14-9-19

UNIT - IV

NUCLEAR PHYSICS

Contents :-

S.A.Q
⇒ Nuclear Constituents.

S.A.Q
⇒ Basic properties of Nucleus

L.A.Q
⇒ Impossibility of an electron being in the nucleus as the Consiquence of the uncertainity principle.

→ Nuclear models :-

L.A.Q
⇒ liquid drop model

L.A.Q
⇒ Semi emperical mass formula

S.A.Q L.A.Q
⇒ Nuclear shell model.

⇒ Radio Active decay :-

⇒ α - decay

⇒ Basics of α-decay process.

⇒ Theory of α-emission

⇒ Gamo's factor

⇒ Geiger nuttal law

⇒ α-decay Spectroscopic.

17-9-19

* Nuclear structure :-

The atomic nucleus was discovered in 1911 by Rutherford.

⇒ α-particles and gold atom interaction lead to discover charge of the nucleus and existence of nucleus and its structure.

* Nucleus :-

The atom of any element (elementary particle) Consist of Central Core Called Nucleus.

⇒ The atomic nuclei made up of elementary particles Called proton and neutrons.

⇒ A proton has a +ve charge of Same magnitude as that of electrons.

⇒ Nutrons are electrically nuetral.

⇒ Protons and neutron are Considered to different charge states of Same particle Called Nucleon. A Species of nucleus is Called nucleoid.

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Mathematically represented as X,

where X = name of the atom.

Z = Atomic number

A = Atomic mass.

Z = no. of proton = no. of electron.

A = no. of proton + no. of neutrons

no. of nutrons = A − Z.

Example :- $_{1}H^{1}$ $_{17}Cl^{35}$

$_{1}H^{1}$ = Z = 1

A = 1

X = no. of neutrons = A − Z = 1 − 1 = 0.

$_{17}Cl^{35}$ = Z = no. of protons = no. of electrons = Z = 17.

A = 35 = no. of protons + no. of neutrons

no. of neutrons A − Z = 35 − 17 = 18.

⇒ No. of neutrons in any atom few greater than no. of protons or no. of electrons.

⇒ $_{6}C^{12}$ Considered as a reference for identifying mass of the element.

⇒ All the nuclei of the given element do not necessarily have equal no. of nutrons.

⇒ The mass of the nuclei is specified in unified atomic mass unit 1amu = 1U in a mass scale of the $_6C^{12}$ atom.

⇒ For nutral hydrogen $_1H^1$ (1 proton, 1 electron, 0 neutron) 1·007825 amu or 1·007825 u

$$1\ amu = 1{\cdot}67353 \times 10^{-27}\ kg.$$

$$1u = \frac{1{\cdot}67353 \times 10^{-27}}{1{\cdot}007825} = 1{\cdot}66054 \times 10^{-27}\ kg.$$

energy ≈ 931·47 Mev = 1u.

⇒ Some other particles at list mass in case of electron mass is $9{\cdot}1094 \times 10^{-21}$ kg.

1 amu = 0·00054858.

energy ≈ 0·511 mev/c^2 = 1U

⇒ for proton $1{\cdot}67262 \times 10^{-27}$ kg

amu = 1·007276.

energy ≈ 938·27 mev/c^2 = 1U

⇒ for neutron $1{\cdot}67493 \times 10^{-27}$

amu = 1.008665

energy ≈ 939·57 mev/c^2 = 1U.

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$_1H^1 = 1.67353 \times 10^{-27}$ Kg

1 amu = 1.007825

energy ≈ 931.47 meV/e^2 = 1u.

* classification of Nuclei :-

⇒ Atoms of different elements are classified as

(1) Isotopes :- Isotopes are nuclei with Same atomic no. and different mass no.

ex : $_1H^1$, $_1H^2$, $_1H^3$ = $_zX^A$

$_{3}IU^{28}$ $_{3}IU^{29}$ $_{3}IU^{30}$ = $_zX^A$

$_{17}Cl^{35}$ $_{17}Cl^{37}$ = $_zX^A$

⇒ As atomic no. is the Same different mass leads different characteristics in properties of an atom and identical chemical behaviour and different physical state.

23-09-18

(2) Isobars : Same atomic mass no. different atomic no.

$_{Z_1}X^A \quad _{Z_2}X^A$

ex : $_8O^{16} \quad _7N^{16}$.

(3) Isotones : A nuclei with the equal no. of neutrons are called Isotones.

ex : $_6C^{14} \quad _7N^{15} \quad _8O^{16}$

$A-Z$	$A-Z$	$A-Z$
$n = 14-6$	$n = 15-7$	$n = 16-8$
$n = 8$.	$n = 8$.	$n = 8$.

(4) Isomer / Isomeric Nuclei : The atoms which have same atomic no. & same mass no and different nuclear energy states which differs internal structure of the nuclei which effects lifetimes.

ex : $_{92}U^{235} \quad _{92}U^{238} \quad _{92}U^{239}$.

(5) **Mirror Nuclei** :- Nuclei have Same mass no. 'A' but with the proton and neutron no. interchanged that means no. of protons in 1 nuclei = no. of neutrons in another nuclei.

ex : $_4Be^7$ $_3Li^7$.

Be	Li
$P = 4$	$P = 3$
$e = 4$	$e = 3$
$n = 7 - 4$	$n = 7 - 3$
$= 3$	$n = 4$

mirror reaction.

note :- Nuclei Consist of even/odd no. of protons and even/odd of protons, even/odd of nutrons are Said to be a pair of Even-even-protons and odd-odd-protons

* Basic properties of Nucleus

(or)

General properties of Nucleus :

* Explain indetail the properties of nucleus.

→ Nuclear Size :-

According to Rutherford's the mean radius of atomic nucleus is about the order of −14 to −15 (or) −13 to −15 m. and size of the atom.

Thus, nucleus is about 10,000 tyms smaller in radius than the atom.

Semi emperical formula / relation gives radius of nucleus $R_0 = A^{1/3}$.

Here, A = mass number.

$R_0 = 1.3 \times 10^{-15} m = 1 fm = 1.3 fm.$

which is very Small as it is Considered fundamental unit for nucleus.

ex : (1) C = 12

$R = r_0 \cdot A^{1/3}.$

$= 1.3 fm \times (12)^{1/3}.$

$= 3.21 fm.$

(2) CU = 63

$R = r_0 \cdot A^{1/3}$

$= 1.3 fm \times (63)^{1/3}$

$= 5.97 fm.$

(3) U – 238

$R = r_0 \cdot A^{1/3}$.

$= 1.3\ fm \times (238)^{1/3}$

$= 8.68 \times 10^{-15} m$.

* <u>Nuclear</u> <u>Mass</u> :-

Nucleus Consist of protons and nutrons. Mathematically expressed as assumed nucleus mass.

Assumed nuclear mass $= Z \cdot m_p + (A-Z) m_n$

where . Z – atomic number.

N – no. of neutrons.

$m_p - m_n$ – mass of proton and neutron.

⇒ Experimentally observed mass (real nuclei mass) is less than $Z \cdot m_p + (A-Z) m_n$.

⇒ difference $= Z \cdot m_p + (A-Z) m_n$ – real mass

$= \Delta m$.

Here Δm Called mass defect.

⇒ Usually mass is expressed interms of

1 amu $= 1.67 \times 10^{-27}$ Kg (or)

931.48 mev.

* **Nuclear density** :- The nuclear density can be calculated as $\rho_n = \frac{\text{nuclear mass}}{\text{nuclear Volume}}$.

⇒ Nuclear mass of the nucleus = A × proton mass

(or)

$= A \times m_n$

$= A \times (1.67 \times 10^{-27} \text{ kg})$

⇒ Volume of the nucleus $= \frac{4}{3}\pi R^3$.

$= \frac{4}{3}\pi (R_0 . n^{1/3})^3$

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

$$\rho_N = \frac{A \times 1.67 \times 10^{-27}}{\frac{4}{3} \times 3.14 \times (1.5 \times 10^{-15})^3 \times A}$$

$$\rho_N = \frac{3 \times 1.67 \times 10^{-27}}{4 \times 3.14 (1.5)^3 \times 10^{-45}}$$

$$\rho_N = \frac{3 \times 1.67}{4 \times 3.14 \times (1.5)^3}$$

$$\rho_N = 0.17 \times 10^{18}.$$

$$\boxed{\rho_N = 1.7 \times 10^{17} \text{ kg/m}^3}$$

Conclusion :-

⇒ The density of the nucleus is very high which gives nuclei matrix extremely Composed state in terms of pressure & density.

(4) **Nuclear charge :-**

The charge of the nuclear is due to protons with a '+ve' charge of 1.6×10^{19} e. Generally expressed as z.e.

where z = atomic no.

$e = 1.6 \times 10^{19}$.

⇒ This Can be find from artifical radio activity γ radiation (or) α radiation (or) X-ray Spectrum.

(5) **Nuclear Spin :-**

In the nucleus both protons & neutrons exist which are similar to electrons have an intensity angular momentum Spin expressed as

$$I_s = \sqrt{l(l+1)}\,\hbar \quad \text{(or)}$$

$$l_s = \sqrt{l(l+1)}\; h/2\pi$$

and Spin $= \pm 1/2$.

∴ Result in angular momentum is due to spin and orbital angular momentum of the nucleus (or) with in the nucleus.

∴ Total Angular momentum of the nucleus

$C_J = \sqrt{J(J+1)}\,\hbar$ (or) $\sqrt{J(J+1)}\ h/2\pi$

which is Called nuclear Spin.

6. Nuclear magnetic dipole moment :-

Spinning electron has an associative magnetic dipole moment of 'I'. Bohr magnetism.

$$\mu_e = \frac{e \cdot \hbar}{2m} \text{ (or)}$$

$$\mu_e = \frac{e \cdot h}{n \pi m}.$$

Similarly, in nucleus proton has a '+ve' elementary charge and due to its Spin has a magnetic dipole moment μ_N explained by Dirse theory.

Mathematically expressed as,

$$\mu_N = \frac{P \cdot \hbar}{2 \cdot m_p} - \frac{Ph}{4 \pi m_p}.$$

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Here $p = e =$ charge of electron / proton.

m_p = mass of proton.

μ_N = nuclear magnetron.

⇒ It is the unit of nuclear magnetic moment.

$\therefore M_p = 18.36\ M_e$

⇒ from of the measurements for nucleons found that $\mu_p = 2.795\ \mu_N$.

$\mu_N = -1.912\ \mu_N$.

4-10-19

* Electric Quadrupole moment :-

In addition to the magnetic moment a nucleus may have an electric Quadrupole moment.

This is a Consequence of the Symmetry of muceli about the Centre of mass. An electric dipole moment is zero per atoms and nuclei in stationery states which gives Symmetry does not

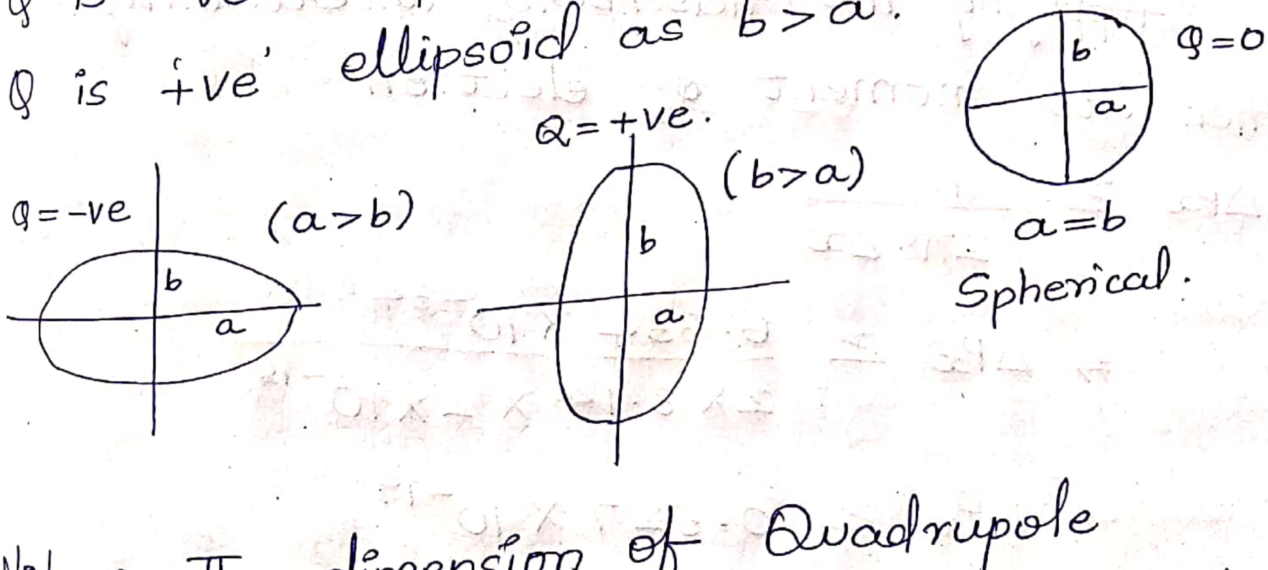
Spherical but ellipsoid of revolution.
This deviation from Spherical Symmetry is expressed as electric Quadrupole moment. denoted by 'Q' $= \frac{1}{e}\int(3z^2 - r^2)\,\rho\,.\,d\tau$.
where 'ρ' is charge density.
r is radius (Semi major & Semi minor).

$d\tau$ = Volume element.
z is axis.

This also expressed as,

$$Q = \frac{2}{5}\,z\,.\,e(b^2 - a^2).$$

As 'Q' $= 0$ Spherical shaped nucleis
Q is '-ve' ellipsoid as $a > b$.
Q is '+ve' ellipsoid as $b > a$.



Note :- The dimension of Quadrupole moment is that of an area measured as barn. (1 barn = $10^{-28}\,m^2$)

L.A.Q.

** Impossibility of an electron Being in the nucleus as the Consequence of Uncertainity principle.

(or)

Non existence of electrons & existence of Protons and neutrons in nucleus.

Ans :- The radius of neucleus in any atom is about the order of 10^{-15} m. If an electron Confined to nucleus then uncertainity position in the Δx of the electron is equal to the diameter of nucleus.

$\therefore$ Δx = diameter. $= 2 \times 10^{-15}$ m.

Applying the Heisenberg uncertainity then its moment of electron

$$\Delta P_x \geq \frac{h}{2\pi \cdot \Delta x}$$

$$\Rightarrow \Delta P_x \geq \frac{6.634 \times 10^{-34}}{2 \times 3.14 \times 2 \times 10^{-15}}$$

$$\Delta P_x \geq 0.527 \times 10^{-19}$$

$$\Delta P_x \geq 0.527 \times 10^{-19} \text{ N-Sec.}$$

it means that the Component of momentum P_x is the magnitude of total momentum of electron in the nucleus