NUCLEI

MASS-ENERGY AND NUCLEAR BINDING ENERGY

MASS DEFECT

An observable variance has been identified between the anticipated mass and the observed mass of a nucleus. The anticipated mass ($M_{expected}$) is calculated as the sum of the products of the atomic number (Z) multiplied by the mass of a proton (m_p), and the quantity of neutrons ($A - Z$) multiplied by the mass of a neutron(m_n), expressed by the equation:

$$M_{expected} = Zm_p + (A - Z)m_n$$

Conversely, the observed mass ($M_{observed}$) is derived from the difference between the atomic mass (M_{atom}) and the product of the atomic number (Z) and the mass of an electron (m_e), as depicted by:

$$M_{observed} = M_{atom} - Z_{me}$$

Upon comparison, it has been established that $M_{observed}$ is less than $M_{expected}$. Consequently, the discrepancy between these values is quantified as the mass defect, denoted as Δm, calculated by subtracting the observed mass from the expected mass:

$$\Delta m = [Zm_p + (A - Z)mn] - [M_{atom} - Zm_e]$$

BINDING ENERGY

The binding energy of a nucleus is defined as the minimum energy needed to disassemble the nucleus into its individual constituent particles. Alternatively, it represents the energy released during the formation of a nucleus by bringing its constituent particles from infinite separation. Mathematically, the binding energy ($B.E.$) is expressed as $\Delta m \cdot c^2$, where Δm is the mass defect. This binding energy can be calculated in terms of atomic mass units (amu) and converted to energy using the conversion factor 931.5 MeV/amu. Thus, the binding energy (BE) can be given as:

$$BE = \Delta m \times 931.5MeV/amu$$

Simplified, this can also be expressed as:

$$BE = \Delta m \times 931MeV$$

This equation quantifies the amount of energy associated with the binding of nucleons within a nucleus.

Note:
The stability of a nucleus is closely associated with its binding energy per nucleon. Specifically, if the binding energy per nucleon for one nucleus ($B.E_1/A_1$) is greater than that for another nucleus($B.E_2/A_2$), then the former is considered to be more stable. In mathematical terms, if:

$\frac{B.E_1}{A_1} > \frac{B.E_2}{A_2}$

Then nucleus 1 is deemed to possess greater stability compared to nucleus 2. This relationship signifies that a higher binding energy per nucleon contributes to the enhanced stability of a nucleus.

Variation of binding energy per nucleon with mass number:

The trend in binding energy per nucleon exhibits an initial increase, on average, culminating in a maximum value of approximately 8.7 MeV for nuclei within the mass range of A. 50 to 80. Subsequently, for heavier nuclei, there is a gradual decrease in the binding energy per nucleon with increasing mass number (A). Notably, the nucleus with the maximum binding energy per nucleon is $_{26}Fe^{56}$, reaching a value of 8.8 MeV.

An interesting observation arises wherein the binding energy per nucleon is higher for medium-sized nuclei than for their heavier counterparts. Consequently, medium-sized nuclei demonstrate heightened stability. This trend suggests that heavier nuclei, inherently less stable, exhibit a propensity to undergo a process known as fission, wherein they split into medium-sized nuclei. Conversely, lighter nuclei, also possessing lower stability, tend to fuse together, forming a medium-sized nucleus. This fusion process is referred to as fusion. In summary, the stability of nuclei is influenced by their size, with medium nuclei exhibiting a higher binding energy per nucleon and, consequently, greater stability.