Lecture 1

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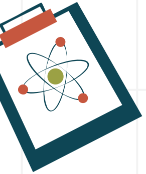


What is Chemistry

Matter

Matter is anything that has mass and occupies space. Matter can be distinct substances or mixtures. The distinct substances are either **elements or compounds**.

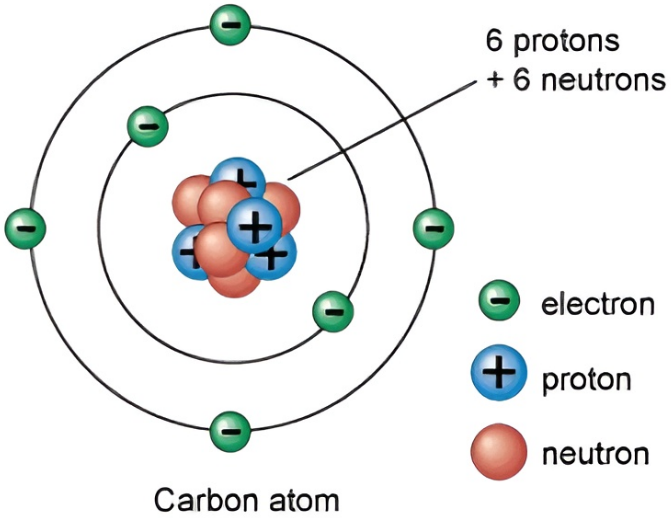
If a substance is made up of only one kind of atom, it is called an **element.**

If, however, it is made up of two or more kinds of atoms joined together in a definite proportion, it is called a **compound.**

Atom

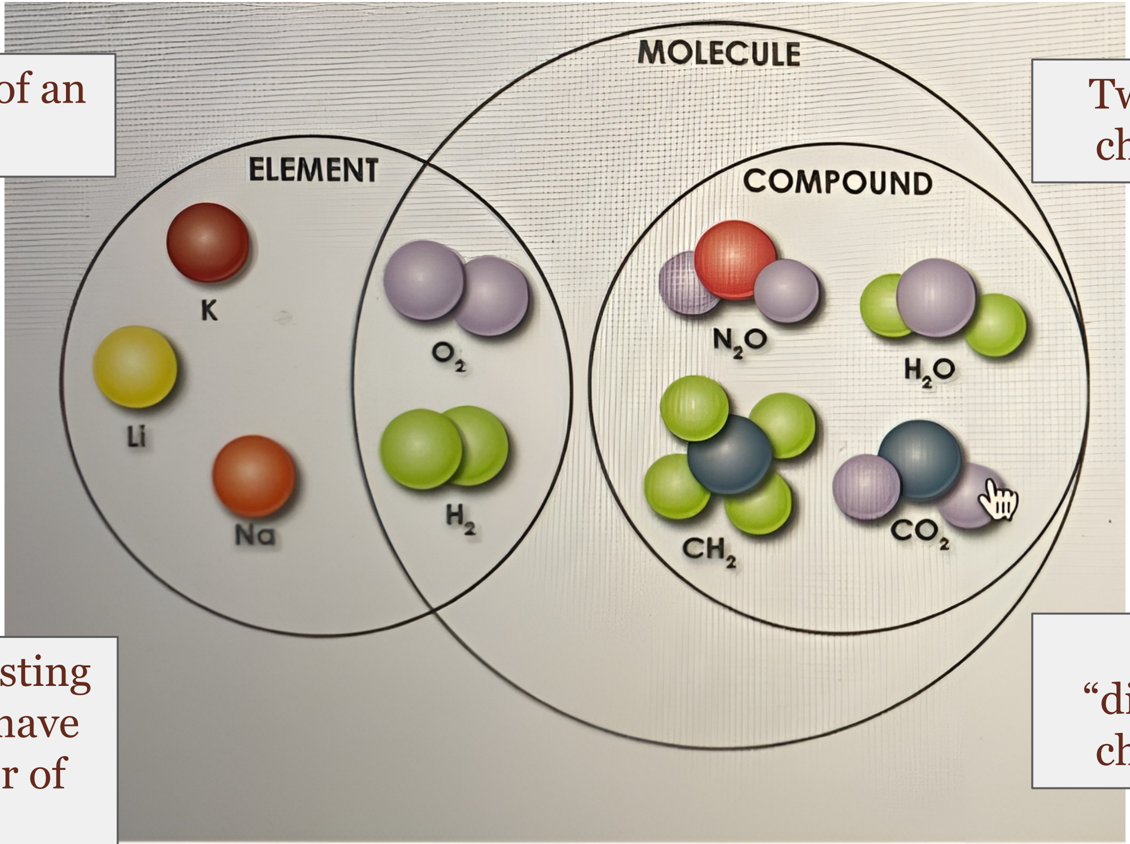
All matter – whether element, compound, or mixture, is composed of extremely small particles of matter that retain their identity during chemical reactions called atoms.

A table, a chair, even you are made up of atoms!



Atom

Smallest amount of an element



Molecule

Two or more atoms chemically bonded

Elements

A substance consisting of atoms that all have the same number of protons

Compound

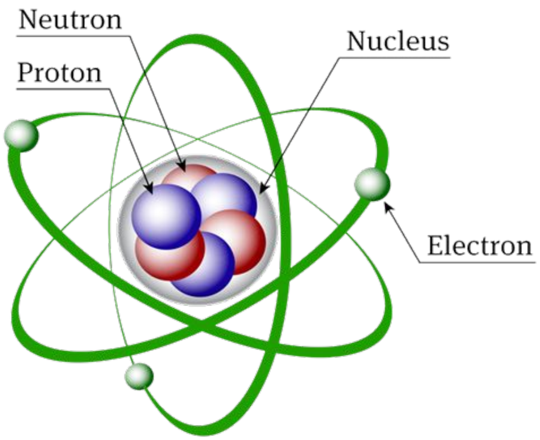
Two or more “different” elements chemically bonded

Substance: It is matter that has a specific combination and specific properties.

- All atoms are made of three subatomic particles

- **Electrons, protons, and neutrons**

Particle	Actual Charge	Actual Mass	Position	Discovered by
Electron	-1.6×10^{-19} C	9.1x10-28 g	Orbital	J.J Thomson -1897
Proton	$+1.6\times10^{-19}$ C	1.673x10-24 g	Nucleus	Ernest Rutherford -1919
Neutron	0	1.675x10-24 g	Nucleus	James Chadwick-1932

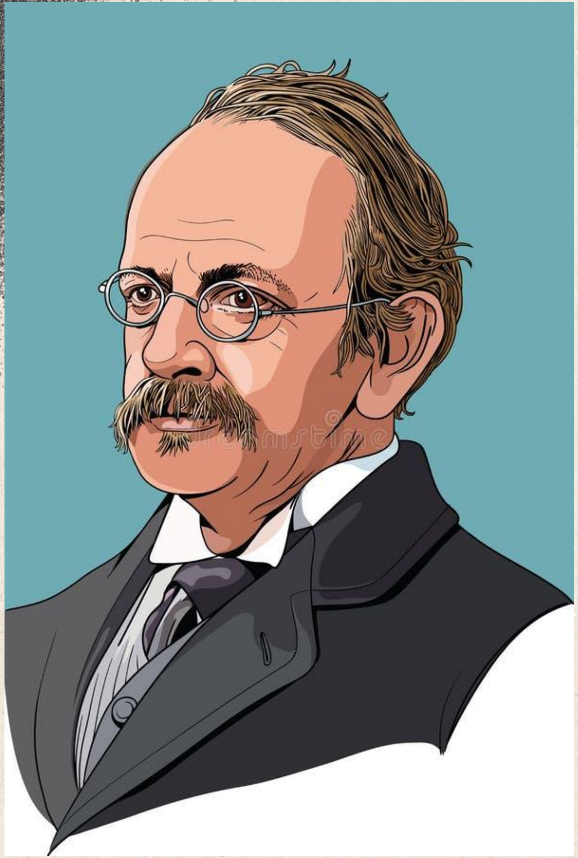


What does an atom look like?

Protons and neutrons are held together rather closely in the center of the atom. Together, they make up the nucleus, which accounts for nearly all of the mass of the atom.
Electrons move rapidly around the nucleus and constitute almost the entire volume of the atom. Atoms have sizes on the order of 10^{-10} m.

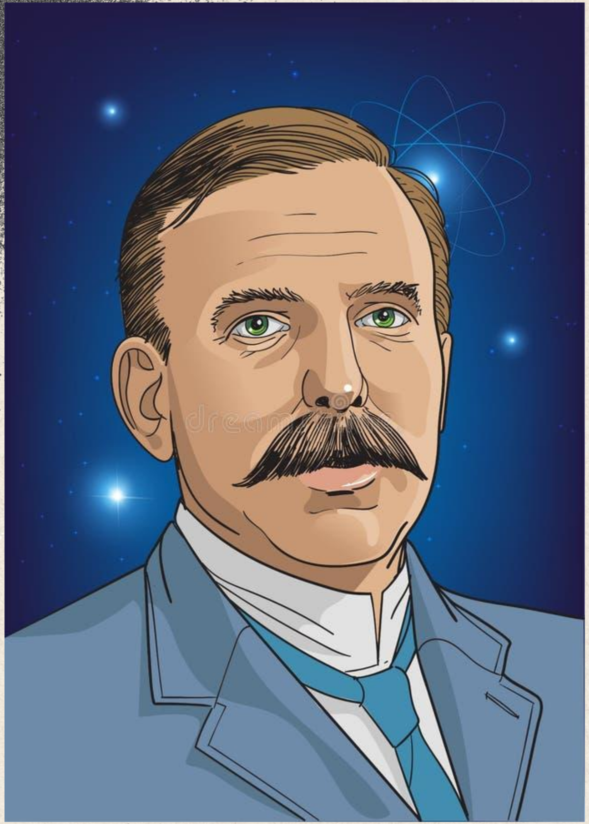
What holds an atom together?

The negatively charged electron is attracted to the positively charged nucleus by a Coulombic attraction.
The protons and neutrons are held together in the nucleus by the strong nuclear force (Binding energy).



J. J. Thomson

J. J. Thomson's early studies at Owens College and Trinity College, Cambridge, laid the foundation for his groundbreaking work at the Cavendish Laboratory. His pioneering research on cathode rays led to the discovery of the electron in 1897, and his work on the conduction of electricity in gases earned him the Nobel Prize in Physics in 1906.



Earnest Rutherford

Ernest Rutherford's academic journey began in New Zealand and later took him to the University of Cambridge's Cavendish Laboratory. There, his pioneering work on radioactivity and atomic structure led to the discovery of the nuclear model of the atom, fundamentally transforming modern physics. For his groundbreaking research on the disintegration of elements and the chemistry of radioactive substances, he was awarded the Nobel Prize in Chemistry in 1908.

James Chadwick

James Chadwick's academic journey began at the University of Manchester, where he studied under Ernest Rutherford. He later continued his research at the Cavendish Laboratory, Cambridge. In 1932, his experiments revealed the existence of the neutron—an uncharged particle within the atomic nucleus—fundamentally advancing the understanding of atomic structure. For this landmark discovery, he was awarded the Nobel Prize in Physics in 1935.

John Dalton

John Dalton’s curiosity about the natural world grew early on as he worked as a teacher and observer of weather. Through his experiments, he developed the atomic theory, showing that all matter is made of tiny, indivisible atoms. For his important contributions to science, he was awarded the Royal Medal in 1826. His work laid the foundation for modern chemistry and changed how we understand matter.

Dalton's atomic theory

Democritus first suggested the existence of the atom, but it took almost two millennia before the atom was placed on a solid foothold as a fundamental chemical object by John Dalton (1766-1844). Although two centuries old, Dalton's atomic theory remains valid in modern chemical thought. Dalton based his theory on two laws: **the law of conservation of mass** and the **law of constant composition.**

He couldn't see them, but he believed in them—Democritus, the ancient mind behind modern atoms

Postulates of Dalton's Atomic Theory

1. All matter is composed of minute particles called atoms. An atom is an extremely small particle of matter that retains its identity during a chemical reaction. These atoms are indivisible and indestructible.

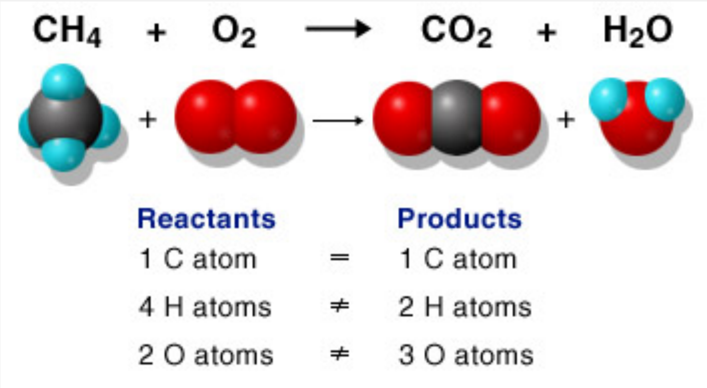
2. An element is a type of matter composed of only one kind of atom, each atom of a given kind having the same properties. Mass is one such property. Thus, the atoms of a given element have a characteristic mass.

3. The properties and masses of atoms of different substances are different.

4. A compound is a type of matter composed of atoms of two or more elements chemically combined in fixed proportions. Water, for example, a compound of the elements hydrogen and oxygen, consists of hydrogen and oxygen atoms in the ratio of 2: 1.

5. A chemical reaction consists of the rearrangement of the atoms present in the reacting substance to give new chemical combinations present in the substances formed by the reaction. So only atoms take part in a chemical reaction.

6. Atoms are not created, destroyed, or broken into smaller particles during a chemical reaction.



The law of conservation of mass says that matter is not created or destroyed in a closed system. That means if we have a chemical reaction, the amount of each element must be the same in the starting materials and the products. We use the law of conservation of mass every time we balance equations!

If you burn 10 grams of wood in a sealed container, the total mass of the smoke, ash, and gases inside the container will still be 10 grams. No mass is lost or gained; it just changes form.

The law of constant composition says that a pure compound will always have the same proportion of the same elements. For example, table salt, which has the molecular formula NaCl, contains the same proportions of the elements sodium and chlorine, no matter how much salt you have or where the salt came from.

Water (H_2O) is always made up of 2 hydrogen atoms and 1 oxygen atom. Whether you have a glass of water from the tap or water from a river, the ratio of hydrogen to oxygen atoms is always the same.

The structure of atom

- Several experiments showed that an atom consists of two kinds of particles: a **nucleus**, the atom's central core, which is positively charged and contains most of the atom's mass, and **one or more electrons.**

Electron

An electron is a very light, negatively charged particle that exists in the region around the atom's positively charged nucleus.

Charge of electron: 1.602 X 10^{-19} coulombs (C)

Mass of Electron: 9.109 X 10^{-31} kg (more than 1800 times smaller than the mass of the lightest atom (hydrogen)

Proton: A proton is a nuclear particle having a positive charge equal to that of the electron and a mass more than 1800 times that of an electron.

The proton in a nucleus gives the nucleus its positive charge.

Mass of proton is 1.672×10^{-27} Kg and charge is 1.602×10^{-19} C

Neutron: The neutron is a nuclear particle having a mass almost identical to that of the proton but no electrical charge.

Mass of neutron is 1.674×10^{-27} Kg and charge is 0 C

Composition of the nucleus: The nuclei of atoms contain protons and neutrons, except hydrogen, which consists of a single proton. The protons and the neutrons in the nucleus are held together by a force known as the nuclear force.

- ## Atomic number

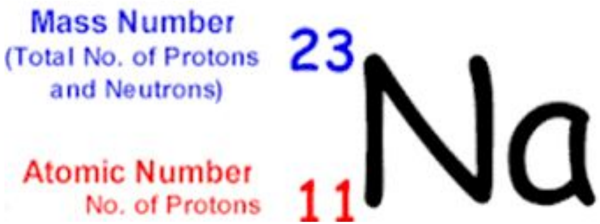
It is the number of protons in the nucleus of an atom.
The number of protons and electrons is equal in an atom, as they are electrically neutral. So it can also be defined by the total number of electrons in the atom.

- ## Atomic mass or mass number

It is the total number of protons and neutrons in a nucleus.

- ## Nuclide

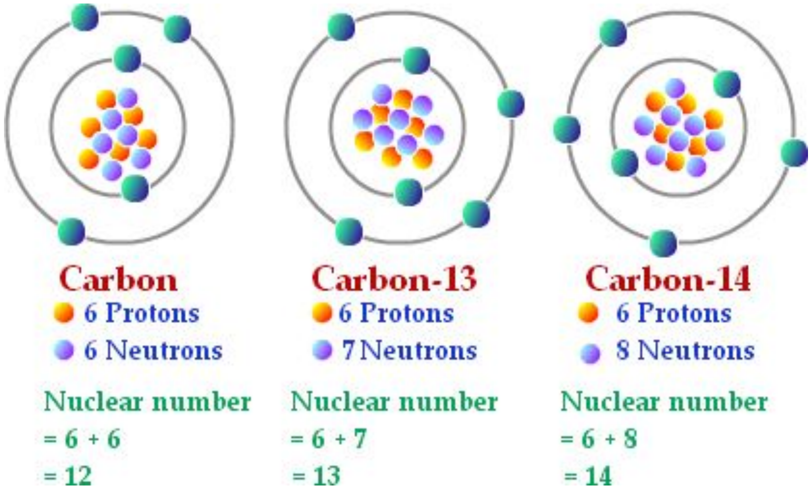
A nuclide is an atom characterized by a definite atomic number and mass number.
The symbol for naturally occurring sodium nuclide is as follows:

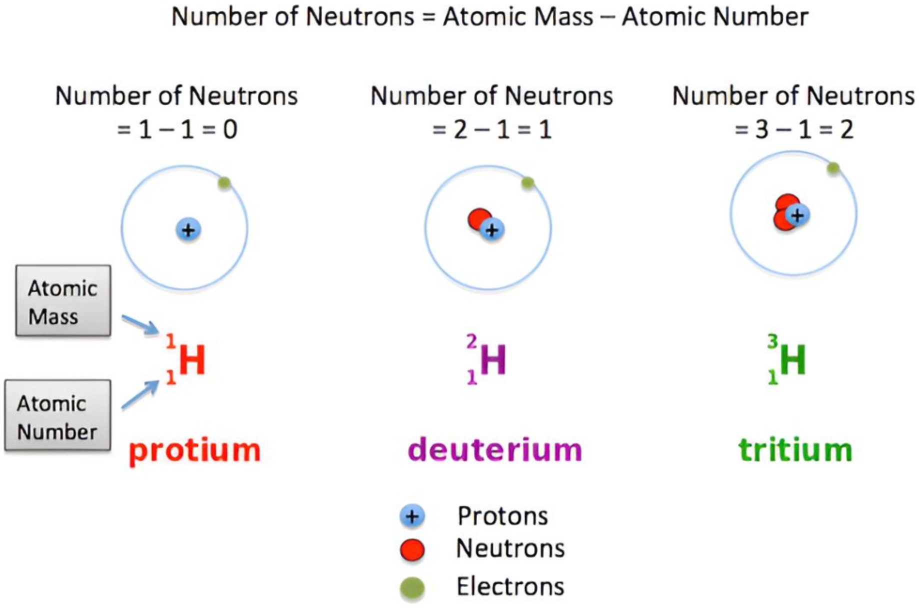


Here, the atomic number is written as a subscript and the mass number is written as a superscript. The atomic number of Na is 11; that is, Na has 11 protons. As the number of protons and electrons in an atom is equal, Na has 11 electrons. The number of neutron in Na is = 23 – 11 = 12

Isotopes

The atoms having the same atomic/proton number but different atomic mass numbers are called **isotopes**. Or each of two or more forms of the same element that contain equal numbers of protons but different numbers of neutrons in their nuclei, and hence differ in relative atomic mass but not in chemical properties; in particular, a radioactive form of an element





Isotopes of Hydrogen

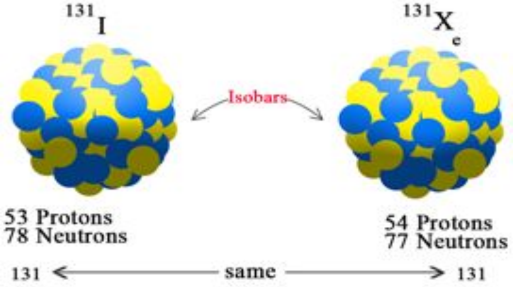
Isobars

Atoms of different elements having the same mass number but different proton/atomic number are called **Isobars. Example,**

$^{58}_{26}Fe$ $^{58}_{27}Ni$

$^{76}_{32}Ce$ $^{76}_{34}Se$

Th^{228}_{90} Ra^{228}_{88}



Isotones

Atoms of different elements having different mass numbers and different atomic numbers but the same neutron number are called **Isotones.**

Example:

Oxygen $^{16}_{8}O$ (p=8; n=8)

Nitrogen $^{15}_{7}N$ (p=7; n=8)

Carbon $^{14}_{6}C$ (p=6; n=8)

All are isotones because they have the same number of neutrons (8)

Limitations of Dalton’s atomic theory

1. According to Dalton’s theory, atoms are indivisible. Now it is established that atoms are divisible into fundamental particles- proton, neutron, and electron.

2. Atoms of the same element have the same mass according to Dalton. But isotopes show that atoms of the same element can have different masses. Hydrogen has three isotopes having masses of 1, 2, and 3 units.

3. Dalton said that atoms of different elements will have different masses. After the discovery of isobars, we see that atoms of different elements can have the same masses. Example: Tellurium (atomic number 52) and iodine (atomic number 53) have the same atomic mass of 127.

4. Dalton called an atom the smallest part of both an element and a compound. But now it is known that atoms are the smallest part of an element that can exist in a free state, and molecules are the smallest part of a compound. Dalton did not show any difference between an atom and a molecule.

Sir Joseph John Thomson 18 December 1856 – 30 August 1940) was an English physicist and Nobel laureate in physics, credited with the discovery and identification of the electron, and with the discovery of the first subatomic particle.

One of Thomson's greatest contributions to modern science was in his role as a highly gifted teacher. One of his students was Ernest Rutherford, who later succeeded him as Cavendish Professor of Physics. In addition to Thomson himself, six of his research assistants (Charles Glover Barkla, **Niels Bohr: Influenced Hisenberg**, **Pauli;** Max Born, William Henry Bragg, Owen Willans Richardson and Charles Thomson Rees Wilson) won Nobel Prizes in physics, and two (Francis William Aston and **Ernest Rutherford: father of nuclear physics; Under his leadership the neutron was discovered by James Chadwick: honoured by being interred near Sir Isaac Newton's tomb**) won Nobel prizes in chemistry. In addition, Thomson's son (George Paget Thomson) won the 1937 Nobel Prize in physics for proving the wave-like properties of electrons.

Discovery of the Electron

In 1897, the British physicist **J. J. Thomson** conducted a series of experiments that showed the atoms were not indivisible particles.

In this experiment, two electrodes from a high-voltage source are sealed into a glass tube from which the air has been evacuated. The negative electrode is called the cathode, and the positive one is the anode. When high-voltage current is turned on, the glass tube emits a greenish light. This greenish light is caused by the interaction of the glass with cathode rays, which are rays that originate from the cathode.

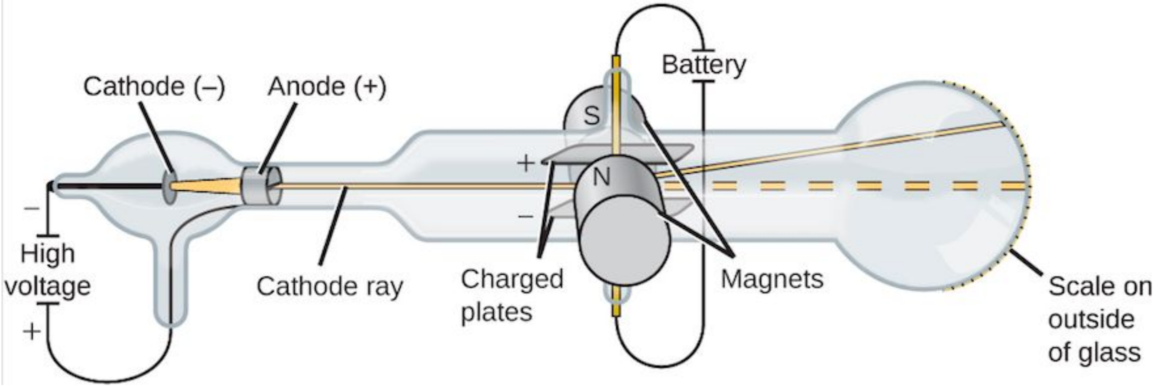
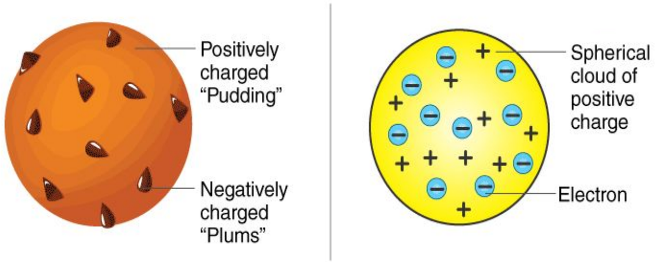


Figure: Formation of cathode rays

After the cathode rays leave the negative electrode, they move toward the anode, where some rays pass through a hole from a beam. This beam bends away from the negatively charged plate and toward the positively charged plate. From such evidence, Thomson concluded that a cathode ray consists of a beam of negatively charged particles (electrons) and that electrons are constituents of all matter.

The plum pudding model

Thomson knew that atoms had an overall neutral charge. Therefore, he reasoned that there must be a source of positive charge within the atom to counterbalance the negative charge on the electrons. This led Thomson to propose that atoms could be described as negative particles floating within a soup of diffuse positive charge. This model is often called the *plum pudding model* of the atom, since its description is very similar to plum pudding, a popular English dessert.



Thomson's model of an atom

- **Postulate 1**: An atom consists of a positively charged sphere with electrons embedded in it
- **Postulate 2**: An atom as a whole is electrically neutral because the negative and positive charges are equal in magnitude

Limitations of Thomson's Atomic Model →

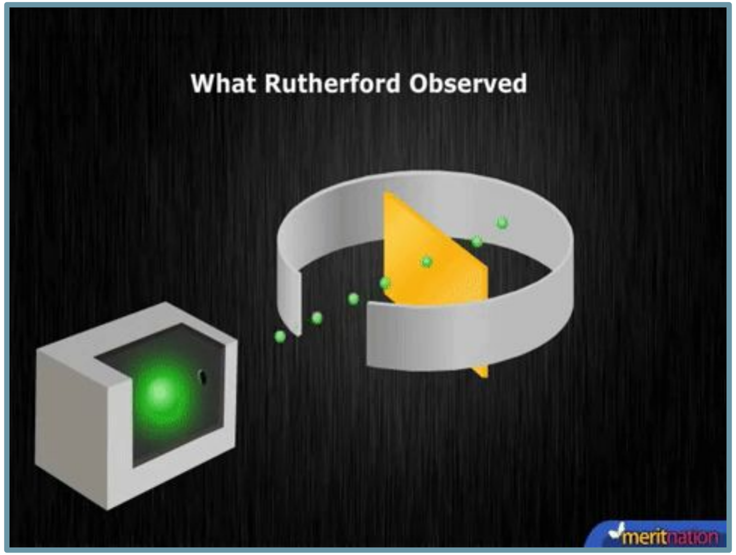
Thomson's atomic model failed to explain how the positive charge holds on the electrons inside the atom. It also failed to explain an atom's stability.

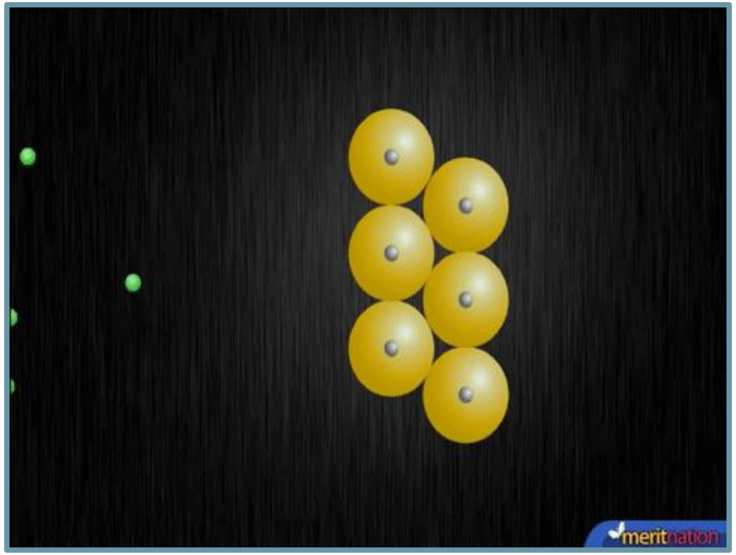
The theory did not mention anything about the nucleus of an atom.

It was unable to explain the scattering experiment of Rutherford.

The idea of nucleus
(Gold Foil Experiment or α-scattering experiment)

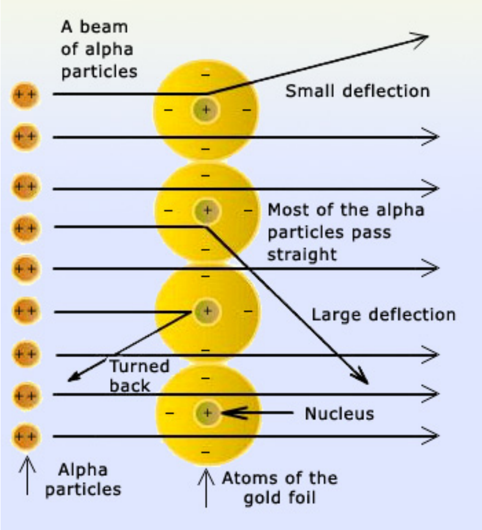
Rutherford in 1911 projected a beam of alpha (α) particles from a radioactive source upon a very thin gold foil. The α-particles emitted from radioactive elements with great velocities, on average about 180,000 miles per second.



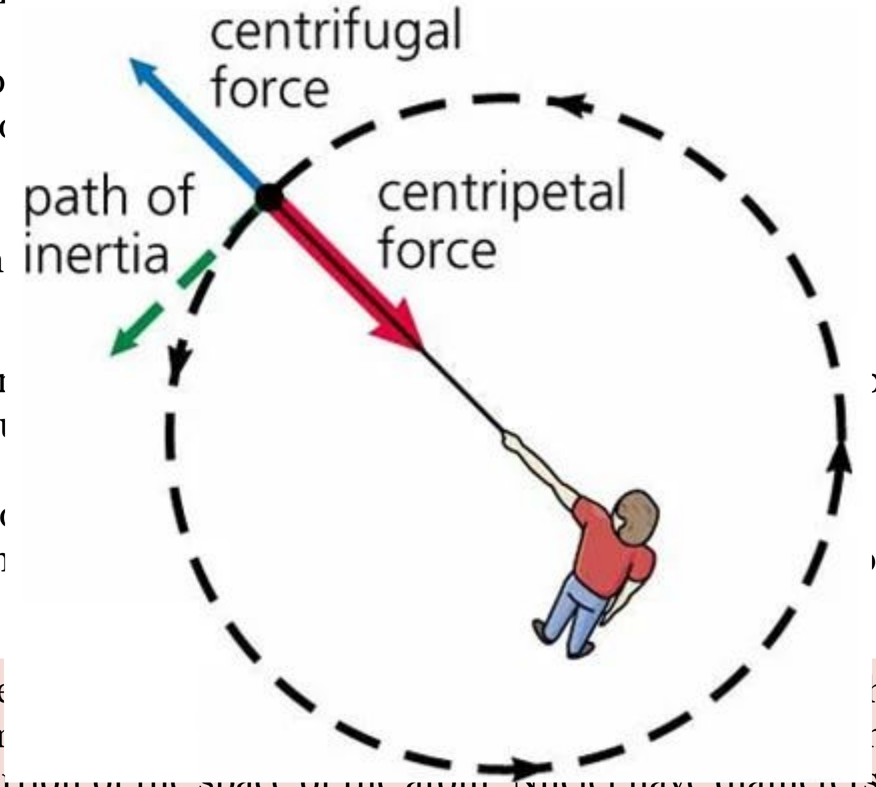


1. Most α-particles were observed to pass straight through the gold foil without deflection
2. A few were scattered at large angles
3. Some even bounced back toward the source as if the α-particles had met with some obstacles in their onward journey

Rutherford's Atom Model



1. Most of the space of an atom is empty



2. Most of the mass of an ato
called the nucleus, which is p
to the total size of the atom.

3. Electrons move around th
planets move around the sun.

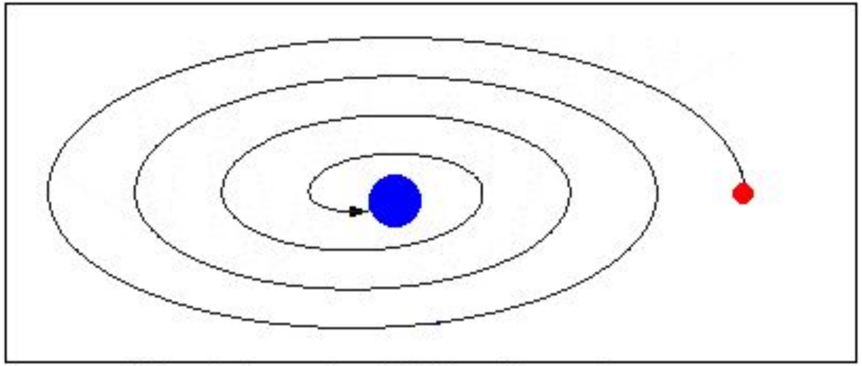
4. The number of electrons … particles in the nucleus so that the atom as a whole is ne

5. Due to the rapid rotation … of electrostatic attraction (centripetal force) between th … by the outward centrifugal force.

The Rutherford atomic mode … he planetary model of the atom, or the Solar system m … n its nucleus, the nucleus occupies only a very small portion of the space of the atom. Nuclei have diameters of about 10^{-15} m, whereas the atomic diameter is about 10^{-10} m, a hundred thousand times smaller.

Limitations of Rutherford's Atom Model

1. Rutherford proposed that the electrons revolve around the nucleus in fixed paths called orbits. According to Maxwell's electromagnetic theory, any charged body, such as electrons rotating in an orbit, must radiate energy continuously, thereby losing kinetic energy. Thus, rotating electron will lose energy, and its orbit will become smaller and smaller, and it will ultimately fall into the nucleus following a spiral path, annihilating the atom model.



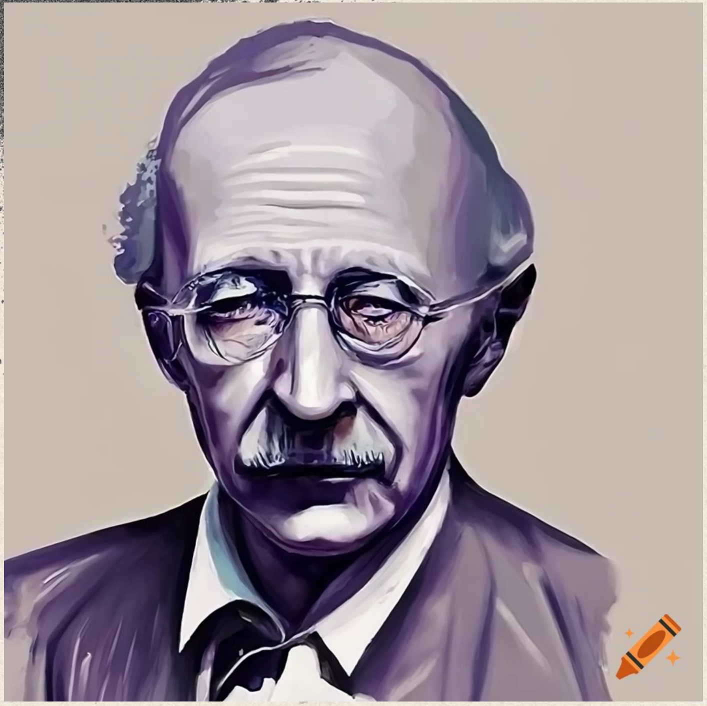
The electron should fall on the nucleus.

2. This model is based upon Newton's laws of motion and gravitation. But Newton's laws of motion and gravitation can only be applied to neutral bodies, such as planets, and not to charged bodies such as tiny electrons moving around a positive nucleus. The analogy does not hold good since the electrons in an atom repel one another, whereas planets attract each other because of gravitational forces. Besides, there is electrostatic attraction in a nuclear atom model.

3. Rutherford did not give any idea about the shape of the orbits.

4. There was no explanation about the rotation of electrons in an atom with many electrons.

5. If there is continuous emission of radiation, the spectra of an atom will be a band or continuous spectra. But an atom gives discontinuous or line spectrum.



Max Planck

Max Planck was a German physicist who revolutionized physics by introducing the concept of energy quanta. His work laid the foundation for quantum theory, changing the way we understand energy and matter at the atomic level. In recognition of this groundbreaking contribution, he was awarded the Nobel Prize in Physics in 1918.

Niels Bohr

Niels Bohr was a Danish physicist known for his pioneering model of the atom, where electrons orbit the nucleus in defined energy levels. His theory helped explain atomic structure and spectral lines, marking a major step in quantum mechanics. For his contributions to our understanding of atomic structure and radiation, he received the Nobel Prize in Physics in 1922.

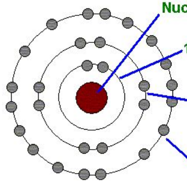
George Paget Thomson

G. P. Thomson was a British physicist best known for his experimental discovery of the wave properties of electrons. His work confirmed the principles of quantum mechanics and wave-particle duality. In recognition of this achievement, he was awarded the Nobel Prize in Physics in 1937, which he shared with Clinton Davisson. Interestingly, his father, J. J. Thomson, had earlier discovered the electron as a particle.

Aage Niels Bohr

Aage Niels Bohr, the son of Niels Bohr, was a Danish physicist who made significant contributions to the understanding of nuclear structure. He developed the collective model of the atomic nucleus, explaining how nuclear particles behave both individually and collectively. For this work, he was awarded the Nobel Prize in Physics in 1975, which he shared with Ben R. Mottelson and James Rainwater.

Bohr's Atomic Model



1. Postulates of Energy Levels

- An atom has several stable orbits in which an electron can revolve without the radiation of energy. These orbits are referred to as ‘Energy Levels’.

- An electron moving in an orbit can have only a certain amount of energy, not an infinite number of values, i.e., its energy is quantized.

- While rotating in an orbit, an electron does not absorb or emit energy.

- The energy that an electron needs to move in a particular orbit depends on the radius of the orbit. An electron in an orbit distant from the nucleus requires higher energy than an electron in an orbit near the nucleus.

- If the electrons move in a circular orbit, their motion is subject to the ordinary laws of electrical and centrifugal force. These orbits are decided by the condition that the angular momentum of the electron in such an orbit must be an integral multiple of $h/2\pi$, that is,

$$mvr = nh/2\pi$$

where m is the mass of the electron, v is its velocity, r is the radius of the orbit, h is Planck’s constant, and n is 1, 2, 3, 4, 5 etc.

2. Postulates of radiation of energy

When an electron jumps from one energy level to another, there is absorption or emission of energy. When an electron moves from a higher energy level to a lower energy level, there is emission of radiation, and when an electron moves from a lower level to a higher one, there is absorption of radiation. The energy radiated is electromagnetic.

If E_1 and E_2 are energies of the electron in the initial and final levels, respectively, the difference of energy radiated when the electron passes from the higher to the lower energy level is given by the relation: $E_2 - E_1 = h\upsilon$
where h is Planck's constant and υ is the frequency of radiation.

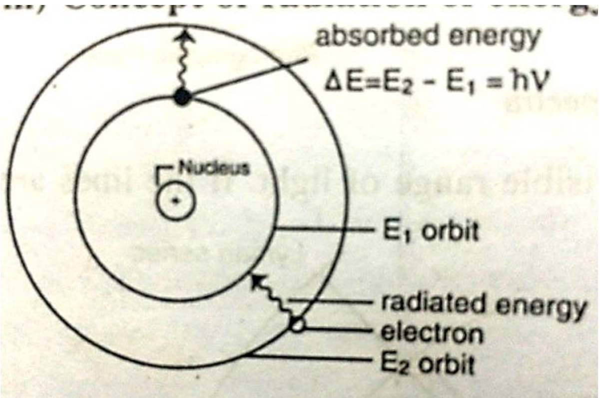


Fig. 2.10: Bohr Atom Model

Limitations of Bohr's Atomic Model

1. Bohr theory successfully explains the spectrum of hydrogen but can not explain the spectral lines of atoms with more than one electron.

2. According to Bohr's model, when an electron jumps from one energy level to another, a single line is supposed to appear on the spectrum. However, when a spectrograph is developed with high resolving power, there are two or more lines very close together observed. Bohr's atomic model does not explain this.

3. This theory is unrealistic in the sense that periodic motion around a central body usually follows an elliptical path rather than a circular path, which has been assumed in the case of Bohr theory. If electrons follow an elliptical path, the velocity along the path does not remain constant.

Thanks!