NUCLEI

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.

The atomic mass unit (u), defined as 1/12th of the mass of the carbon (^{12}C) atom. According to this definition

$$1u = \frac{\text{mass of one } ^{12}\text{C atom}}{12}$$

$$= \frac{1.992647 \times 10^{-26} \text{ kg}}{12}$$

$$= 1.660539 \times 10^{-27} \text{ kg}$$

isotopes

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.

The positive charge in the nucleus is that of the protons. A proton

carries one unit of fundamental charge and is stable.

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.

Discovery of Neutron

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. $\mathbf{m_n = 1.00866\ u = 1.6749 \times 10–27\ kg}$

A **free neutron**, unlike a free proton, is **unstable**. It **decays** into a **proton, an electron and a antineutrino** (another elementary particle), and has a mean life of about 1000s. It is, however, **stable** inside the **nucleus**.

Z - atomic number = number of protons

N - neutron number = number of neutrons

A - mass number = Z + N

isobars and isotones

All nuclides with same mass number A are called **isobars**. For example, the nuclides $^{3}\mathbf{H}_{1}$ and $^{3}\mathbf{He}_{2}$ are isobars.

Nuclides with **same neutron number** N but **different atomic number** Z, for example $^{198}\mathbf{Hg}_{80}$ and $^{197}\mathbf{Au}_{79}$, are called **isotones**.

SIZE OF THE NUCLEUS

From Rutherford's Scattering experiments revealed that the distance of closest approach to a gold nucleus of an α-particle of kinetic energy 5.5 MeV

is about $\mathbf{4.0 \times 10^{-14}}$ **m**.

The scattering of α -particle by the gold sheet could be understood by

Rutherford 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. 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**

This means the volume of the nucleus, which is proportional to $\mathbf{R}^3$ is proportional to A. **$V \propto A$**

Thus the density of nucleus is a constant, independent of A, for all nuclei. Different nuclei are likes drop of liquid of constant density.

The density of nuclear matter is approximately

$$\mathbf{2.3 \times 10^{17}\ kg\ m^{-3}}.$$