1. Details of Module and its structure

Module Detail	
Subject Name	Physics
Course Name	Physics 04 (Physics Part 2 ,Class XII)
Module Name/Title	Unit-08, Module-04: Atomic Nucleus Chapter-13: Nuclei
Module Id	leph_201301_eContent
Pre-requisites	Atomic structure, electrons, protons, neutrons, nucleus, Rutherford experiment as done up to secondary level, limitations of Rutherford's atomic model m line spectrum of hydrogen, Bohr's postulates, radius of stationary orbits, energy associated with each stationary state
Objectives	After going through the module the learners will be able to: • Understand the composition of nucleus and atomic mass • Know about discovery of neutron • Appreciate the size of nucleus • Reason out the properties of nuclear forces
Keywords	Nuclear size, nucleon, discovery of neutron, nuclear force, isotope, isotone, isobar, magic number, atomic mass ,nuclear energy states

2. Development Team

Role	Name	Affiliation
National MOOC Coordinator (NMC)	Prof. Amarendra P. Behera	Central Institute of Educational Technology, NCERT, New Delhi
Programme Coordinator	Dr. Mohd Mamur Ali	Central Institute of Educational Technology, NCERT, New Delhi
Course Coordinator / (PI)	Anuradha Mathur	Central Institute of Educational Technology, NCERT, New Delhi
Subject Matter Expert (SME)	Anuradha Mathur	Central Institute of Educational Technology, NCERT, New Delhi
Review Team	Prof. V. B. Bhatia (Retd.) Associate Prof. N.K. Sehgal (Retd.) Prof. B. K. Sharma(Retd.)	Delhi University Delhi University DESM, NCERT, New Delhi

Table of content

1. UNIT SYLLABUS

Unit 8 Atoms and Nuclei

Chapter 12 Atoms

Alpha particle scattering experiment, Rutherford's model of atom, Bohr model, energy levels, hydrogen spectrum

Chapter 13 Nuclei

Composition and size of nucleus, radioactivity, alpha, beta and gamma particles/rays and their properties, radioactive decay laws

Mass energy relations, mass defect, binding energy per nucleon and its variation with mass number, nuclear fission and nuclear fusion

2. MODULE WISE DISTRIBUTION OF UNIT SYLLABUS 7 MODULES

Module 1	• **Introduction** • **Early models of atom** • **Alpha particle scattering and Rutherford's Nuclear model of atom** • **Alpha particle trajectory** • **Results and interpretations** • **Size of nucleus** • **What Rutherford's model could not explain**
Module 2	• **Bohr's model of hydrogen atom** • **Bohr's postulates** • **Electron orbits, what do they look like?** • **Radius of Bohr orbits** • **Energy levels, Energy states, energy unit eV**

	• Lowest energy -13.6 eV interpretation • Velocity of electrons in orbits
Module 3	• The line Spectrum of hydrogen atom • de Broglie's explanation of Bohr 's second postulate of quantisation • Departures from Bohr model energy bands • Pauli's Exclusion Principle and Heisenberg's uncertainty principle leading to energy bands
Module 4	• Atomic masses and composition of nucleus • Discovery of neutron • Size of nucleus • Nuclear forces • Energy levels inside the nucleus
Module 5	• Mass and energy, Einstein's relation $E = mc^2$ • Mass defect • MeV • Nuclear binding energy • Binding energy per nucleon as a function of mass number • Understanding the graph and interpretations from it
Module 6	• Radioactivity • Laws of radioactivity • Half life • Rate of decay -disintegration constant • Alpha decay • Beta decay • Gamma decay
Module 7	• Nuclear energy • Fission • Controlled fission reaction • Nuclear Reactor • India atomic energy programme • Nuclear Fusion – energy generation in stars • controlled thermonuclear fusion

MODULE 4

3. WORDS YOU MUST KNOW

Atoms: Atoms are the fundamental building blocks of matter. The existence of different kinds of matter is due to different atoms constituting them.

Molecules: A molecule can be defined as the smallest particle of an element or a compound that is capable of an independent existence and shows all the properties of that substance. Atoms of the same element or of different elements can join together to form.
The molecules of an element are constituted by the same type of atoms

Charge: electrical property of nucleons, electrons, ions due to which there is electrical interaction between them ..

Electron: The electron is a subatomic particle, symbol e^- or β^-, whose electric charge is negative one

Proton: A *proton* is a subatomic particle, symbol p or p^+, with a positive electric charge of +1e elementary charge and a mass slightly less than that of a neutron

Neutron: A subatomic particle of about the same mass as a proton but without an electric charge, present in all atomic nuclei except those of ordinary hydrogen.

Atomic mass:
One atomic mass unit is a mass unit equal to exactly one-twelfth (1/12th) the mass of one atom of carbon-12. The relative atomic masses of all elements have been found with respect to an atom of carbon-12

Molecular mass of a substance is the sum of the atomic masses of all the atoms in a molecule of the substance. It is therefore the relative mass of a molecule expressed in atomic mass units (u)

The mass of 1 mole of a substance is equal to its relative atomic or molecular mass in grams. The atomic mass of an element gives us the mass of one atom of that element in atomic mass units (u)

Molar mass: Mass of 1 mole of a substance is called its molar mass.

Avogadro constant: 6.022×10^{23} is defined as the number of atoms in exactly 12 g of carbon-12.

The mole is the amount of substance that contains the same number of particles (atoms/ ions/ molecules/ formula units etc.) as there are atoms in exactly 12 g of carbon-12.

Rutherford's model of an atom: Ernest Rutherford was interested in knowing how the electrons are arranged within an atom. Rutherford designed an experiment for this. In this experiment, fast moving alpha(a)-particles were made to fall on a thin gold foil.

On the basis of alpha particle scattering Rutherford proposed the following model of an atom

i) **An atom consists of a small and massive central core in which the entire positive charge and almost entire mass of the atom are concentrated. The core is called the nucleus**
ii) **The size of the nucleus is very small ~10^{-15}m as compared to the size of the atom ~10^{-10}m**

iii) **The nucleus is surrounded by suitable number of electrons so that the atom remains neutral**

iv) **The electrons revolve around the nucleus in orbits as the planets around the sun the centripetal force is provided by the electrostatic attraction between the electrons and the nucleus**

Limitations of Rutherford model of the atom: According to electromagnetic theory an accelerated charged particle must radiate electromagnetic energy. An electron revolving around the nucleus is under continuous acceleration towards the centre as they are revolving in a circle.

It should thus continuously loose energy and move in orbits with gradually decreasing radii and finally collapse into the nucleus. BUT THE NUCLEUS is stable.

eV kinetic energy gained by an electron when subjected to a potential difference of 1 volt

MeV 10^6 eV

Orbit: Supposed track of electron inside the atom

Behr's Postulates:

i) Bohr's **first postulate** an **electron in an atom could revolve in certain stable orbits without the emission of radiant energy**, these are called the **stationary states of the atom.**

ii) Bohr's **second postulate** defines these stable orbits.

This postulate states that **the electron revolves around the nucleus only in those orbits for which the angular momentum is some integral multiple of h/2π**

where h is the Planck's constant (= $6.6 \times 10^{--34}$ J s).

Thus the angular momentum (L) of the orbiting electron is quantised.

That is $\mathbf{L = nh/2\pi}$

iii) **Third postulate It states that an electron might make a transition from one of its specified non-radiating orbits to another of lower energy**

Spectrum spread of colours when a polychromatic light is dispersed. by refraction a prism, interference**, or diffraction**

4. INTRODUCTION

You will recall some of the Atomic Properties from your secondary school course and from this course.

The electrons associated with atoms are found to have measurable properties which exhibit quantization. The electrons are normally found in quantized energy states of the lowest possible energy for the atom, called ground states. The electrons can also exist in higher "excited states", as evidenced by the line spectra (e.g. the hydrogen spectrum) observed when they make transitions back to the ground states. The existence of these excited states can be demonstrated more directly in collision experiments like the **Franck-Hertz experiment.**

Other properties associated with the electron energy levels such as orbital angular momentum and electron spin are also quantized and give rise to the quantum numbers used to characterize the levels. These quantized properties are associated with periodic table of the elements, and the requirements of the Pauli Exclusion Principle on the quantum numbers can be viewed as the origin of the periodicity. The periodic table provides a convenient framework for cataloguing other physical and chemical properties of atoms.

From Rutherford's experiment and Bohr's model we know that in every atom, the positive charge and mass are densely concentrated at the centre of the atom forming its nucleus. The overall dimensions of a nucleus are much smaller than those of an atom. Experiments on scattering of α-particles demonstrated that the radius of a nucleus was smaller than the radius of an atom by a factor of about 10^4.

This means the volume of a nucleus is about 10^{-12} times the volume of the atom.

In other words, **an atom is almost empty**. If an atom is enlarged to the size of a classroom, the nucleus would be of the size of pinhead. Nevertheless, the nucleus contains most (more than 99.9%) of the mass of an atom.

THINK ABOUT THIS

- **Does the nucleus have a structure, just as the atom does?**

If so,

- **What are the constituents of the nucleus?**
- **How are the protons, all positive, held together?**

In this Module we shall look for answers to such questions.

We shall discuss various properties of nuclei such as their size, mass and stability.

5. ATOMIC MASSES AND COMPOSITION OF NUCLEUS

The mass of an atom is very small, compared to a kilogram; for example, the mass of a, carbon atom (^{12}C), is **1.992647×10^{-26} kg.**

Kilogram is not a very convenient unit to measure such small quantities.

Therefore, a different **mass unit** is used for expressing atomic masses. This unit is the **atomic mass unit (u), defined as 1/12th of the mass of the carbon (^{12}C)** atom.

Accurate measurement of atomic masses is carried out with a **mass spectrometer**,

Just to help you understand how a mass spectrometer works

In a typical experiment with a mass spectrometer, a sample, which may be solid, liquid, or gas, is ionized, for example by bombarding it with electrons.

This may cause some of the sample's molecules to break into charged fragments. These ions are then separated according to their mass-to-charge ratio, typically by accelerating them and subjecting them to an electric or magnetic field:

$$\mathbf{F = q(E + v \times B)} \ \ \textbf{lorentz force}$$

F = ma

$$\left(\frac{m}{q}\right)\mathbf{a = E + v \times B}$$

Thus the application of mass spectrometer depends on Lorentz force-(force on a moving charged particle by electric and magnetic fields, as this is unique and predictable).

Ions of the same mass-to-charge ratio will undergo the same amount of deflection
The ions are detected by a mechanism capable of detecting charged particles.

Results are displayed as spectra of the relative abundance of detected ions as a function of the mass-to-charge ratio.

The atoms or molecules in the sample can be identified by correlating known masses (e.g. an entire molecule) to the identified masses.

You can read more
https://en.wikipedia.org/wiki/Mass_spectrometry

The measurement of atomic masses reveals the existence of different types of atoms of the same element, which exhibit the same chemical properties, but differ in mass. Such atomic species of the same element differing in mass are called ***isotopes*.**

(In Greek, isotope means the same place, i.e. they occur in the same place in the periodic table of elements.)

It was found that practically every element consists of a mixture of several isotopes. The relative abundance of different isotopes differs from element to element.

Chlorine, for example, has **two isotopes** having masses **34.98 u and 36.98 u,** which are nearly integral multiples of the mass of a hydrogen atom.

The relative abundances of these isotopes are 75.4 and 24.6 per cent, respectively.

Thus, the average mass of a **chlorine atom** is obtained by the **weighted average of the masses of the two isotopes, which works out to be**

$$= \frac{75.4 \times 34.98 + 24.6 \times 36.98}{100}$$

= **35.47 u**

which agrees with the atomic mass of chlorine.

Even the lightest element, **hydrogen** has three isotopes having masses 1.0078 u, 2.0141 u, and 3.0160 u.

The nucleus of the lightest atom of hydrogen, which has a relative abundance of 99.985%, is called the proton.

The mass of a proton is (m_p) = 27 1.00727 u = 1.67262×10^{-27} kg

This is equal to the mass of the hydrogen atom (= 1.00783u), minus the mass of a single electron (m_e = 0.00055 u).

The other two isotopes of hydrogen are called **deuterium and tritium**. Tritium nuclei, being unstable, do not occur naturally and are produced artificially in laboratories.

The positive charge in the nucleus is that of the protons. A proton carries one unit of fundamental charge (= charge on one electron) and is stable.

MORE ABOUT ISOTOPES

These are some isotope facts obtained experimentally

- **The different isotopes of a given element have the same atomic number, but different mass numbers, since they have different number of neutrons.**
- **The chemical properties of different isotopes of an element are identical**
- **The nuclear stability is different**
- **For isotopes of light elements to be stable, the number of neutrons will be almost equal to the number of protons.**
- **For heavy nuclei to be stable, excess neutrons are needed as compared to protons**
- **The element tin (Sn) has the most stable isotopes with 10, the average being about 2.6 stable isotopes per element.**

The nucleus is extremely tiny compared to the size of the atom. The nuclear radius of carbon-12 is 2.7 x 10^{-15} m while the size of the atom is about 0.9 x 10^{-10} m,

about 33,000 times larger!

It was earlier thought that the nucleus may contain electrons, but this was ruled out later using arguments based on quantum theory.

All the electrons of an atom are outside the nucleus. We know that the number of these electrons outside the nucleus of the atom is *Z*, the atomic number.

The total charge of the atomic electrons is thus (–*Ze*), and since the atom is neutral, the charge of the nucleus is (+*Ze*).

The number of protons in the nucleus of the atom is, therefore, exactly *Z*, the atomic number.

6. DISCOVERY OF NEUTRON

The problem!

Since the nuclei of deuterium and tritium are isotopes of hydrogen, they must contain only one proton each. But the masses of the nuclei of hydrogen, deuterium and tritium are in the ratio of 1:2:3.
Therefore, the nuclei of deuterium and tritium must contain, in addition to a proton, some **neutral matter.**

The amount of neutral matter present in the nuclei of these isotopes, expressed in units of mass of a proton, is approximately equal to one and two, respectively. This fact indicates that the nuclei of atoms contain, in addition to protons, neutral matter in multiples of a basic unit of mass.

Arguments!

This hypothesis was verified in 1932 by James Chadwick who observed emission of neutral radiation when beryllium nuclei were bombarded with alpha-particles.

It was found that this neutral radiation could knock out protons from light nuclei such as those of helium, carbon and nitrogen. The only neutral radiation known at that time was photons (electromagnetic radiation).

Application of the **principles of conservation of energy and momentum** showed that if the neutral radiation consisted of photons, the energy of photons would have to be much higher than is available from the bombardment of beryllium nuclei with α-particles.

The clue to this puzzle, which Chadwick satisfactorily solved, was to assume that the neutral radiation consists of a new type of neutral particles called neutrons.

From conservation of energy and momentum, he was able to determine the mass of new particle 'as very nearly the same as mass of proton'.

The **mass of a neutron** is now known to a high degree of accuracy.

Chadwick was awarded the 1935 Nobel Prize in Physics for his discovery of the neutron.

IMPORTANT FACTS ABOUT NEUTRON

- **mass of the neutron $m_n = 1.00866 \text{ u} = 1.6749 \times 10^{-27}$ kg**
- **A free neutron, unlike a free proton, is unstable.**
- **It decays into a proton, an electron and an antineutrino (another elementary particle)**
- **It has a mean life of about 1000s. which about 16 minutes, outside the nucleus**

- **Neutrons are stable inside the nucleus**.

We can say ,nuclei are made up of **protons** and **neutrons** bound together, Both protons and neutrons are referred to as **nucleons.**

The **number of protons** is called the **atomic number** and determines the chemical element. Nuclei of a given element (same atomic number) may have different numbers of neutrons and are then said to be different **isotopes** of the element

The composition of a nucleus can now be described using the following

terms and symbols:

Z - atomic number = number of protons

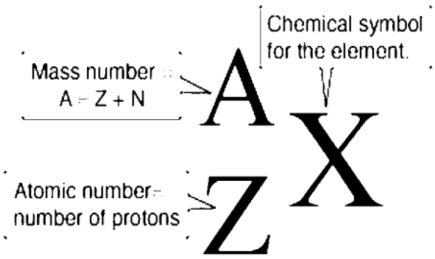
N - neutron number = number of neutrons

A - mass number = Z + N

= total number of protons and neutrons.

Thus the number of nucleons in an atom is its mass number A.

If **X is the chemical symbol** for an element a notion as shown is used to represent its nucleus



The composition of isotopes of an element can now be readily explained.

The nuclei of isotopes of a given element contain the same number of protons, but differ from each other in their number of neutrons.

Deuterium $^{2}_{1}H$, which is an isotope of hydrogen, its nucleus contains **one proton and one neutron**.

Nucleus of another isotope Tritium $^{3}_{1}H$, contains one proton and two neutrons.

The element gold has 32 isotopes, ranging from ***A* = 173 to *A* = 204**.

We have already mentioned that chemical properties of elements depend on their electronic structure. As the atoms of isotopes have identical electronic structure they have identical chemical behaviour and are placed in the same location in the periodic table.

Note we can describe isobars and isotones

- **All nuclides with same mass number *A* are called *isobars*.**

For example, the nuclides **$^{3}_{1}H$ and $^{3}_{2}He$** are **isobars.**

- **Nuclides with same neutron number *N* but different atomic number *Z*,**

For example the nuclides **$^{198}_{80}Hg$ and $^{197}_{79}Au$,** are **isotones.**

7. SIZE OF THE NUCLEUS

Rutherford was the pioneer who postulated and established the existence of the atomic nucleus. At Rutherford's suggestion, **Geiger and Marsden** performed their classic experiment: on the scattering of α-particles from thin gold foils. Their experiments revealed that the distance of closest approach to a gold nucleus of an α-particle of kinetic energy 5.5 MeV is about 4.0×10^{-14} m.

Rutherford explained the scattering of α-particle by the gold foil, by assuming that the coulomb repulsive force was solely responsible for scattering.

Since the positive charge is confined to the nucleus, the actual size of the nucleus has to be less than 4.0×10^{-14} m.

If we use α-particles of higher energies than 5.5 MeV, the distance of closest approach to the gold nucleus will be smaller and at some point the scattering will begin to be affected by the short range nuclear forces, and differ from Rutherford's calculations.

Rutherford's calculations are based on **pure coulomb repulsion between the positive charges of the α-particle and the gold nucleus.**
From the distance at which deviations set in, nuclear sizes can be inferred.

Various types of scattering experiments suggest that nuclei

- **Are roughly spherical in shape**
- **Appear to have the same density.**

By performing scattering experiments in which fast electrons, instead of α-particles, are projectiles that bombard targets made up of various elements, the sizes of nuclei of various elements have been accurately measured.

It has been found that a nucleus of **mass number *A*** has a radius

$$\mathbf{R = R_0\, A^{1/3}}$$

where $\mathbf{R_0 = 1.2 \times 10^{-15}}$ **m.**

the nuclear sizes are quite small and need smaller units:

Atomic sizes are of the order of 0.1 nm = 1 Angstrom = 10^{-10} m

Nuclear sizes are of the order of femto-metres which in the nuclear context are usually called **fermi.**

$$1 \text{ fm} = 10^{-15} \text{m}$$

8. DENSITY OF NUCLEUS

Considering nucleus to be spherical, **the volume of the nucleus, which is proportional to *R^3* is proportional to *A*.**

The density of nucleus is a constant, independent of *A*, for all nuclei.

Different nuclei are likes drop of any liquid of constant density.

The density of nuclear matter is approximately 2.3 × 10^{17} kg m^{-3}.

This density is very large compared to ordinary matter, say density of water, is **10^3 kg m^{-3}.**

So our atomic picture now is –

- **matter consists of atoms.**
- **inside the atoms there is a large amount of empty space,**
- **electrons move in different energy states and**
- **the dense core of protons and neutrons is the nucleus.**
- **All atoms are neutral**

EXAMPLE

Given the mass of iron nucleus as 55.85 u and A= 56,
Take u =1.6605 10^{-27} kg
Calculate the nuclear density?

SOLUTION

m_{Fe} =55.85 u = 55.85 x 1.6605 × 10^{-26} kg **= 9.27 x $10^{=27}$ kg**

$$\text{nuclear density} = \frac{\text{mass}}{\text{volume}} = \frac{9.27\times10^{-26}}{\left(\frac{4\pi}{3}\right)(1.2\times10^{-15})^3}\times\frac{1}{56} = 2.29\times10^{17}\text{kgm}^{-3}$$

Note radius of the nucleus is obtained using
$R = R_0 A^{1/3}$

where **$R_0 = 1.2 \times 10^{-15}$ m.**

The density of matter in neutron stars (an astrophysical object) is comparable to this

density. This shows that matter in these objects has been compressed to such an extent that they resemble a ***big nucleus***

The nucleus is not a hard sphere.

There is evidence that points to a **mass radius** and a **charge radius** which agree with each other within about 0.1 fermi. Or in other words the **centre of mass and centre of charge almost coincide**

9. NUCLEAR FORCE

The fact that the nuclear density seems to be independent of the details of neutron number or proton number implies that the force between the particles is essentially the same whether they are protons or neutrons. This correlates with other evidence that the strong force is the same between any pair of nucleons.

The force that determines the motion of atomic electrons is the familiar Coulomb force. What keeps a pair of protons together?

Logically

The force that keeps the nucleus together must be a strong attractive force of a totally different kind.

It must be strong enough to overcome the repulsion between the (positively charged) protons and to bind both protons and neutrons into the tiny nuclear volume.

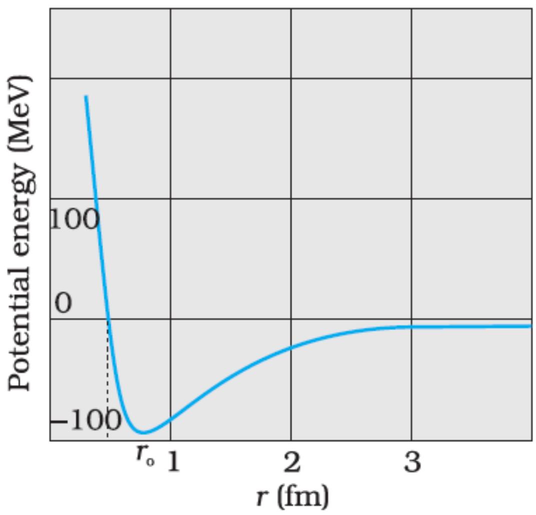
They must be acting at short range within the nucleus

Many features of the nuclear binding force are summarised below.

These are obtained from a variety of experiments carried out during 1930 to 1950.

(i) **The nuclear force is much stronger than the Coulomb force acting between charges or the gravitational forces between masses. The nuclear binding force has to dominate over the Coulomb repulsive force between protons inside the nucleus. This happens only because the nuclear force is much stronger than the coulomb force. The gravitational force is much weaker than even Coulomb force.**

(ii) **The nuclear force between two nucleons falls rapidly to zero as their distance is more than a few femtometres.** ***This leads to saturation of forces in a medium or a large-sized nucleus, which is the reason for the constancy of the binding energy per nucleon.***
A rough plot of the potential energy between two nucleons as a function of distance is shown in the figure



The potential energy is a minimum at a distance r_0 of about 0.8 fm. This means that the force is attractive for distances larger than 0.8 fm and repulsive if they are separated by distances less than 0.8 fm

(iii) **The nuclear force between neutron-neutron, proton-neutron and proton-proton is approximately the same.**

(iv) **The nuclear force does not depend on the electric charge.**
Unlike Coulomb's law or the Newton's law of gravitation there is no simple mathematical form of the nuclear force

THINK ABOUT THIS

- The electron in a hydrogen atom is attracted to the proton in the nucleus, with a force so strong that gravity and all other forces are negligible by comparison.

- But two protons close each other would feel a repulsive force over **100 million times stronger!!**
- So how can such protons stay in such close proximity? This may give you some feeling for the enormity of the strength of nuclear force which holds the nuclei together.

10. DISTRIBUTION OF NUCLEONS IN THE NUCLEUS

This is just to help you understand.

Visualizing the densely packed nucleus in terms of orbits and shells seems much less plausible than the corresponding shell model for atomic electrons. You can easily believe that an atomic electron can complete many orbits without running into anything, but you expect protons and neutrons in a nucleus to be in a continuous process of collision with each other. But dense-gas type models of nuclei with multiple collisions between particles didn't fit the data and remarkable patterns like the "magic numbers" in the stability of nuclei suggested the seemingly improbable shell structure, with energy states like those for electrons in the atom.

With the enormous strong force acting between them and with so many nucleons to collide with, how can nucleons possibly complete whole orbits without interacting?

From Pauli exclusion principle, two nucleons cannot occupy the same quantum state. The evidence for a kind of shell structure and a limited number of allowed energy states suggests that a nucleon moves in some kind of effective potential well created by the forces of all the nucleons.

Since the details of the well determine the nuclear energy levels

Just like the atomic case. The level just start at n = 1 for the lowest level.

INTERESTING TO KNOW

"Magic Numbers" in Nuclear Structure

It is found that nuclei with even numbers of protons and neutrons are more stable than those with odd numbers. In particular, there are "magic numbers" of neutrons and protons which seem to be particularly favoured in terms of nuclear stability:

2,8,20,28,50,82,126

Nuclei which have both neutron number and proton number equal to one of the magic numbers can be called "doubly magic", and are found to be particularly stable.

11. SUMMARY

- An atom has a nucleus. The nucleus is positively charged.
- The radius of the nucleus is smaller than the radius of an atom by a factor of10^4. More than 99.9% mass of the atom is concentrated in the nucleus.
- On the atomic scale, mass is measured in atomic mass units (u). By definition,
  1 atomic mass unit (1u) is 1/12th mass of one atom of 12C;
  $1u = 1.660563 \times 10^{-27}$ kg.

- A nucleus contains a neutral particle called neutron. Its mass is almost the same as that of proton
- The atomic number Z is the number of protons in the atomic nucleus of an element. The mass number A is the total number of protons and neutrons in the atomic nucleus; A = Z+N; Here N denotes the number of neutrons in the nucleus. A nuclear species or a nuclide is represented as ${}^{A}_{z}X$, where X is the chemical symbol of the species.
- Nuclides with the same atomic number Z, but different neutron number N are called isotopes.
- Nuclides with the same A are isobars and those with the same N are isotones.
- Most elements are mixtures of two or more isotopes.
- The atomic mass of an element is a weighted average of the masses of its isotopes. The masses are the relative abundances of the isotopes.

- A nucleus can be considered to be spherical in shape and assigned a radius. Electron scattering experiments allow determination of the nuclear radius; it is found that radii of nuclei fit the formula

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

  where R_0 = a constant = 1.2 fm.
- The nuclear density is independent of A. It is of the order of 10^{17} kg/m^3.
- Neutrons and protons are bound in a nucleus by the short-range strong nuclear force.
- The very strong nuclear force does not distinguish between neutron and proton.