INDEX

NUCLEAR PHYSICS

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Chapter 1

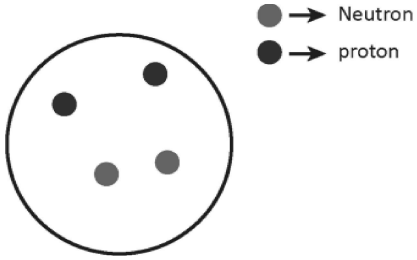
Basic Property of Nuclei

Basic properties of Nucleus

Nuclear physics is the field of physics that studies the constituents of matter (protons and neutrons) and interactions between them.

Structure of Nuclei:-

Inside the nucleus proton (z) and Neutron are present.



⇒ Sum of Number of proton $(z)R$ neutron (N) is known as Mass No (A).

$$A = N + Z$$

⇒ Neutron No $N = A - Z$

⇒ **Nucleus:-** Concept of Nucleus was introduced by Rutherford by scattering Experiment.

Nucleus is central part of atom which contain most of the weight of atom.

• Inside the Nucleus two type of force exist one is Nuclear force between (P-P, n-n & P-n) & other is Electrostatic force (P-P)

Properties of Nuclear force:

1. It is Attractive in Nature.
2. Strongest force.
3. It is short Range force.
4. It acts between (P-P, n-n & p-n) So, it is charge independent.
5. Nuclear force is spin dependent.
6. It is Non-Central in Nature.

Study of Nuclear property:-

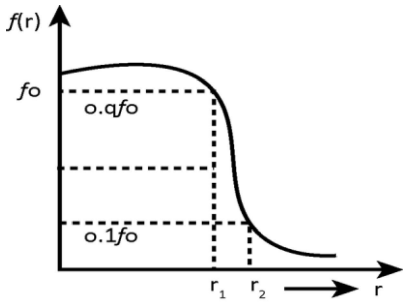
Nuclear properties can be studied by two ways

(i) *Scattering of charge particle:*
It gives information about distribution inside the Nucleus.

(ii) Scattering of Neutral particles:
It gives information about mass distribution inside the Nucleus.

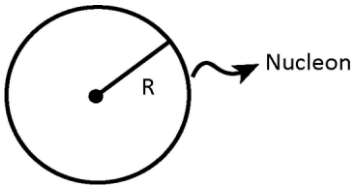
From these Experiment it is conclude that charge & No. density inside the Nucleus is almost constant.

Experimental Plot:



$f = \frac{f_0}{e^{k(r-r_0)}+1}$

& $f(r) = \{f_0 r \le R 0 r > R$



$f =$ constant

$\Rightarrow \frac{No.\ of\ Nucleon}{V} = constant$

$\Rightarrow \frac{A}{\frac{4}{3}\pi R^3} = constant$

$\Rightarrow R = R_0 A^{\frac{1}{3}}$

$A =$ *Mass No*

$R_0 = 1.2\ fm (1\ fm = 10^{-15} m)$

$R = Radius\ of\ Nucleus$

Nuclear Density:-

No. density $= \frac{No.of\ Nucleons}{Volume}$

$= \frac{A}{\frac{4}{3}\pi R^3}$

$= \frac{A}{\frac{4}{3}\pi R_0^3 A}$

$= \frac{3}{4\pi(1.2\times10^{-15})^3}$

$\simeq 10^{44}\ Nucleon/Volume$

Nuclear Mass Density:

$$N.Mass\ density = \frac{Mass}{Volume}$$

$= \frac{No.\ of\ Nucleons}{Volume} \times mass\ of\ one\ Nucleon$

$= 10^{44} \times 1.67 \times 10^{-27}$

$= 10^{17}\ kg/m^3$

Electric field inside Nucleus

$$E = \int \frac{KQr}{R^3}$$

$$\frac{KQ}{r^2}$$

$$Q = Ze \sim \frac{A}{2}e$$

$$r < RR = R_0 A^{\frac{1}{3}}$$

$$E = \frac{kAer}{2R_0^3 A}$$

$$E = \frac{Ker}{2R_0^3}$$

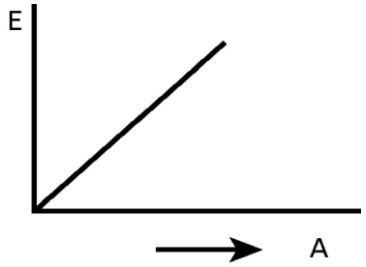
Independent of A

Almost in all Nuclei field inside is almost same.

$$r > R$$

$$E = \frac{KQ}{r^2}$$

$$E = \frac{KAe}{2r^2}$$



Ratio of Electrostatic Energy of two Nuclei having Mass No $A_1 A_2 \& Z_1 Z_2$

$$U = \frac{3}{5}\frac{KQ^2}{R}$$

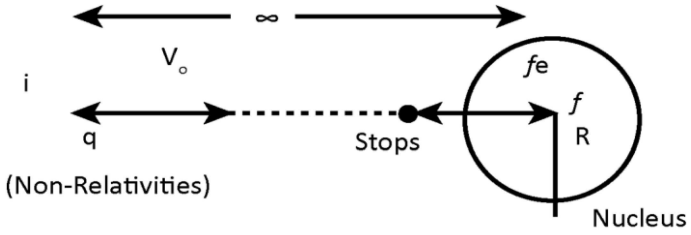
$$Q = Ze$$

$$R = R_0 A^{\frac{1}{3}}$$

$$U = \frac{3}{5}\frac{Z^2 e^2}{R_0 A^{\frac{1}{2}}}$$

$$\frac{u_1}{u_2} = \left(\frac{Z_1}{Z_2}\right)^2 \left(\frac{A_2}{A_1}\right)^{\frac{1}{3}}$$

Min Distance of approach of a $+ve$ charge directly thrown a Nucleus.



Let a positively charge particle thrown from very large distance towards the nucleus and it stopped at distance d from centre of nucleus, this distance is known as Distance of min approach.

Lets calculate it.

$$V = \frac{kq_1 q_2}{r}$$

$$d_{min} = Min\ dis\ of\ approach$$

Using Cons. of Energy

$$(K.E. + P.E.)_i = (K + P.E.)_f$$

$$= \frac{1}{2}mv_0^2 + \frac{kq_1q_2}{\infty} = 0 + \frac{kqze}{d_{min}}$$

$$\Rightarrow d_{min} = \frac{kzeq}{\frac{1}{2}mv_0^2}$$

$$k = \frac{1}{4\pi\ \epsilon_r}$$

$$d_{min} = \frac{2kq}{mv_0^2}$$

$$d_{min} = \frac{qZe}{2\pi\ \epsilon_0\ mv_0^2}$$

Nuclear Mass density:-

$$N.mass\ density = \frac{Mass}{Volume}$$

$$= \frac{No.\ of\ Nucleon}{Volume} \times mass\ of\ one\ Nucleon$$

$$= 10^{44} \times 1.67 \times 10^{-27}$$

$$= 10^{17}\ kg/m^3$$

Isotopes:-

Nuclei with same atomic Number z, but different mass no. A are called isotopes.

Ex. $1\ H^1 \cdot 1\ H^2 \cdot 1\ H^3$

Isobars:-Nuclei with same mass no. A but different Atomic no. are called Isobars.

Ex. $O_8^{16} \& N_7^{16}$

Isotones:-

Nuclei with same number of Neutrons N are called isotones.

Ex. $Na_{11}^{23} \& C_6^{13}$

Binding Energy:-

The energy required to separate all Nucleon (P.H.) from Nucleus is known as Binding Energy.

Suppose you have one proton (m_p) & Neutron (m_n) separately and now you are making Nucleus from it. Then rest mass energy of Nucleus is less than the sum of Rest less energy of proton & Neutron.

$$m_nC^2 < \left(zm_p + (A-Z)m_n\right)C^2$$

& this Difference is known as Binding Energy.

Mathematically:-

$$B.E. = [zm_P + (A-z)m_n - m_n]C^2$$

$\Delta m = zm_p + (A-z)m_n - m_n$ is known as mass defect.

But we measure mass of Nucleus so we convert this Relation in Atomic mass.

$$B.E. = \left[zm_p - zm_e + (A-z)m_n - (m_n + zm_e)\right]e^2$$

$$= \left[z\left(m_p + m_e\right) + (A-z)m_n - m(A,z)Atomic\right]c^2$$

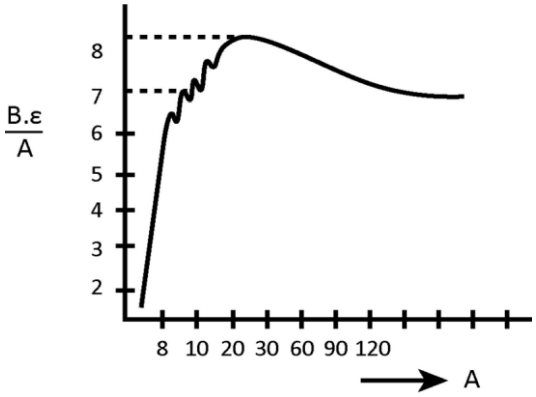
$$B.E. = [zm_H + (A-z)m_n - m(A,z)Atomic]c^2$$

If masses are given in amv.

$$|a.m.v = 931.5\ MeV|c^2$$

$$\Rightarrow B.E. = \Delta m \times 931.5 \frac{MeV}{c^2} c^2$$

$$= B.E. = \Delta m \times 931.5\ MeV$$



Special features of graph:-

(i) B.E. is very small for lighter Nuclei & goes on increasing rapidly with increasing A & reaches to maximum value for Fe v 8 MeV / A.

(ii) The variation in B.E. is very slight in the mass number for $20 < A < 180$& in this Region B.E. curve saturated. We can say it is independent on mass no.

(iii) Energy will Release in Both fusion & fission process.

Separation Energy:-

The energy required to separate one nucleon form nucleus is known as separation energy

Proton Separation Energy:-

Energy required proton form nucleus is known as proton separation energy

$$X_Z^A \rightarrow Y_{Z-1}^{A-1} + P$$

$$S_p = [M(A-1, Z-1) + m_P - M(A, Z)]c^2$$

Neutron separation energy

The energy required to separate neutron form nucleus is known as neutron separation energy

$$X_Z^A \rightarrow X_Z^{A-1} + \eta$$

$$S_n = [M(A^{-1}, Z) + m_n - M(X_Z^A)]c^2$$

Q-Value:-

The energy change during the Reaction is known as Q-value.

$$A_{\downarrow m_A} + B_{\downarrow m_B} \rightarrow C_{\downarrow m_C} + D_{\downarrow m_D}$$

$$\Rightarrow Q = \left[\sum m_R - \sum m_P\right] c^2$$

$$Q = [m_A + m_B - m_c - m_o]c^2$$

$$\Rightarrow Q = \left[\sum m_R - \sum m_P\right] c^2$$

$$Q = [m_A + m_B - m_C - m_O]c^2$$

$$Q = [B.E._P - B.E._R]$$

$$Q = [K.E_p - K.E._R]$$

P: Product

R: Reactant

Mass Defect:

Difference between measured atomic mass & mass no known as mass defect.

$$\Delta M = m(A,Z) - A$$

Packing fraction:-

Mass defect per nucleon is known as packing fraction.

$$f = \frac{\Delta m}{A} = \frac{m(A,Z) - A}{A}$$

$$f = \frac{\Delta m}{A} = \frac{m(A,Z) - A}{A}$$

$\Rightarrow f = \frac{m(A,z)}{A} - 1$

$\Rightarrow Af = m(A,Z) - A$

$\Rightarrow m(A,z) = Af + A$

$\Rightarrow m(A,Z) = A(f+1)$

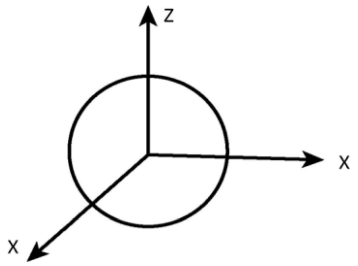
Nuclear comparison & its stability:-

Z	N	Type
Even	Even	Most stable (He_2^4)
Even	Odd	Moderate
Odd	Even	
Odd	Odd	Least stable

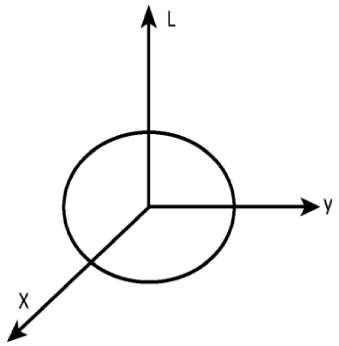
Electric Quadrupole moments:-

Charge distribution consider _____

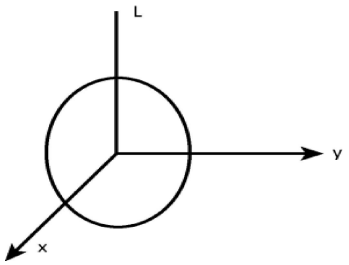
Case I: If $Q = 0 \Rightarrow$ spherical shape



Case 2: If $Q < 0$ then problate



Case 3: If $Q > 0$ then oblate



Quadrupole moment is define as $Q = \int \quad P(r)\left(3x_i x_j - r^2 s_{ij}\right)dz$

Quadrupole moment is a tensor quality of Rank 2nd.

So Q.M.

$$Q = \left|Q_{11}Q_{12}Q_{13}Q_{21}Q_{22}Q_{23}Q_{31}Q_{32}Q_{33}\right|$$

$$Q = [3x^2 - r^2 3xy 3xz 3yx 3y^2 - r^2 3yz 3zx 3zy 3z^2 - r^2]$$

Now, $Q_{22} = Q_{33} = 3z^2 - r^2$

Case I. If $3z^2 = r^2$

Then $Q = 0$

$3z^2 = x^2 + y^2 + z^2$

$2z^2 = x^2 + y^2$

$z^2 = x^2 + y^2$

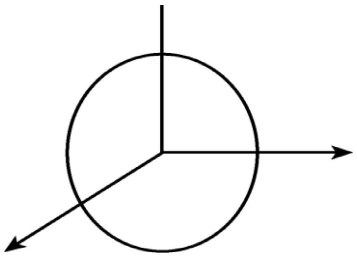
So $x^2 = y^2 = z^2$

Case II. If $3z^2 > r^2$

Then $Q_{2z} > 0$

$3z^2 \times x^2 + y^2 \times z^2$

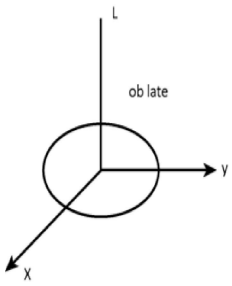
$\Rightarrow 2z^2 = x^2 + y^2$



Case III. If $3z^2 < r^2$ then $Q_{22} < 0$

$3z^2 < x^2 + y^2 + z^2$

$\Rightarrow 2z^2 < x^2 + y^2$



SOLVED EXAMPLE

1. Radius of $^{2}_{1}H$ can be estimated to be1.2×10^{-13}cm. Then the radius $^{16}_{8}O$ is
(a) 8.6×10^{-10}cm (b) 5.2×10^{-13}cm
(c) 2.4×10^{-13}cm (d) 8.6×10^{-13}cm
Solution: (c)
Radius of $^{1}_{1}H$ - 1.2×10^{-13}cm
$R = R_0 A^{\frac{1}{3}}$
$\frac{R_H}{R_0} = \left(\frac{A_H}{A_0}\right)^{\frac{1}{3}} = \left(\frac{2}{16}\right)^{\frac{1}{3}} = \frac{1}{2}$
$R_0 = 2 \times R_H = 2 \times 1.2 \times 10^{-13}$
$R_0 = 2.4 \times 10^{-13}$cm.

2. Radius of $^{1}_{1}H$ is 1.2×10^{-13}cm. Then radius of $^{8}_{4}Be$
(a) 2.86×10^{-13}cm (b) 5.2×10^{-13}cm
(c) 4.8×10^{-13}cm (d) 2.4×10^{-13}cm
Solution: (d)
Radius of $^{1}_{1}H$ - 1.2×10^{-13}cm
$R = R_0 A^{\frac{1}{3}}$
$\frac{R_H}{R_{Be}} = \left(\frac{A_H}{A_{Be}}\right)^{\frac{1}{3}} = \left(\frac{1}{8}\right)^{\frac{1}{3}} = \frac{1}{2}$
$R_{Be} = 2 \times 1.2 \times 10^{-13} = 2.4 \times 10^{-13}$cm.

3. If nuclear radius of $^{4}_{2}He$is 3.6fm, then approx. nucleon radius of $^{256}_{100}Fm$ in fm
(a) 14.4 (b) 13.6
(c) 12.4 (d) 11.2
Solution: (a)
Radius of $^{4}_{2}He -$ 3.6fm
$R = R_0 A^{\frac{1}{3}}$
$\frac{R_{He}}{R_{Xe}} = \left(\frac{A_{He}}{A_{Xe}}\right)^{\frac{1}{3}} = \left(\frac{4}{256}\right)^{\frac{1}{3}} = \frac{1}{(64)^{\frac{1}{3}}} = \frac{1}{4}$
$R_{Xe} = 4 \times R_{Xe} = 4 \times 3.6$fm
$R_{Xe} = 14.4$fm.

4. An $^{8}_{4}Be$ nucleus in spherical has a charge radius R and volume $V = \frac{4}{3}\pi R^3$. According to empirical observation of charge radius the volume of $^{64}_{24}Cu$nucleus will be
(a) 2 (b) 4
(c) 8 (d)16
Solution: (a) Radius of $Be = R_0 A_{Be}^{\frac{1}{2}}$
$R_{Cu} = R_0 A_{Cu}^{\frac{1}{3}}$
$\frac{R_{Be}}{R_{Cu}} = \left(\frac{A_{Be}}{A_{Cu}}\right)^{\frac{1}{3}} = \left(\frac{8}{64}\right)^{\frac{1}{3}}$
$R_{Cu} = 2R_{Be}$

5. A nucleus with A=90 splits up into two nuclei whose radii are in ratio 2:1 then their mass no with
(a) 80,10 (b) 70,20
(c) 75,15 (d) 10,100
Solution: (a)
$A \rightarrow A_1 + A_2$
$A_1 + A_2 = 90$
$\frac{A_1}{A_2} = \left(\frac{R_1}{R_2}\right)^3 = (2)^3 = 8$
$A_1 = 8A_2$
$A_1 + A_2 = 9A_2 = 90$
$A_2 = 10$

6. The radius of Xe nucleus is measured to be twice the radius of$^{16}_{8}O$. How many nucleons are there in Xe nucleus?
(a) 128 (b) 72
(c) 82 (d) 86
Solution: (a)
Radius of $O \times 2 =$ Radius of Xe
$2R_O = R_{Xe}$
As $R = R_O A^{\frac{1}{3}}$
$\frac{R_0}{R_{Xe}} = \left(\frac{A_O}{A_{Xe}}\right)^{\frac{1}{3}} = \frac{1}{2}$
$\frac{A_O}{A_{Xe}} = \frac{1}{8}$
$A_{Xe} = 8A_O$
$= 8 \times 16$
$A_{Xe} = 128$

7. The ratio of nuclei of $Cu^{64}$and Te^{125} is:
(a) $\frac{2}{1}$ (b) $\frac{3}{2}$
(c) $\frac{5}{4}$ (d) $\frac{4}{5}$
Solution: (d)
As $R = R_O A^{\frac{1}{3}}$
$\frac{R_{Cu}}{R_{Al}} = \left(\frac{A_{Cu}}{A_{Te}}\right)^{\frac{1}{3}} = \left(\frac{64}{125}\right)^{\frac{1}{3}} = \frac{4}{5}$
$\frac{R_{Cu}}{R_{Te}} = \frac{4}{5}$

8. $^{16}_{8}O$and $^{16}_{7}N$ are:
(a) isotones (b) isobars
(c) isotopes (d) mirror nuclei
Solution: (b)
As above two atoms has same number of nucleons in their nucleus, thus isobars.

9. The stable nucleus that has half the radius of $^{128}_{54}\mathrm{Xe}$ nucleus is,
   (a) Be^{8} (b) O^{16}
   (c) He^{4} (d) N^{14}
   Solution: (b)
   $\text{Radius of x} = \frac{1}{2} \times \text{Radius of Xe}$
   $\frac{\mathrm{R_x}}{\mathrm{R_{Xe}}} = \frac{1}{2}$
   $\text{As } \mathrm{R} = \mathrm{R_O A^{\frac{1}{3}}}$
   $\frac{\mathrm{R_x}}{\mathrm{R_{Xe}}} = \left(\frac{\mathrm{A_x}}{\mathrm{A_{Xe}}}\right)^{\frac{1}{3}} = \frac{1}{2}$
   $\frac{\mathrm{A_x}}{\mathrm{A_{Xe}}} = \frac{1}{8}$
   $\mathrm{A_x} = \frac{1}{8}\mathrm{A_{Xe}} = \frac{1}{8} \times 128 = 16$
   Thus $\mathrm{A} = 16 \Rightarrow \mathrm{O}^{16}$

10. The ratio of nuclei of $^{1}_{1}\mathrm{H}$ and $^{8}_{4}\mathrm{Be}$ is:
   (a) 2/1 (b) 1/2
   (c) 4/3 (d) 4/1
   Solution: (c)
   $\frac{\mathrm{R_H}}{\mathrm{R_{Be}}} = \left(\frac{\mathrm{A_H}}{\mathrm{A_{Be}}}\right)^{\frac{1}{3}} = \left(\frac{1}{8}\right)^{\frac{1}{3}} = \frac{1}{2}$
   $\frac{\mathrm{R_H}}{\mathrm{R_{Be}}} = \frac{1}{2}$

11. For the shape of prolate spheroid
   (a) $\mathrm{Q} = 0$ (b) $Q > 0$
   (c) $Q < 0$ (d) none of the above.
   Solution: (b)
   As quadrupole moment defines shape
   $\mathrm{Q} = 0 \rightarrow \text{spherical}$
   $Q > 0 \rightarrow prolate$
   $Q < 0 \rightarrow oblate$

12. For a nucleus to possess quadrupole moment:
   (a) $\mathrm{I} = 0$
   (b) $\mathrm{I} = \frac{1}{2}$
   (c) $\mathrm{I} > \frac{1}{2}$
   (d) spherical shape of nucleus.
   Solution: (c)
   If nuclear spin is less than half its quadrupole moment is zero.

13. Which of following is NOT TRUE for nuclear forces?
   (a) short range forces
   (b) charge dependent
   (c) strongest known forces in nature
   (d) spin dependent
   Solution: (b)
   Nuclear forces are independent of charges. Forces between proton and proton are same as between proton and neutrons hence charge independent.

14. Experimental evidence for energy levels in nuclei is :
   (a) equality of binding energy of mirror nuclei H^1 and He^3
   (b) continous energy spectrum in beta decay
   (c) discrete energy specimen in alpha decay
   (d) different scattering lengthd for spin triplet and spin singlet scattering
   Solution: (c)
   After observing alpha decay to be of discrete energy it was concluded that energy levels exist.

15. Two protons are placed at a distance of about 10^{-13} cm from each other. The ratio of strength of strong and electromagnetic forces between them is roughly
   (a) 10 (b) 1
   (c) 10^{3} (d)10^{-3}
   Solution: (c)
   Strong forces are 1000 times stronger than electromagnetic forces.

CSIR NET PYQ

[NET/JRF (DEC-2019)]

1. The strong nuclear force between a neutron and a proton in a zero orbital angular momentum state is denoted by $F_{np}(r)$, where r is the separation between them. Similarly, $F_{nn}(r)$ and $F_{pp}(r)$ denote the forces between a pair of neutrons and protons, respectively, in zero orbital momentum state. Which of the following is true on average if the inter-nucleon distance is $0.2\ fm < r < 2\ fm$?
   (a) F_{np} is attractive for triplet spin state, and F_{nn}, F_{pp} are always repulsive
   (b) F_{nn} and F_{np} are always attractive F_{pp} is repulsive in the triplet spin state
   (c) F_{pp} and F_{np} are always attractive F_{nn} is always repulsive
   (d) All three forces are always attractive
   Solution:- (b)
   We know that, nucleon-nucleon spin interaction potential is of the form $\vec{S}_1 \cdot \vec{S}_2\, V(r)$.
   As, $S^2 = (\vec{S}_1 + \vec{S}_2) \cdot (\vec{S}_1 + \vec{S}_2)$