NUCLEI

INTRODUCTION OF NUCLEI AND ATOMIC MASSES AND COMPOSITION OF NUCLEUS

INTRODUCTION OF NUCLEI

To quantify the mass of different entities, we employ grams or kilograms as standard units of measurement. Nevertheless, when dealing with the mass of individual atoms, these units prove impractical due to the exceedingly minute scale involved in atomic masses as compared to kilograms. To illustrate this point, consider the mass of a carbon atom with the isotope ^{12}C, which amounts to 1.992647×10^{-26} kilograms. The impracticality of expressing atomic masses in kilograms becomes apparent. Consequently, Atomic Mass is denoted using alternative units. Further insights into the structure of a nucleus will be explored in the following section.

Atomic Mass and Isotopes

An Atomic Mass Unit (u) is precisely defined as 1/12th of the mass of a carbon atom with the isotope ^{12}C. This relationship is expressed mathematically as follows:

$$1u = \frac{(mass\ of\ one\ 12C\ atom)}{12} = \frac{1.992647 \times 10^{-26}}{12} = 1.660539 \times 10^{-27} kg \qquad \text{..... (i)}$$

When expressing the atomic mass of various elements in atomic units (u), it is observed that these values are approximately integral multiples of the mass of a hydrogen atom. It is crucial to recognize, however, that exceptions to this pattern exist.

The subsequent consideration revolves around the accurate measurement of atomic mass, achieved through the utilization of a mass spectrometer. Notably, an intriguing discovery in the study of atomic masses is the existence of atoms belonging to the same element that possess different masses while displaying identical chemical properties; these are termed 'Isotopes.'

Further investigations have disclosed that nearly all elements consist of a mixture of numerous isotopes. However, the quantity of isotopes can vary, contingent upon the specific element. Let's delve into more details on this topic.

Note:

Important to note is that chlorine exhibits two isotopes with masses of 34.98u and 36.98u, closely approximating integral multiples of the atomic mass of a hydrogen atom. Additionally, these isotopes have relative abundances of 75.4% and 24.6%, respectively. To determine the average mass of chlorine, a weighted average of the masses of these isotopes is computed using the formula:

$$\text{Average Mass of Chlorine} = \frac{(75.4 \times 34.98) + (24.6 \times 36.98)}{100}$$

This calculation yields an average mass of 35.47u, which is considered the atomic mass of chlorine.

Note:

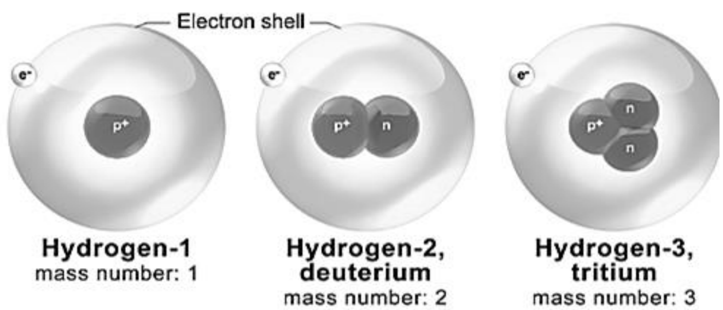
In contrast, hydrogen is characterized by three isotopes with masses of 1.0078 u, 2.0141 u, and 3.0160 u. Among these, the lightest isotope, with a relative abundance of 99.985%, is identified as the proton. The mass of a proton (m_p) is defined as 1.00727 u, corresponding to $1.67262 \times 10^{-27} kg$, as denoted by Equation (ii):

$$mp = 1.00727u = 1.67262 \times 10^{-27} kg \qquad \text{..... (ii)}$$

By subtracting the mass of an electron from the mass of a hydrogen atom, we obtain:

$$1.00783u - 0.00055u = 1.00728u = m_p$$

The isotope with a mass of 2.0141 u is referred to as deuterium, while the one with a mass of 3.0160 u is known as tritium. It is noteworthy that tritium nuclei are inherently unstable and do not occur naturally; they are artificially produced in laboratory settings.



Important Note:

A proton, being stable, bears a single unit of fundamental charge, constituting the positive charge within the atomic nucleus. Following the advent of Quantum theory, a consensus emerged that electrons are situated outside the nucleus, resolving previous debates that posited their presence within the nucleus. The quantity of electrons in an atom corresponds to the atomic number of the element, denoted as Z.

Consequently, the collective charge of the atomic electrons is represented as -Ze. In order to maintain electrical neutrality within an atom, the nucleus carries a positive charge of +Ze. From this, it can be deduced that the number of protons in an atom is identical to the number of electrons, both equal to the atomic number Z.

Discovery of Neutron

Deuterium and tritium, being isotopes of hydrogen, both inherently contain one proton each in their atomic structure. However, a noticeable disparity exists in their atomic masses.

The ratio of the atomic masses of hydrogen, deuterium, and tritium is 1:2:3, indicating the presence of additional matter contributing to their overall atomic masses. Importantly, this additional matter must be electrically neutral to maintain the equilibrium between protons and electrons.

This neutral matter is found in multiples of the mass of a proton, where deuterium has additional matter equivalent to the mass of one proton, and tritium has matter equivalent to the mass of two protons. Consequently, it is reasonable to deduce that atomic nuclei comprise neutral matter alongside protons, organized in multiples of a fundamental unit.

In 1932, James Chadwick made a groundbreaking observation during the bombardment of a Beryllium nucleus with alpha particles, noting the emission of neutral radiation. At that time, the only known form of neutral radiation was photons or electromagnetic radiation. If this neutral radiation were composed of protons, the energy associated with photons would far exceed the energy available from bombarding Beryllium nuclei with alpha particles.

Chadwick proposed a revolutionary concept: the neutral radiation consisted of a novel type of neutral particles—neutrons. Through subsequent calculations, he demonstrated that the mass of a neutron closely approximates that of a proton. Presently, the accurately known mass of a neutron is denoted as $m_n = 1.00866u = 1.6749 \times 10^{-27} kg$, a value that is nearly equivalent to the mass of a proton.

Composition of Nucleus

A free neutron, in its standalone state, exhibits instability and undergoes decay into a proton, an electron, and an antineutrino—an elementary particle—with an average lifespan of approximately 1000 seconds. However, within the confines of a nucleus, a neutron is stable. Consequently, the constitution of a nucleus is expressed by the equation:

$$A = Z + N$$

Where:

- Z Represents the atomic number, denoting the quantity of protons,
- N Signifies the neutron number, indicating the count of neutrons, and
- A Stands for the mass number, representing the total tally of protons and neutrons.

Protons and neutrons collectively are referred to as nucleons. Consequently, the mass number (A) of an atom corresponds to the cumulative number of nucleons within it. An atomic nuclide is typically denoted as ${}^{A}{}_{Z}X$, with X being the chemical symbol of the atom.

Illustratively, the nuclide for gold is represented as ${}^{197}{}_{79}Au$, implying that there are 197 nucleons in the gold nucleus, consisting of 79 protons and 118 neutrons (calculated as 197-79).

Furthermore, the notation for deuterium is ${}^{2}{}_{1}H$, signifying one proton and one neutron, while tritium is denoted as ${}^{3}{}_{1}H$, indicating one proton and two neutrons.

Isobars and Isotones

Isobars are nuclides characterized by having the same mass number (A), despite differences in their atomic numbers (Z). For instance, consider isotopes $^{31}{}_{1}H$ and $^{32}{}_{1}H$, both falling under the category of isobars due to their shared mass number.

Isotones, on the other hand, represent nuclides possessing an identical number of neutrons (N), yet exhibiting distinct atomic numbers (Z). An illustrative example involves the isotones $^{198}{}_{80}Hg$ and $^{197}{}_{79}Hg$, where the neutron count remains constant at 118, while the atomic numbers differ.

Example.

In the realm of stable lithium isotopes, specifically $^{6}{}_{3}Li$ and $^{7}{}_{3}Li$, their respective abundances are documented as 7.5% and 92.5%. These isotopes carry individual masses of 6.01512 atomic mass units (u) and 7.01600 u, correspondingly. The task at hand is to determine the atomic mass of lithium.

Solution.

Mass of the first lithium isotope $^{6}{}_{3}Li = m_1 = 6.01512u$

Mass of the second lithium isotope $^{7}3Li = m_2 = 7.01600u$

Abundance of $^{6}{}_{3}Li = n_1 = 7.5\%$

Abundance of $^{7}{}_{3}Li = n_2 = 92.5\%$

The atomic mass (m) of lithium is

$m = (m_1n_1 + m_2n_2) / (n_1 + n_2)$

$= \{(6.01512u \times 7.5) + (7.01600u \times 92.5)\} / (7.5 + 92.5)$

$= 6.940934u$

Hence, the atomic mass of lithium is 6.940934u.