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Nuclear Physics

Ques-1 explain the liquid drop model and compare with shell model

Liquid drop model : given by Neils Bohr in 1937. According to this model, nucleus was compared with a liquid drop. The similarities between the nucleus and liquid drop are -

- Both of them contain a large number of particles
- They are both homogenous and incompressible
- each nucleon in the nucleus is interacting solely with its nearest neighbours just like the molecules in a liquid which ideally move while maintaining a fixed intermolecular distance.

$$\boxed{\text{volume energy } E_V = a_1 A}$$

The no. of surface nucleons depends on the surface area of nucleus

$$4\pi R^2 = 4\pi R_0^2 A^{2/3}$$

$$\boxed{\text{surface energy } E_s = -a_2 A^{2/3}}$$

The electric repulsion between each pair of protons in a nucleus also contributes toward decreasing its binding energy

$$V(\text{potential energy}) = \frac{-e^2}{4\pi\epsilon_0 r}$$

since $z(z-1)/2$ pair of protons

$$E_c = \frac{z(z-1)}{2} V = \frac{-z(z-1)e^2}{8\pi\epsilon_0} \left(\frac{1}{r}\right)_{avg}$$

$$\boxed{\text{coloumb energy} = E_c = \frac{-z(z-1)a_3}{A^{1/3}}}$$

comparison between liquid drop model and shell model →

① Liquid drop model treats the nucleus as a liquid, the nuclear shell model is similar to the atomic model where electrons arrange themselves into shells around the nucleus.

② Nuclear properties such as the binding energy are described in terms of volume energy, surface energy and coulomb energy. The shell structure is due to the quantum nature of electrons.

Ques-2 For the following nuclear reaction

$$ {}_{92}U^{238} \longrightarrow {}_{90}Th^{234} + {}_{2}He^{4} $$

calculate -

1) the total energy released in the reaction

2) the KE of α particle, assume the nucleus being at rest initially given that mass of -

$$ U^{238} = 238.12492u $$
$$ Th^{234} = 234.11650u $$
$$ He^{4} = 4.00387u $$

(1) $$ {}_{92}U^{238} \longrightarrow {}_{90}Th^{234} + {}_{2}He^{4} $$

$$ Q = \left(m_{U^{238}} - m_{Th^{234}} - m_{He^{4}} \right) \times 931.5 \text{ MeV}/u $$

$$ = 0.00455 \times 931.5 $$

$$ \boxed{Q = 4.2383275 \text{ MeV}} $$

↳ total energy released

(2) $$ m_{Th} V_{Th} = M_{He} V_{He} $$ (conservation of momentum)

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$$V_{th} = \frac{m_{He} \cdot V_{He}}{m_{th}} = \left(\frac{4.00387}{234.1165}\right) V_{He} \quad \text{— (1)}$$

$$4.238325 = \frac{1}{2} m_{th} V_{th}^2 + \frac{1}{2} m_{He} V_{He}^2 \quad \text{— (2)}$$

$$\boxed{V_{He}^2 = 2.08151}$$

$$\text{KE of } \alpha \text{ particle} = \frac{1}{2} m_{He} V_{He}^2$$

$$= \frac{1}{2} \times 4.00387 \times 2.08157$$

$$= 4.16704 \text{ MeV}$$

Ques-3 Define binding energy of nucleus. Sketch the BE per nucleon versus mass no curve and mention the important things (findings) of the curve.

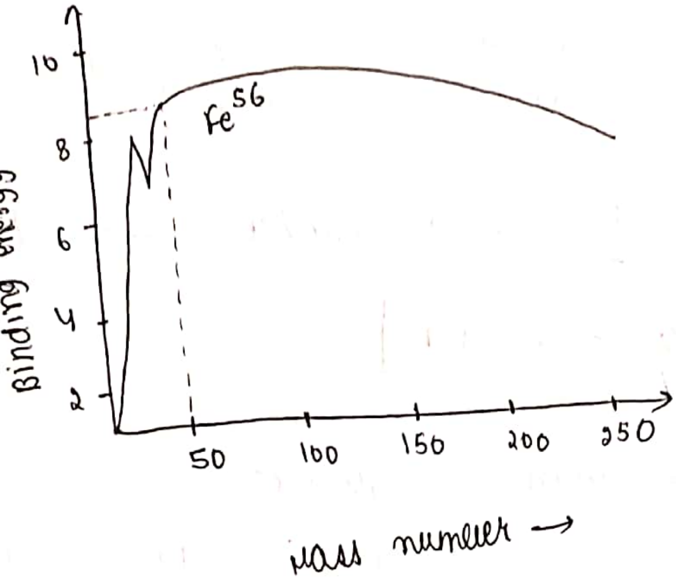
- The binding energy of a nucleus is defined as the energy required to break the nucleus into its constituent nucleons apart such that they do not interact with each other.

- The binding energy of nucleus is a measure of its stability; ↑ the energy more stable is the nucleus

- There is always a difference between the mass of a nucleus and the sum of masses of its nucleons, often called the mass defect.

$$E = \Delta m c^2$$

$$E_b = \left[Z m_p + N m_n - m\, {}^{A}_{Z}X\right] c^2$$



Conclusions.-

- For low atomic mass number $(A<20)$, the binding energy per nucleon is very low. This decrease in (E_b/A) occurs because almost all nucleons in a nucleus are close to the surface and surface energy is more negative

- For most nuclei, the binding energy per nucleon is close to 8 MeV with max. (E_B/A) of 8.8 MeV for iron (Fe^{56}). such nuclei are not stable.

Ques-4 Define Q value of a nuclear reaction, Explain its physical significance. For the fission curve, calculate the Q value of reaction

$${}_1H^2 + {}_1H^3 \longrightarrow {}_2He^4 + {}_0n^1$$

The Q value for a reaction is the amount of energy absorbed or released during the nuclear reaction.

$$\boxed{Q = (m_i - m_f - m_x)c^2}$$

mass of initial nucleus; mass of final nucleus; particle mass

$${}_1H^2 + {}_1H^3 \rightarrow {}_2He^4 + {}_0n^1$$

$$Q = (2.01355 + 3.01604 - 4.0026 - 1.00866) \times 931.5$$

$$= 17.67439 \text{ Mev}$$

Ques-5 What is thermonuclear fusion? Explain proton-proton cycle and the carbon-nitrogen cycle for thermonuclear fusion.

Nuclear fusion is the process in which two or more lighter nuclei fuse to form a single stable and heavy nucleus

Q is the energy released in the process. The difference in the mass of reactant and product is due to the tremendous amount of energy released.

Condition for nuclear fusion -

The fusion reaction takes place under the conditions of extremely high temperature and pressure. This is necessary so that protons have high enough kinetic energy to overcome their mutual repulsion and to come closer than the range of nuclear force.

Two types of thermonuclear reactions have been proposed. These are - (1) Proton-proton cycle (2) carbon-nitrogen cycle

Proton - proton cycle

It is so called because the first step involves the combination of two protons (or hydrogen nuclei). Together they produce a deutron -

$${}_1H^1 + {}_1H^1 \longrightarrow {}_1D^2 + {}_1e^0 + \nu + Q_1 \quad \times 2$$

The neutron then combines with another proton to yield helium

$${}_1D^2 + {}_1H^1 \longrightarrow {}_2He^3 + Q_2 \quad \times 2$$

The two helium -3 nuclei fuse together to produce

$${}_2He^3 + {}_2He^3 \longrightarrow {}_2He^4 + 2{}_1H^1 + {}_1e^0 + Q_3$$

The value of $\boxed{Q = 26.7\ \text{Mev}}$

carbon - nitrogen cycle

In this cycle, carbon acts as a nuclear catalyst. It consists of the following reactions.

formation of ${}_7N^{13}$ takes place -

$${}_6C^{12} + {}_1H^1 \longrightarrow {}_7N^{13} + Q_1$$

The product ${}_7N^{13}$ is radioactive with half life of 10min

$${}_7N^{13} \rightarrow {}_6C^{13} + {}_1e^0 + \nu + Q_2$$

$${}_6C^{13} + {}_1H^1 \longrightarrow {}_7N^{14} + Q_3$$

$${}_7N^{14} + {}_1H^1 \longrightarrow {}_6O^{15} + Q_4$$

$${}_6O^{15} \rightarrow {}_6N^{15} + {}_1e^0 + \nu + Q_5$$

Finally, ${}_7N^{15}$ reacts with the fourth proton as -

$${}_7N^{15} + {}_1H^1 \longrightarrow {}_6C^{12} + {}_2He^4 + Q_6$$

$$\boxed{4\,{}_1H^1 \longrightarrow {}_2H^4 + 2{}_1e^0 + Q}$$

$Q \rightarrow 26.7\ \text{Mev}$

Ques-7 The half life of radium is 1500 years. In how many years will 1gm of pure radium

(a) lose 1mg

(b) Reduced to 10mg

$t_{1/2} = 1500 yrs$ $\lambda = \frac{0.693}{t_{1/2}} = \frac{0.693}{1500}$

$N_0 = 1gm$ $-N + N_0 = 0.001$

$N = 0.999$

$0.999 = 1.e^{-\lambda t}$

$t = \frac{1 \times 1500}{\ln\left(\frac{1000}{999}\right)} = 2.165 years$

(b) $\lambda = 0.693/1500$

$N_0 = 1g$ $N = 0.01g$

$0.01 = 1.e^{-\lambda t}$

$\ln 100 = 4.6051 = \lambda t$

$\boxed{t = 9967.53 years}$

Ques-8 The atomic ratio between uranium isotopes U^{238} and U^{234} in a mineral sample is found to be 1.8×10^4. The half life of U^{234} is 2.5×10^5 years. Find the mean life of U^{238}

$\frac{N(U^{238})}{N(U^{234})} = 1.8 \times 10^4$ $t_{1/2} = 2.5 \times 10^5$

$\lambda_1 N_1 = \lambda_2 N_2$

$\frac{N(U^{238})}{N(U^{234})} = \frac{\lambda(U^{234})}{\lambda(U^{238})}$

$\lambda(U^{234}) = \frac{0.693}{t_{1/2}} = \frac{0.693}{2.5 \times 10^5}$

$$\lambda(U^{238}) = \frac{0.693}{2.5\times10^{5}\times1.8\times10^{4}}$$

$$t_{1/2} = 2.5\times1.8\times10^{9}$$

$$\boxed{\tau(\text{mean life}) = 1.44\times t_{1/2} = 6.48\times10^{9}}$$

Ques-9 How nuclear reactions are different from chemical reactions?

NUCLEAR REACTION	CHEMICAL REACTION
1) Nuclear reactions involve a change in atom's nucleus, usually producing a different element, along with emission of radiations like α, β, γ etc. so nuclear reaction is nuclear phenomenon	chemical reactions involve only a rearrangement of electrons and do not involve changes in the nuclei. chemical reaction is extra nuclear phenomenon.
2) The nuclear chemistry vary greatly from each other for different isotopes.	The different isotopes of an element normally behave similarly as their extra nuclear electronic configurations are same.
3) Hardly any nuclear reactions take place in the normal circumstances. This is because nuclei being positively charged, the coloumbic repulsion prevent them to come close enough for nuclear reaction to occur.	chemical reactions occur naturally and abundantly. This is because for two atoms or molecules to react chemically, they only need to come to each other so that their outer electrons overlap, which is possible at NTP.
4) Rates of nuclear reactions are spontaneous and are unaffected by such factors.	Rates of chemical reactions are influenced by external effect like temperature, pressure and catalyst

Ques-10 Write a short note on nuclear reactor, explaining the main reactions.

In a nuclear reactor, a controlled self-sustaining chain reaction of nuclear fission takes place producing a large amount of heat energy. Nuclear reactors are used for following purposes -

1) to generate electrical power
2) to produce radioactive isotopes which are used in the fields of medicine, agriculture etc.
3) to produce bomb grade missile materials like Pu^{239}
4) Research

Release of significant amounts of energy from nuclear fission requires a chain reaction. For the buildup of chain reaction, each generation must have more fission events than the preceding ones. This means that the average number of neutrons produced in a fission event must be significantly greater than unity.

This excess is necessary because some neutrons will be lost, instead of inducing fission in the next generation.