Nuclear Physics

Chapter 1: Nuclear Structure

➢Discovery of Atom: Dalton, 1808

Atom is the smallest indivisible constituent of matter

➢ Discovery of electron : J.J. Thompson, 1897

J.J. Thomson's experiments with cathode ray tubes showed that all atoms contain tiny negatively charged subatomic particles or **electrons**. Thomson proposed the plum pudding model of the atom, which had negatively-charged **electrons** embedded within a positively-charged "soup."

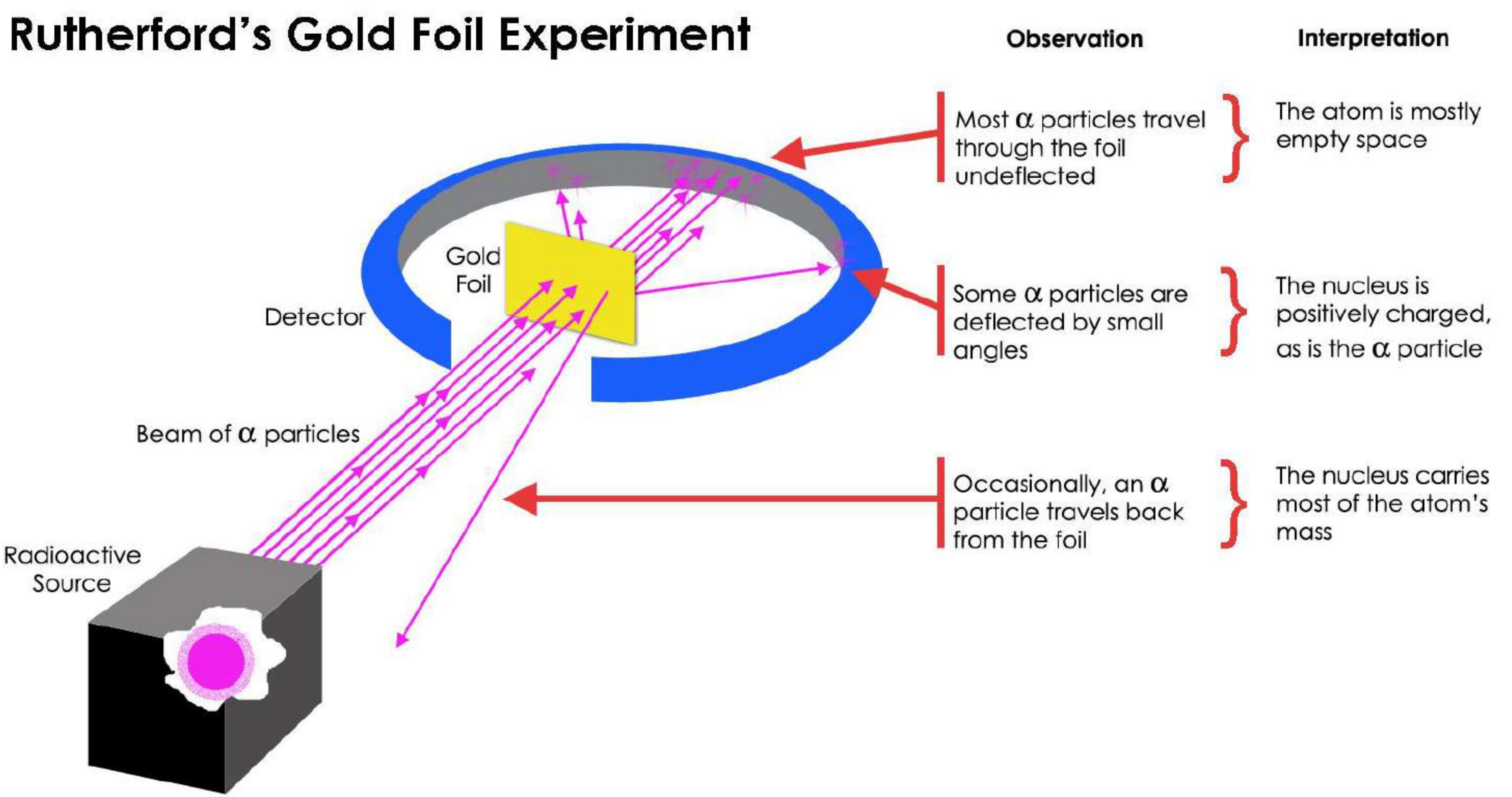


Diagram: from internet

1. Size of Atomic Nucleus:

- **Rutherford α scattering Experiment** : Mass of an atom is concentrated within a small, positively charged region at the centre of an atom, which was called the Nucleus.

- Later, **other scattering experiments** were performed using highly energetic electrons and neutrons as scattering particles to determine the size of nucleus.

- **Electron vs Neutron as scattering particle**: Electron interacts only via electric forces while neutron interact via nuclear forces.

- Electron scattering tells the **charge distribution**

- Neutron scattering tells **mass distribution** of nucleus.

Experimental observation : Volume of the nucleus is directly proportional to the number of nucleons or mass number.

For a nucleus with radius R and volume $\frac{4}{3}\pi R^3$, R^3 is proportional to A. Thus,

$$R = R_0 A^{1/3}$$

The value of R_0 is found experimentally as $R_0 = 1.2\text{x}10^{-15}\text{m} = 1.2\text{fm}$

Though Nuclei do not have sharp boundaries, R represents effective nuclear size.

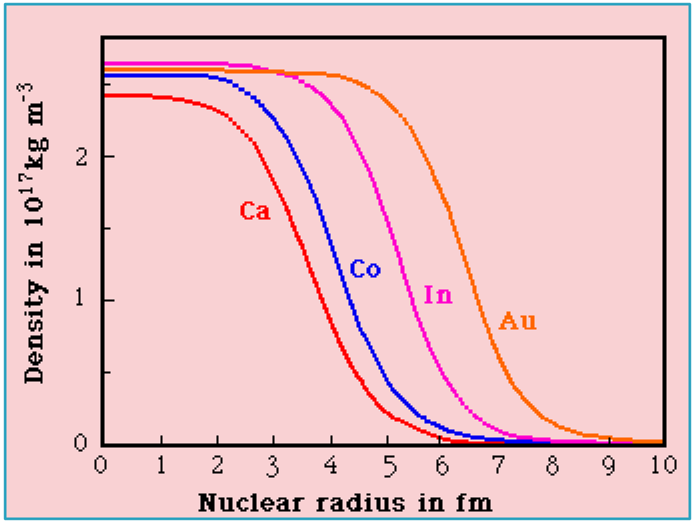


Diagram: from internet

Structure of the Nucleus

1. Proton Electron Hypothesis

2. Proton Neutron Hypothesis

1. Proton Electron Hypothesis:

Impossibility of an electron being in the nucleus as a consequence of the uncertainty principle

- Before the discovery of neutron, the nucleus of an atom was thought to be composed of protons and electrons
- The theory was well fitted to explain mass and charge of any nucleus

Example:

✓ **Helium Nucleus:** Mass is four times of proton but charge is +2e

➡ It is composed of 4 protons and 2 electrons

✓ **β Emission** from Nuclei

Drawbacks:

This hypothesis was failed because of the following arguments.

i) Nuclear Size:

- The radii of the nuclei ~ 10^{-15}m
- Uncertainty principle demands electrons confined to sucha small region must have KE ~ 100 MeV

However, electron emitted during β emission has energy ~ 2-3MeV

ii) Nuclear Spin:

- Electrons and Protons each have spin ½
- So, Nuclei with even no. of (Protons+Electrons)= Integral Spin
- Nuclei with odd no. of (Protons+Electrons)= half Integral Spin

But this is not obeyed. Example-

Deuteron Nucleus: Mass is two times of proton, charge is +e
Must have two protons and one electron

- odd number, half integral spin
  However, *the observed spin is 1*.

iii) Nuclear Magnetic Moments:

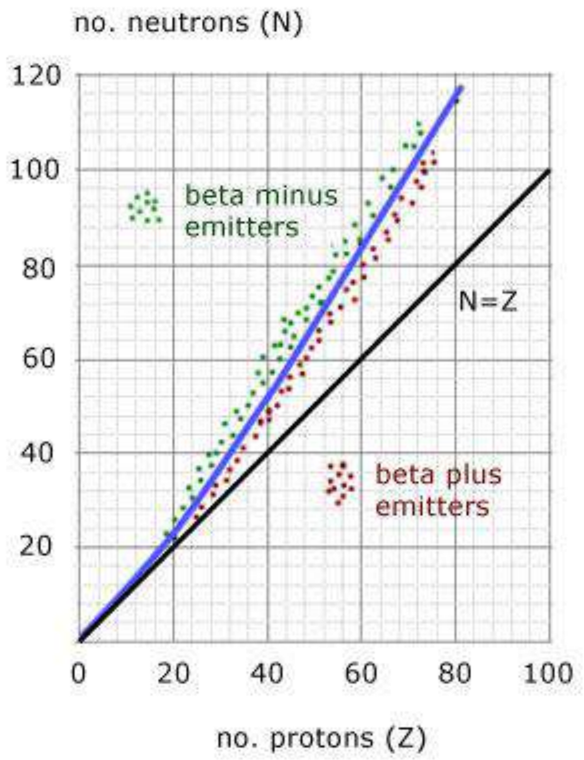
- Owing to its spin, electron has a magnetic moment
- For odd number of electrons, the odd electron should add this amount of magnetic moment to the nucleus.
- Yet, the magnetic moment of nuclei is only 1/1000th of this.
- Hence electrons can not be nuclear constituents.

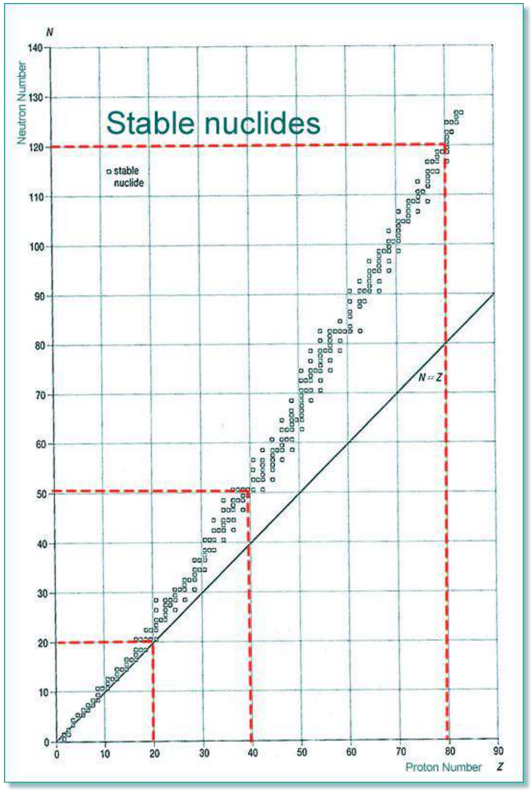
➢ Also the electron scattering experiments by nuclei rule out the existence of electrons in nuclei.

2. Proton Neutron Hypothesis:

- 1932: Discovery of Neutron, an uncharged particle slightly heavier than proton and a spin of ½
- If it is assumed that Nuclei contains Protons and Neutrons, No electrons, all the observations and explanations fit perfectly.
- Nuclei contains Protons and Neutrons tightly packed together.
- The Nucleus of an atom with atomic number Z and mass number A contains Z protons and A–Z neutrons.

Stable Nuclei: N-Z Graph





A	Z	N	No.
Even	Even	Even	166
Odd	Even	Odd	57
Odd	Odd	Even	53
Even	Odd	Odd	8

- Lighter Nuclei : Neutrons $\simeq$ Protons
- Heavier Nuclei : Neutron proportion progressively increases
- Energy levels are filled in sequence with two neutrons of opposite spin and two protons of opposite spins.
- Tendency is to have even values of both Z and N.

Diagram: from internet

Nuclear Forces

Nuclear Constituents:

1. Protons, which repel each other electrostatically
2. Neutrons, which exert no electric force

Fact:

Protons and Neutrons are held extremely close together inside a **stable** Nucleus !!

Conclusion:

Obviously there are some forces operating within the nucleus which is holding it into one piece. This force is termed as Nuclear Force.

Results of p-p and p-n scattering experiments:

- Most straightforward technique

- The study is about the angular distribution of neutrons and protons elastically scattered by protons.

- Study reveals that:

- The internuclear potential has a hard core
- It prevents nucleons to approach closer than 0.4 fm
- Two nucleons within 2 fm feel an attractive force
- This force is zero outside to 3 fm
- Form of nuclear potential for p-p, p-n and n-n pairs are same.

Conclusion:

Nuclear force is ***Attractive***, ***Short range*** and ***Charge Independent***.

Properties of Nuclear Force

Experimental evidences lead to the following properties of nuclear forces.

i. Nuclear forces are primarily attractive.

Otherwise the nucleus would be disrupted under the electrostatic repulsion between the protons.

ii. Nuclear forces are non-electric.

If it were electric, protons would repel each other.

iii. Nuclear forces are non gravitational.

If calculated, the gravitational forces are found to be about 10^{-40} times than the required attractive force.

iv. Nuclear forces are extremely strong.

By far, strongest of the forces known.

v. Nuclear forces are extremely short range.

Acts only over distances as short as a small multiple of 10^{-15} meter.

vi. Nuclear forces are charge independent.

Makes no distinction between neutrons and protons.

vii. Nuclear forces are spin dependent.

Depends on the mutual orientation of the spins of nucleons.