Nucleus

Nucleus of an atom consists of protons and neutrons collectively called nucleons.

Representation

$_{z}X^{A}$

A = mass number

Z = Atomic number

Nuclei can be

- Isotopes (same Z but different A)
- Isobars (same A but different Z)
- Isotones (same N but different A)

Radius of a Nucleus

$R = R_0 A^{\frac{1}{3}}$ { where $R_0 = 1 - 2$ fm}

Mass of nucleus is measured in atomic mass unit (u) or (amu)

1 amu (or u) = $\frac{1}{12}$ (mass of C^{12} atom) = 1.6×10^{-27} kg

Nuclear Density

$$\rho = \frac{\text{Nuclear mass}}{\text{Nuclear volume}} = \frac{mA}{\frac{4}{3}\pi R^3} = \frac{3m}{4\pi R^3_0}$$

Nuclear density is constant its value is nearly $2.29 \times 10^{17}\ kgm^{-3}$

Mass defect: The difference (Δm) between mass of constituent nucleons and nucleus is called mass defect of nucleus.

[Δm = sum of the masses of nucleons - mass of nucleus] = $\{Zm_p + (A - Z)m_n\} - M_n$

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Q-Value

$A + B \rightarrow C + D +$ Energy

$M_A \quad M_B \qquad m_C \quad m_D$

Reactants = product + Q- Value

Q value = B.E of product - B.E. of reactants

Q-value = $[(m_A + m_B) - (m_C + m_D)]\ c^2$

Q-value = $[(k.E_C + k.E_D) - (K.E_A + K.E_B)]$

Mass and energy

- Mass m of a particle is equivalent to energy given by $E = mc^2$
- Also known as rest mass energy.

Binding Energy Curve

- Nuclear force is a force which holds the nucleons together.
- For atomic number < 20, most stable nuclei have n:p ratio nearly 1:1.
- For atomic number > 83, there are no stable nuclei.
- A nucleus is stable when its Binding energy per nucleus value is around 8 MeV per nucleon or more.
- Following are observations from Binding energy per nucleon versus mass number curve.
- B.E. per nucleon is more for some nuclei than their neighbours.
- This indicates a shell type structure of nucleus.
- For 30 < A < 120, these are stable elements.

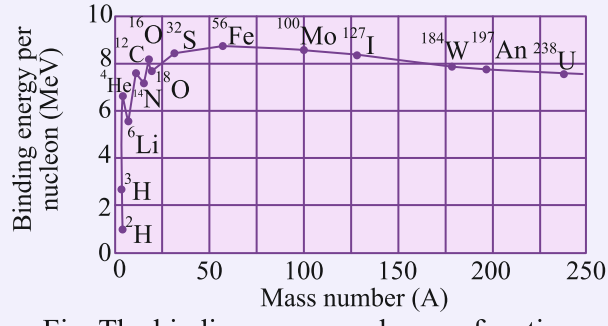


Fig. The binding energy order as a function of mass number

Binding Energy of Nucleus

$B \cdot E = (\Delta m)c^2$

$B \cdot E = [\{Zm_p + (A - Z)m_n\} - M]\ c^2$

(Where, c is the speed of light $c = 3 \times 10^8$ m/sec)

$$B\ E \text{ per nucleon} = \frac{B\ E}{\text{No. of nucleons}}$$

Binding energy is maximum for mass number 50-60.

Radio activity

Phenomenon of disintegration of heavy elements into comparatively lighter elements by emission of α, β, & γ radiations.

α - decay

- α– radiations are the helium nuclei. These are emitted as

$$^{A}_{Z}X \longrightarrow {}^{4}_{2}He + {}^{A-4}_{Z-2}Y$$

α-particle — Daughter nuclei

- highest ionizing power but least penetrating power.

β – decay

- Is two types: β+(positron) and β^-(electron)

$$_{Z}X^{A} \longrightarrow {}_{Z+1}Y^{A} + {}_{-1}e^{0} + \bar{\nu} + Q$$

(proton) (β– -particle)(antineutrino)

$$_{Z}X^{A} \longrightarrow {}_{Z+1}Y^{A} + {}_{1}e^{0} + \nu + Q$$

(proton) (positron β+) (neutrino)

- Less ionizing power than α-particle and moderate penetrating power.

γ - decay

$$_{Z}X^{A} \longrightarrow {}_{Z}X^{A} + \gamma$$

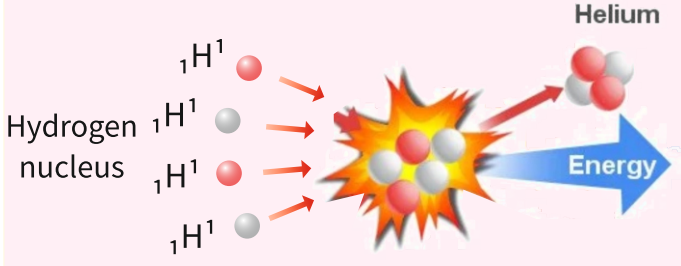
- γ -decay after an α or β - decay, nucleus vibrates with the energy shared by it & electromagnetic waves of very high frequency (α-radition) are emitted.
- Least ionizing power but highest penetrating power.

Nuclear energy

The process of energy generation from the nucleus is examined by the curve of binding energy per nucleon. From binding energy curve nuclei in the middle region $30 \leq A \leq 170$ are more tightly bound than nuclei with $A < 30$ and $A > 170$. Therefore, transformation of less stable nuclei into more stable nuclei, energy will be released. Fission and fusion are two such process.

Nuclear fusion

- Combining two lighter nuclei to form a heavy nucleus.
- Nuclear fusion is the source of energy in the sun and stars.



$$4\,_1H^1 \rightarrow {}_2He^4 + 2e^- + 2\nu + 6\gamma + 26.7\ \text{MeV}$$

Nuclear fission

- Splitting of a heavy nucleus into two or more lighter nuclei.
- Uncontrolled chain reaction: principle of atomic bank.
- Controlled chain reaction: principle of nuclear reactors.