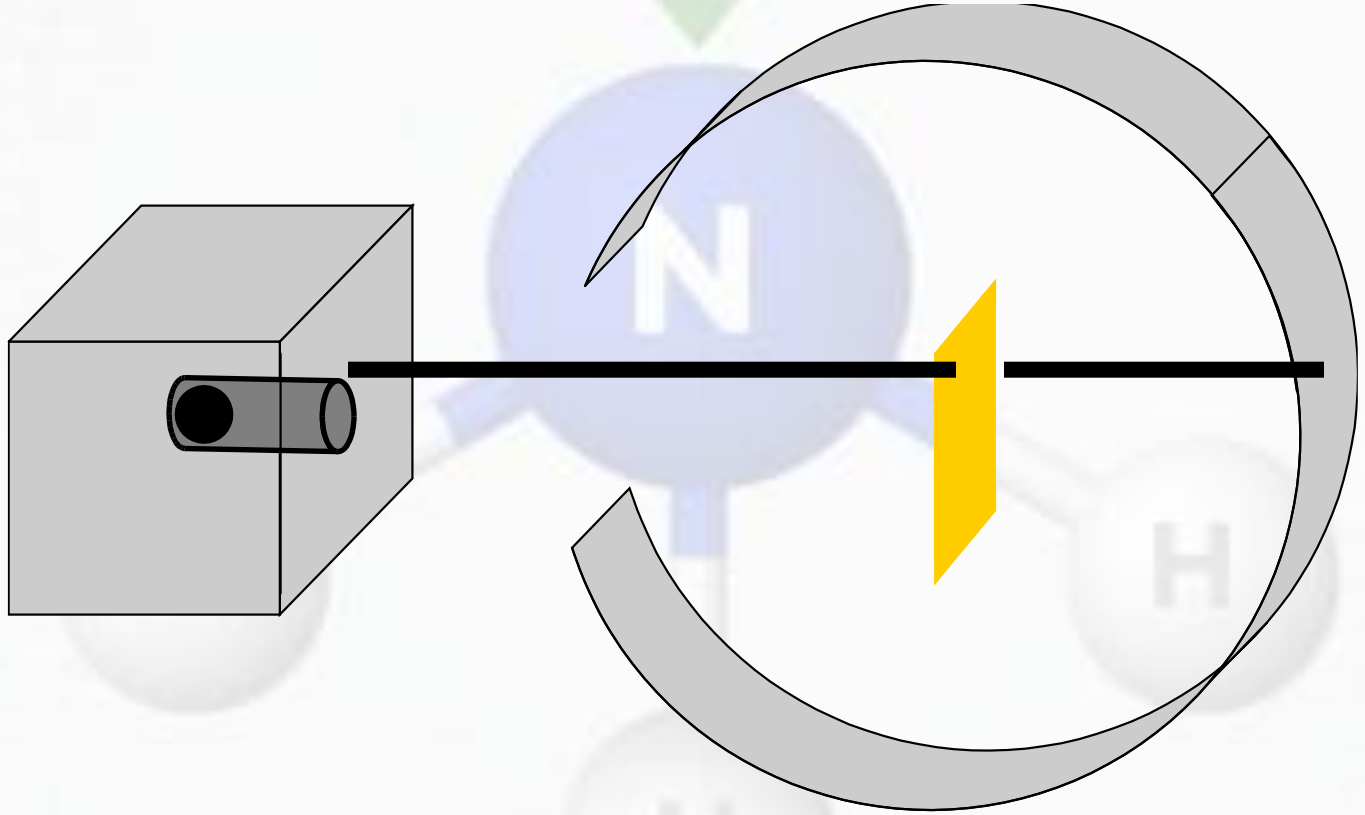
Let's Understand Gold Foil Experiment

Rutherford used alpha particles (like bullets) to hit the atoms: He wanted to confirm Plum Pudding Model

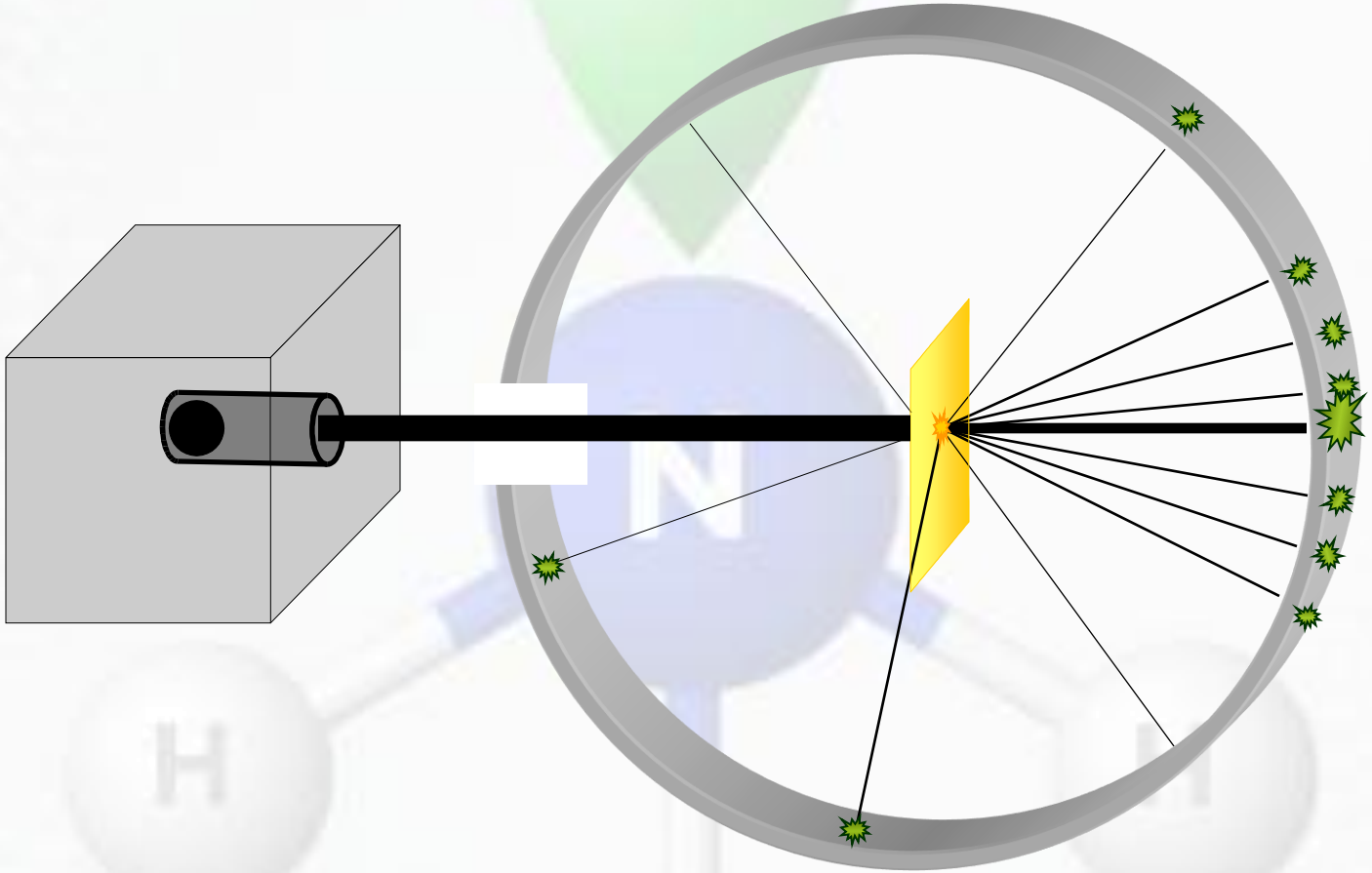


He thought the mass of the atoms was evenly distributed in the atom according to plum pudding model, so heavy mass alpha particles would pass through the atom and go through in straight line

Rutherford's Expectation from Gold Foil Experiment



Rutherford's observation from Gold Foil experiment



Rutherford's Observation and Conclusion from Gold Foil Experiment

- **Since most of the particles went through, that indicates the atom is mostly empty**

- **Few of the positively charged alpha rays were deflected very much, that indicates the positively charged alpha rays get deflected by very dense positive piece**

- **This small dense positive area is the nucleus**

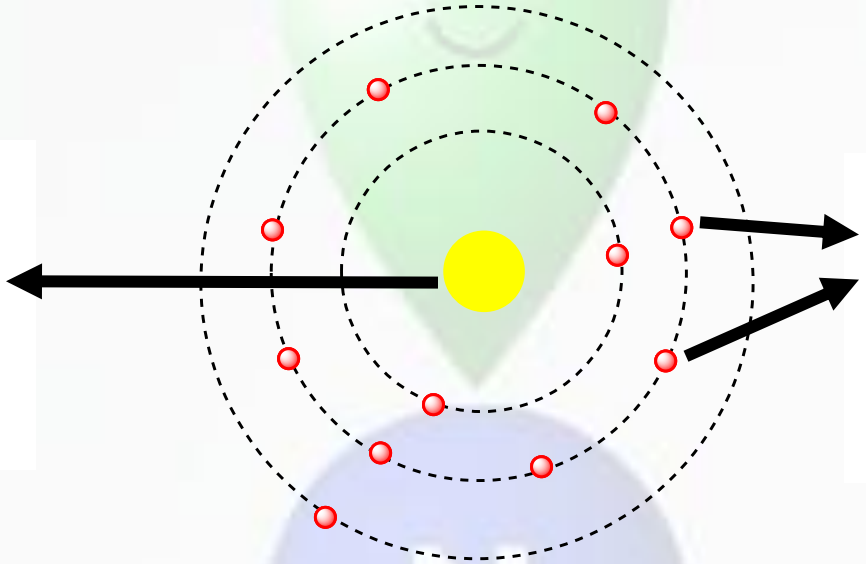
Rutherford's "Gold Foil Experiment" discovers the positively charged nucleus inside atoms

Rutherford's "Gold Foil Experiment "discarded Plum Pudding Model

Rutherford's "Gold Foil Experiment "proposed a new atomic model which is known as Planetary atomic model

Rutherford's Model: Planetary Model

Positively charged dense central nucleus



Negatively charged orbiting electrons

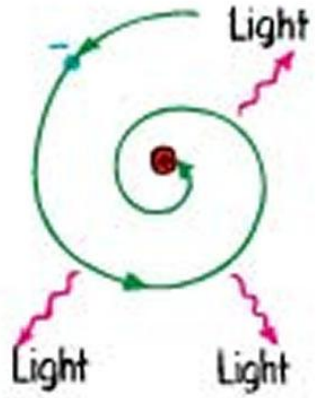
- **Most of the atom is empty space**
- **Most of the atom's mass and +ve charge is located at the centre of the atom**

Demerits of Rutherford's Atomic Model

Orbiting (-)vely charged electrons are accelerating

Accelerating electrons should radiate light

According to Maxwell's theory, a Rutherford atom would only survive for only about 10^{-12} secs

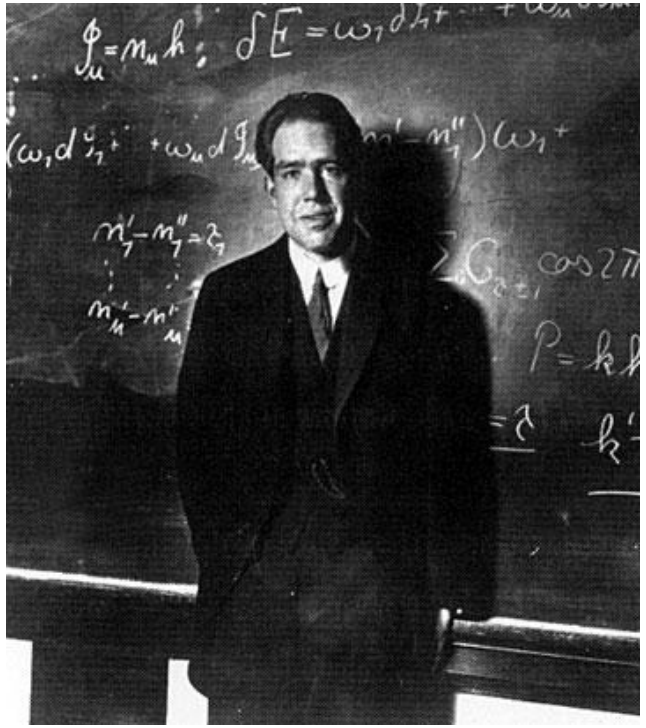


But atoms are very stable and "Rutherford's Model" cannot explain the stability of atoms

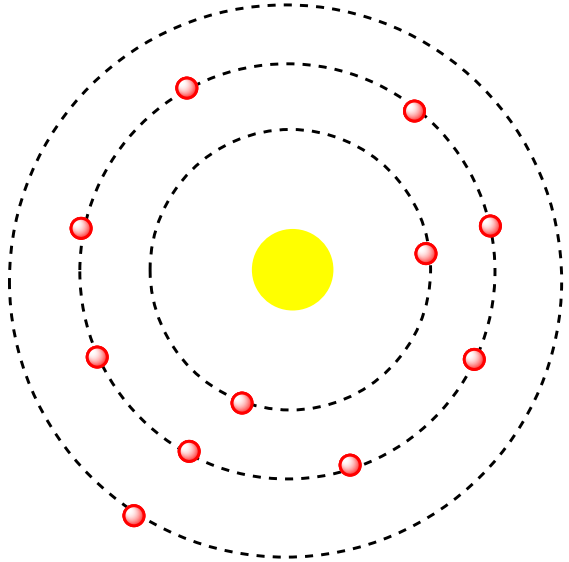
Bohr's Model was able to explain the stability of atoms

Journey Continues....

Bohr's Atomic Theory



Niels Bohr was awarded with Nobel prize in physics in 1922



Before we discuss Bohr's Model let's explore

Electromagnetic radiation

Electromagnetic Radiation

1. Electromagnetic radiation is a type of energy

2. Electromagnetic waves are produced by the motion of electrically charged particles

3. They travel through empty space as well as through air and other substances

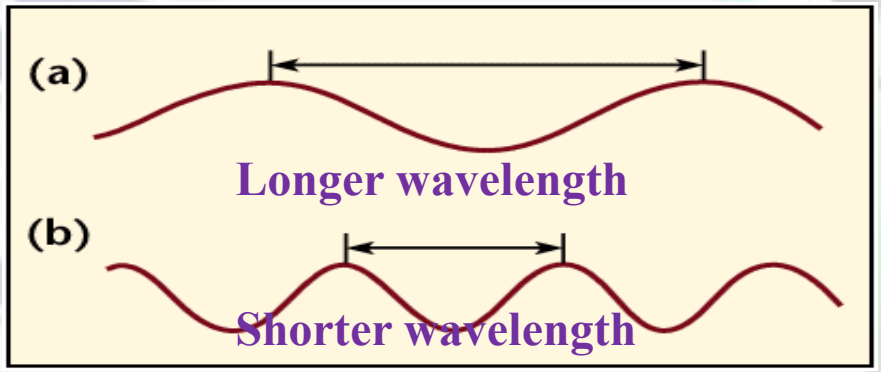
4. Electromagnetic radiation has wave-particle (photon) dual properties

Photon

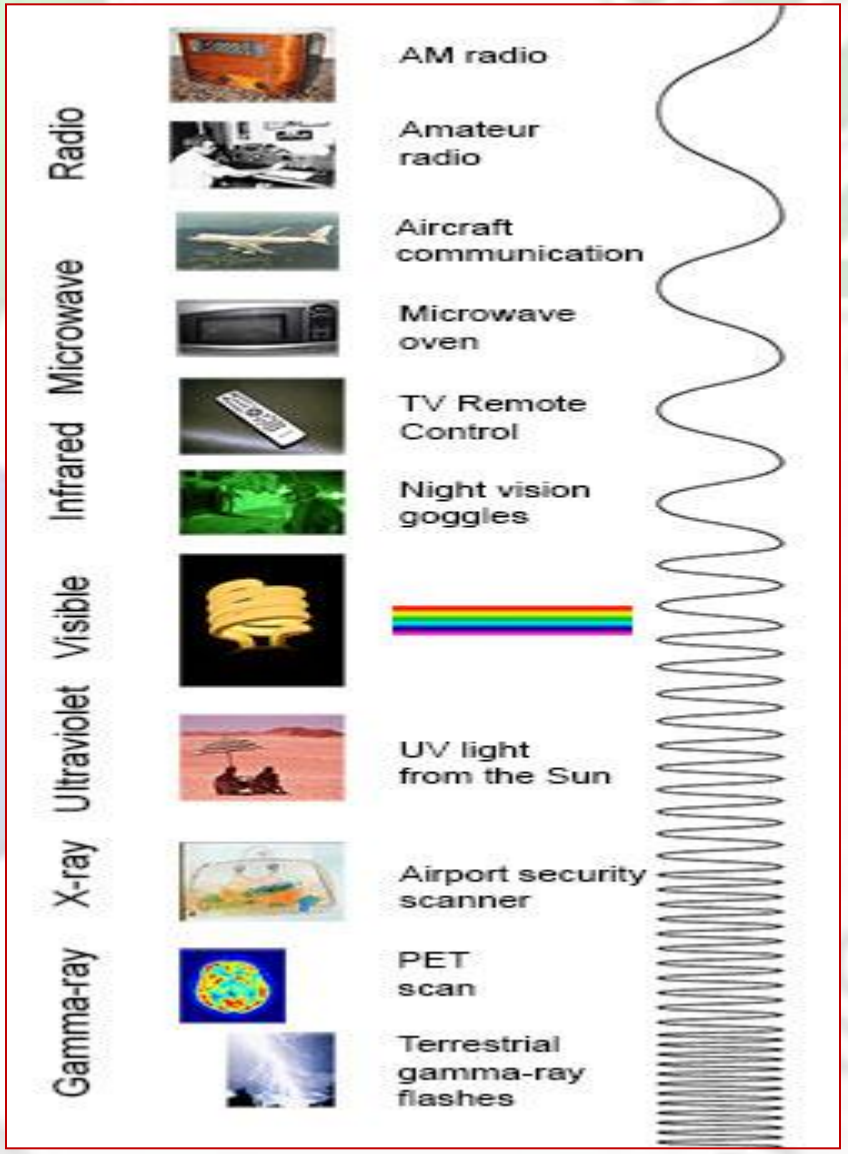
Electromagnetic radiation consists of discrete packets of energy, which we call photons

Each photon carries the energy, E (Joule)

Electromagnetic Radiation



Wavelength increases, Energy decreases



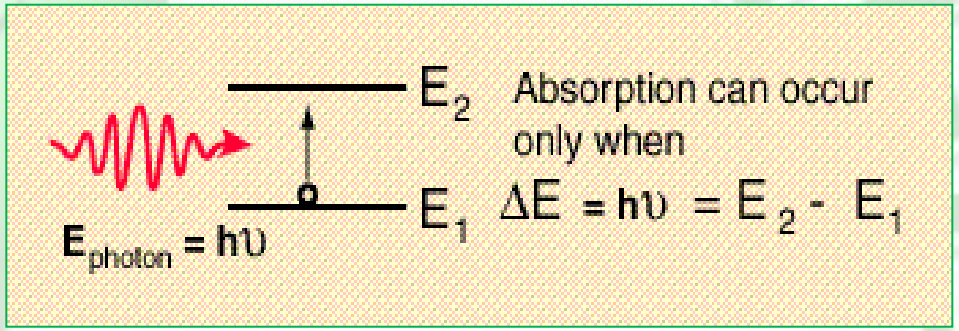
The electromagnetic spectrum from lowest energy/longest wavelength (at the top) to highest energy/shortest wavelength (at the bottom

Bohr's Model was proposed based on hydrogen emission spectra

Let's understand what is emission and absorption?

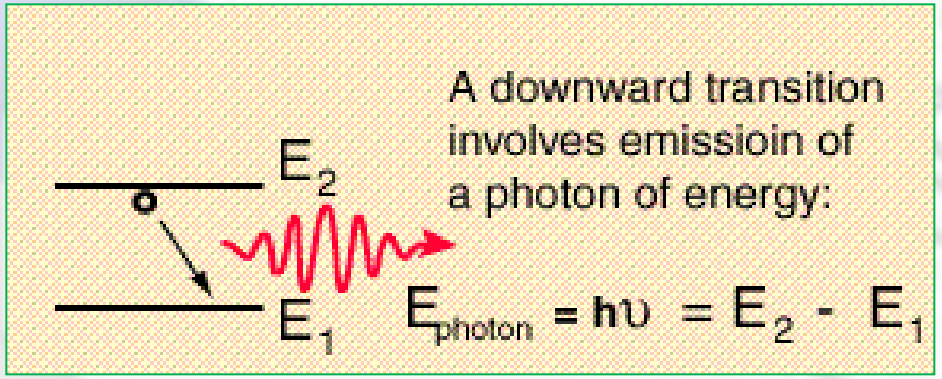
What is absorption?

When atoms or molecules absorb light, the incoming energy excites quantized structure to a higher energy level

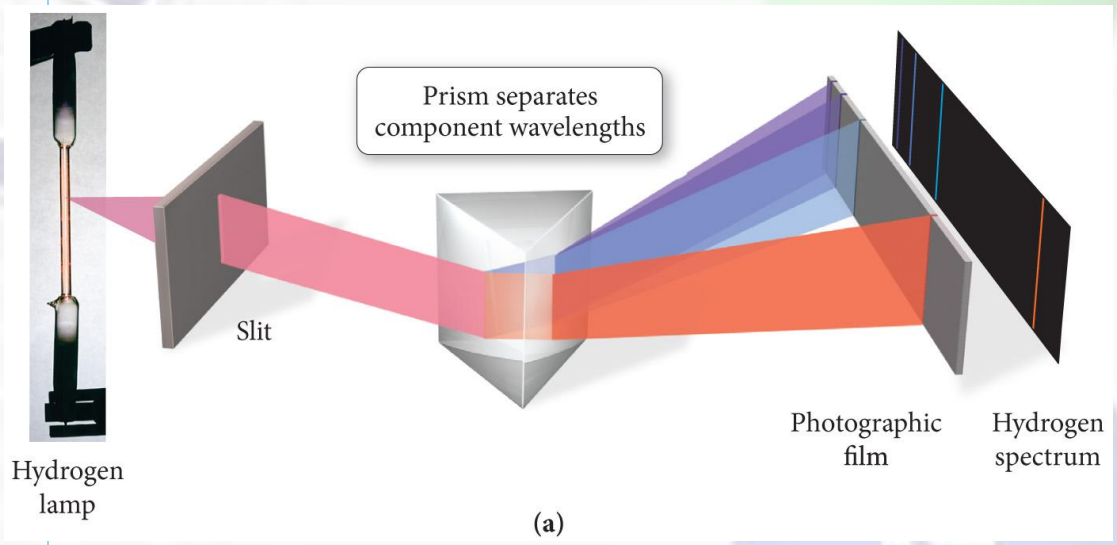


What is emission?

Atoms or molecules that are excited to high energy levels can transit to lower levels by emitting radiation. It is called emission



Hydrogen Emission Spectra



Wavelength	Colour
656.2	Red
486.1	Blue-green
434.0	Blue-violet
410.1	Violet

When an electric current is passed through a glass tube that contains hydrogen gas at low pressure the tube gives off blue light.
When this blue light is passed through a prism (as shown in the figure above), four narrow bands of bright light are observed against a black background.

This is called hydrogen emission spectra

Bohr's Model

When an electron moves along any of the selected orbits, it does not radiate energy in spite of its accelerated motion, because every orbit has a specific energy. Orbits are now considered as energy levels

When an electron rotates in a stationary orbits, it may considered that electrons rotates in a energy level .
Energy of each orbit is E = hv (h = Plank's constant, v = frequency)

The orbit closest to nucleus represents the stable state or ground state of the atom

The further away orbit, from nucleus is considered at higher energy level

Electrons from ground state energy level jumps to higher energy level when it absorbs energy. It is said to be an excited state

Demerits of Bohr's Atomic Model

Bohr's atomic model only can explain the emission spectra of one electron system like hydrogen, He^{+1}, Li^{+2}

It was unable to explain emission spectra for multielectron system

Journey Continues....

Modern Atomic Model:
Quantum Mechanical Model