NUCLEAR PHYSICS

→ Charaterístics of nucleus is studied.

* HRK vol 2 → Introductory of Nuclear Physics Kenneth S. Krane.

Nuclear Physics.

Macroscopic objects (Classical Physics)	Microscopic objects (Modern physics)

Atom ~ 10^{-10} m

Charge on the nucleus is positive

→ Protons

→ Negative charge

→ Nucleus.

Size of 1 Nucleus. = 10^{-15} m = 1 fm ← femto meter.

→ Black Body Radiation was experiment we switched to Q.M (from CM)

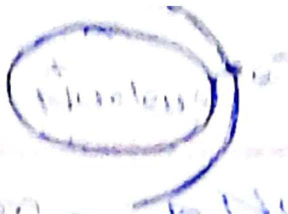
→ Physics after 19 century.

Classical	Modern
Light behave as wave (continous)	▪ Light behave as Particle (Discrete) Photon ($E=hf$)

Nucleus → Proton + Neutron

+ve charge + Neutral particles

Neutron Protons → Quarks



• Nucleus → Proton + Neutron → Nucleons [are the particles which are present in the nucleus]

→ Strong Nuclear forces are present in the nucleus

$P = h/\lambda$

$\lambda = \frac{h}{mv}$

→ QM effects are present in microscopic region

Z is the no. of Protons.

A is the no. of Protons + no. of Neutrons.

$N = A - Z$

no. of neutrons

Nomenclature:

$^{A}_{Z}X$ → $^{1}_{1}H$ (nucleus of H atom)

ISOTOPES: are created by change in nucleus (nuclear Properties changes)

⊙ **Nucleus**

→ Stable Nuclei

→ Unstable Nuclei → Emit Radiation.

(Nucleus is unstable by nature)

• If $Z \geq 82$ emits Radiation.

(Rutherford discovered nucleus)

Radioactive radiations

→ Radiations:
- → α-radiation
- → β-radiation
- → γ-radiation.

■ Parent (Emit rad) → daughter nuclei → Stable (if not emit rad)
→ Unstable (if emit rad)

⊙ α-radiations:

(Helium assembles α-radiations)

$${}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\alpha\text{-particle}$$

or

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

⊙ Gamma-Radiations:

$${}^{A}_{Z}X^{*} \longrightarrow {}^{A}_{Z}X + {}^{0}_{0}\gamma$$

Excited State to → Ground state.

emit → rad

absorbs

⊙ β-Radiations

$${}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}\beta$$

assembles the ${}^{0}_{-1}e^{-}$ (but not actually e^{-})

It can be possible.

$${}^{A}_{Z}X \longrightarrow Y + {}^{0}_{+1}\beta$$

β → negative Decay → e^{-} (resembles the positron)

β → positive Decay → positron Decay.

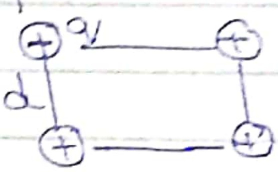
β-radiation → β^{+}-radiation, β^{-}-radiation → emitted during nuclear radiation.

→ NUCLEAR PROPERTIES:

Nucleus is a mysterious object whose properties are much more difficult to characterize than the other macroscopic object. Nuclear characteristics can be described by

1) Electric Charge.
2) Radius of Nucleus.
3) Mass.
4) Binding Energy.
5) Angular Momentum → $\vec{P} = m\vec{v}$, $\vec{L} = \vec{r} \times \vec{p}$
6) Parity
7) Magnetic dipole and Electric quadrupole moments.

All are **static** properties of nucleus (b/c nucleus is stable)

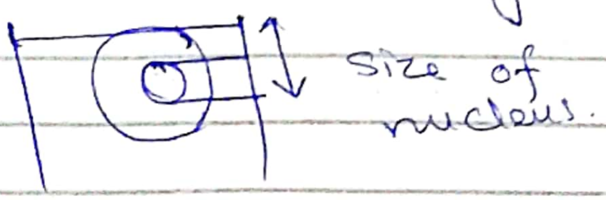


whereas **dynamic** properties of nucleus includes decay / or radiation. and Nuclear Reaction.
(Fusion, fission) → (Nuclear force strongest force in nature)

Nuclear Radius:

is determined by the experiment.

(i) High energy electron scattering
(ii) Muonic X-ray ~ 10^{-10} m
(iii) Optical and X-ray shift.



→ Intensity of deflection tells us about charge concentration.

→ Through coulomb interaction of a charged particle beam with nucleus will determine the distribution of charge present on the nucleus.

{Rutherford scattering α-decay and X-rays scattering}.

→ Radiations used to study nuclear properties of very small wavelength.

Range of wavelength $\lambda \leq 10 fm$

and $E = hc/\lambda$ $\lambda \downarrow$ high energy radiations

Required for study of nucleus beam $\approx 100 MeV$

$$\frac{\text{No. of nucleons}}{\text{Volume}} \sim \text{Constant factor}$$

⊙ Nucleons have a constant distribution out to the surface.

⊙ No. of nucleons per unit volume is roughly constant.

$$\frac{A}{4/3 \pi R^3} \approx \text{Constant}.$$

$$A \approx \text{constant } 4/3 \pi R^3$$

$$A^{1/3} = \text{constant } R.$$

$R \sim 1/_{const} \; A^{1/3}$

$R \sim A^{1/3}$

As $A\uparrow$ also Radius $\uparrow$. no of nucleons $\uparrow$

$R = R_o A^{1/3}$ where $R_o = 1.2 fm$.

$\boxed{R = R_o A^{1/3}}$

Find rad of Hydrogen ?

$R_i = 1.2 fm$

rad. of Helium.

$R_{He} = R_o (4)^{1/3}$

$R_{He} = (1.2)(4)^{1/3} fm$

Nuclear Mass:

Mass of nucleus

$m_{nucleus} = \underbrace{Zm_p}_{\text{mass of single proton}} + \underbrace{Nm_n}_{\text{mass of single nution}}$

if $Z = 3$, $N = 2$

$m_{nucleus} = 3m_p + 2m_n$

$1.6 \times 10^{-27} kg = 5 \times 1.6 \times 10^{-27} kg$

$\boxed{m_n = 5 \times 1.6 \times 10^{-27} kg}$

NUCLEAR PROPERTIES

Static Properties

Nuclei is stable
(No Reactions)
if than able
to measure properties.

Electric charge on Nucleus.
Mass of Nucleus
Radius of Nucleus.

Dynamic Properties.

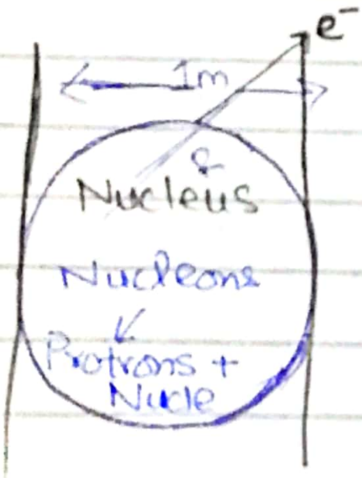
Nuclei is unstable

Nucleus Radiations
and
Nucleas Reactions.

Nuclear Reactions

Fusion + Fission.

Z $\quad 1e = 1.6 \times 10^{-19} C$



* Columb force repulsion present inside while outside columb force of attraction.
* When Z number increase charge on nucleus increases.

Lighter nuclei $\longrightarrow$ Heavier Nucleus

$Z = 1$ U = $Z = 92$

Charge on nucleus = Ze

$= 92 \times 1.6 \times 10^{-19}\,C =$ ______ Ans

* Nucleons $\propto$ charge on nucleus, hence binding energy increases.
* A = No of protons + No of Neutrons

$$\boxed{A = Z + N}$$

$$N = A - Z$$

$\longrightarrow$ For finding the no of neutrons, we have to find proton and multiply with corresponding mass?

$m_{neucleus} = Zm_p + Nm_n$

$m_p = m_n = 1.67 \times 10^{-27}\,kg$

$R = R_o A^{1/3}$

$R_o = 1.2\,fm$

* femto shorter than nano scale.
* Electron can't be in nucleus if electron comes in nucleus then uncertainty principle cons b/c speed of light approaches at particles speed which is in femto

can't be inside

Angular Momentum

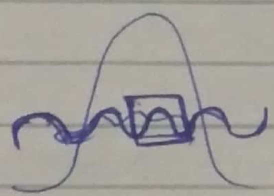
* Parity
* Magnetic dipole
* Electric quadrapole moment

$E = hf$

$E = \frac{hc}{\lambda}$

$\lambda \downarrow = E \uparrow$

Radiations energy $\simeq$ 100 MeV

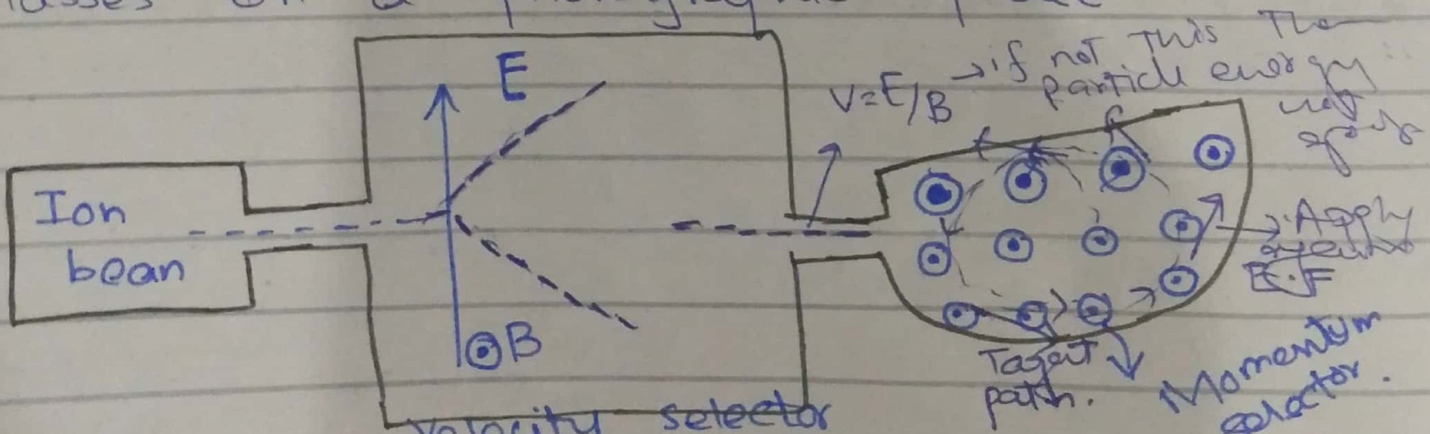


Mass Spectrometer:

- Mass spectrometry is the first technique of high Precision avaiable to the experimentalist to determine some of the static properties of Nucleus.
- Nucleus properties are determined from nucleus isotopes. to determine nucleas abundances and this nucleus mass.

Neutron no charge then nucleus changes

- Mass spectroscope (are injected with mixture of different isotopes) that are separated due to different masses on a photographic plate



* E & B are perpendicular to each other

* $\vec{F_e} = q\vec{E}$

* Mass spectroscopes begin with an ion source which produces a beam of ionized atoms or molecules of material under study is bombarded with electrons to produce the ions or ions can be formed as a result of spark discharge between electrode.

$\vec{F_e} = q\vec{E} \rightarrow ①$

$\vec{F_B} = q(\vec{V} \times \vec{B}) \rightarrow ②$

$\quad " = qVB\sin 90° \rightarrow ③$

Net force on the incident ion beam is zero when $qVB = qE$ (compare ① and ③)

$V = E/B$

Repeated after circle box

* Ions emerging from source have broad range of ~~source~~ velocity

* Velocity selector we apply E and B feild ⊥ to each other

$\vec{F_e} = q\vec{E}$

$\vec{F_B} = q\vec{V} \times \vec{B_0}$

$\vec{F_B} = qVB_0\sin 90$

$\vec{F_B} = qVB_0$

Ion beam will move undeflected only if the net force on the ion particle is zero

$$eE = eVB_0$$

$$\cancel{\vec{F}_{net}} = \vec{F_e} + \vec{F_B}$$

$|\vec{F_e}| = |-\vec{F_B}|$

$V = E/B_o \longrightarrow (1')$

Final element is momentum selector which is electrically a uniform B feild that bend the beam with circular path with radius r. determined by momentum.

$\vec{F_c} = \vec{F_B}$

$\frac{mv^2}{r} = qvB\sin 90^\circ$

$\frac{mv}{r} = qB \longrightarrow r = \frac{mv}{qB} \rightarrow (3)$

$mv = qBr$

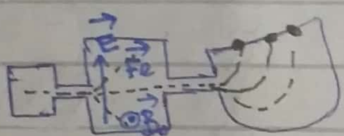
$V = rw \longrightarrow (2)$

$mrw = qBr$

$mw = qB$

putting (1') in (3) eq

$r = \frac{mE}{qB_o B}$



If $B_o = B$

$r = \frac{mE}{qB^2}$

→ Mass spectrometer is a device which different nuclei on basses of their masses.

q, E and B are determined through experimental

Nucleus Dynamic and static Properties

setup Abundance more $r\hat{i}$ than $m\hat{i}$

* Nuclear Reactions:-

$$x + X \longrightarrow y + Y$$

x → projectile
X → Stationary target

- Projectile initiate any nuclear reaction by hitting nuclei.
- When we are studing the Nuclear Decays Projectile in that case is not required.

→ Masses for each in reaction:

$$x + X \longrightarrow y + Y$$
$$m(x) + m(X) \quad m(y) + m(Y)$$

→ Strongest force is nature use Nucleus while their reaction large amount of ambundance and energy is released.

- By measuring the difference of masses in any nuclear reaction we find the Q value for reaction.

$$\boxed{Q = \Delta m c^2}$$

$$\Delta m = \{m(x) + m(X)\} - \{m(y) + m(Y)\}$$

$$Q = \{m(x) + m(X)\} - \{m(y) + m(Y)\} c^2.$$

Reaction Example:

$${}^{1}H + {}^{14}N \longrightarrow {}^{12}N + {}^{3}H$$

$m({}^{1}H) = 1.007825u$

$m({}^{14}N) = 14.003074u$.

→ u = Atomic mass unit

$m(^3H) = 3.016049u$

Mass can be defined in terms of energy in nuclear physics.

$1u = 931 \frac{MeV}{c^2}$.

$E = mc^2$
u = MeV.
= MeV/c^2
Energy unit ÷ by c^2 we get mass unit

$Q = -22.1355 \pm 0.0010$ MeV

-ve means energy released must be smaller than orignal value.

→ if mass or Q value given with some error than result must have an error value (±)

$$\frac{Q}{c^2} = \{m(x) + m(X)\} - \{m(y) + m(Y)\}$$

$$\frac{Q}{c^2} = m(x) + m(X) - m(y) - m(Y)$$

$$m(y) = m(x) + m(X) - m(Y) - \frac{Q^2}{c^2}.$$

$$m(y) = 931\frac{MeV}{c^2} + 931\frac{MeV}{c^2} - 931\frac{Meb}{c^2} - \left(-\frac{22.1355 MeV}{c^2} \pm \frac{0.0010 MeV}{c^2}\right)$$

* not divide c^2 with error and Q term so ~~that~~ all units will be in same and it will not be complex

* In this cource don't put value of c^2 in any numerical ~~cou~~ as it is eliminated by other quantities

$$E = \Delta mc^2$$

Mass spectrometry is used when we have stable Nuclei whereas $E=\Delta mc^2$ is used in all Nuclear Reactions. Either stable or unstable nuclei.

* Sometime the end product nuclei is unstable so it converts to other radioactive nuclei.

■ **Nuclear Binding Energy:**

* In atom we have nucleus with e^- revolve around nucleus. Atom is bounded because of Coulomb force of Attraction

* $m_N = Zm_p + (A-Z)m_n$ Proton Neutrons

If you known m_N then simply $E = m_N c^2$ this E is Energy of nucleus with which nucleons are binded with eachother.

CamScanner

$m_N \neq Zm_p + (A-Z)m_n$.

This is not equal because proton has repulsive force.

$$m_N c^2 = (Zm_p + (A-Z)m_n)c^2 + \sum_{i=1}^{z} B_i \rightarrow (1)$$

Binding energy required to bind proton together

* No of proton increase then $\sum_{i=1}$ increases.

* For heavier nuclei B_i increases as compared with the lighter nuclei b/c of the increase in Z-number.

eq (1) is indicating that.

The B.E of the nucleus is difference in masses of a Nucleus ${}^{A}_{Z}X_N$ and it constituents Z (proton no) & N neutron.

$$B.E = [Zm_p + Nm_n - m[X_N]]c^2$$

$\Rightarrow$ B.E $\approx$ 10 - 100 keV.

For Hydrogen;

$\therefore m_p = 1.67 \times 10^{-27}$ kg

$\therefore 1u = 1.67 \times 10^{-27}$

$\therefore 1u = 931 \frac{MeV}{c^2}$

$Z = 1$

$N = 0$

$$B.E = [1u - 1.007825u]c^2$$

$$- \left[(0.007825)931 \frac{MeV}{c^2}\right]c^2$$

$B.E = 7.285075 MeV$

$\boxed{B.E = 7285.075 keV}$

Neutron & Proton Separation Energy:-

If we have to remove one proton from one

one nucleus how much energy is required? This energy is called Neutron & proton Separation Energy. If we want to take out a neutron energy must be required which must be greater than the B.E energy of the nucleus.

B.E b/w ${}^{A}_{Z}X_{N}$ & ${}^{A-1}_{Z}X_{N-1}$

N neutron. when one neutron is taken out from the nucleons.

Binding Energy of ${}^{A}_{Z}X_{N} = [Zm_p + Nm_n - m({}^{A}_{Z}X_N)]c^2 \rightarrow (1)$

" " " ${}^{A-1}_{Z}X_{N-1} = [Zm_p + (N-1)m_n - m_Z({}^{A-1}_{Z}X_N)]c^2 \rightarrow (2)$

S_n is the energy required to remove the neutron from the nucleus

$$S_n = B.E({}^{A}_{Z}X_N) - B.E({}^{A-1}_{Z}X_{N-1}) \rightarrow (3)$$

using eq (1), (2) in (3)

$$S_n = [Z\cancel{m_p} + N\cancel{m_n} - m({}^{A}_{Z}X_N) - Z\cancel{m_p} - (N-\cancel{1})m_n + m({}^{A-1}_{Z}X_N)]c^2$$

$\therefore p \sim {}^{1}_{1}H$

$$S_n = [-m({}^{A}_{Z}X_N) + m_n + m({}^{A-1}_{Z}X_N)]c^2$$

To remove one neutron we need so amount of energy.
To remove 2 or 3 number of neutron for 3 neutron.

$$S_n = [-m(^A_Z X_N) + 3m_n + m(^{A-3}_Z X_{N-3})]c^2$$

Proton Separation Energy:-

If we want to take out a proton energy must required S_p, must be greater than B.E of the nucleus.

$^A_Z X_N$ & $^{A-1}_Z X_N$ when 1 proton in taken out

Z = Proton number.

$$B.E(^A_Z X_N) = [Zm_p + Nm_n - m(^A_Z X_N)]c^2$$

$$B.E(^{A-1}_{Z-1} X_N) = [(Z-1)m_p + Nm_n - m(^{A-1}_{Z-1} X_N)]c^2$$

S_p = Energy required to remove the proton from the nucleus.

$$S_p = B.E(^A_Z X_N) - B.E(^{A-1}_{Z-1} X_N)$$

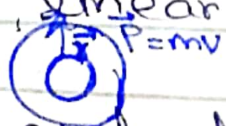
$$S_p = Zm_p + Nm_n - m(^A_Z X_N) - (Z-1)m_p - Nm_n + m(^{A-1}_{Z-1} X_N)]c^2$$

$$S_p = [-m(^A_Z X_N) + m_p + m(^{A-1}_{Z-1} X_N)]c^2$$

Quantum theory of Angular Momentum:

The orbital quantum number l play a very mportant role. In atomic physics it serve to abel different electron wave functions that escribes electron wave functions that escribe the spatial behaviour of wave unction.

In classical physics the angular momentum of a particle moving with linear momentum is $\vec{l} = \vec{r} \times \vec{p}$ ---→



n quantum mechanics we evaluate e expectation values of angular omentum by:-

$$\langle f \rangle = \int \psi^* f \psi \, dx$$

Ve first consider the magnitude of the gular momentum l for this purpose. or this purpose it is simplest to

⋮

calculate l $\quad \boxed{\langle l' \rangle = \int \psi^* l' \psi \, dx}$

$\hat{P}_x = -i\hbar \frac{\partial}{\partial x}$; $\hat{P}_y = -i\hbar \frac{\partial}{\partial y}$; $\hat{P}_z = -i\hbar \frac{\partial}{\partial z}$

Evaluate the cross product

$\vec{l} = \vec{r} \times \vec{p}$

$\vec{r} = x\hat{i} + y\hat{j} + z\hat{k}$

$\hat{l}_x = ?$; $\hat{l}_y = ?$; $\hat{l}_z = ?$

$$\vec{l} = \vec{r} \times \vec{p} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ x & y & z \\ P_x & P_y & P_z \end{vmatrix}$$

- $l_x = yp_z - zp_y$
- $l_y = xp_z - zp_x$
- $l_z = xp_y - yp_x$.

Total angular momentum

$\langle l^2 \rangle = \langle l_x^2 + l_y^2 + l_z^2 \rangle$

$$\boxed{\psi = \underbrace{R(r)}_{\text{Radial part / linear part}} \underbrace{Y_{lm}(\theta, \phi)}_{\text{Angular part}}.}$$

quote after that line

When a particle move in central potential than its wave-function will not have linear dependence it only have angular dependent

The magnitude of angular momentum is fixed

$\langle l^2 \rangle = \hbar^2 l(l+1)$

- Angular momentum describe by orbital quantum number l is used to find the state of the particle.

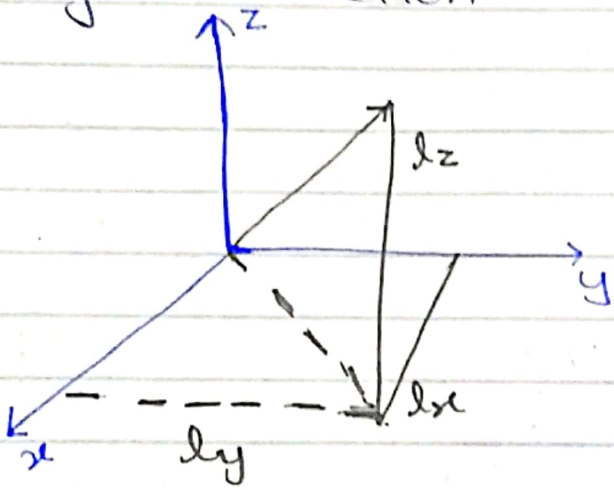
* Nucleus only have spin motion
* Electron, Atom have spin and orbital motion

$l = 0$ [state - s]
$l = 1$ [p - state]
$l = 2$ [d - state]

$\therefore$ $l =$ 0, 1, 2, 3, 4, 5, 6
state = s, p, d, f, g, h, i

- Quantum mechanics permit us to know only one component of l. If l_x is fond l_y and l_z completely indetermined.

So by convection we choose $l_z \to$ z-component of l



$\langle l_z \rangle = \hbar m_l$

m_l = magnetic quantum # $= 0, \pm 1, \pm 2, \pm 3 \ldots\ldots \pm l$

$l = 2$ $\quad m_l = 0, \pm 1, \pm 2$
(5 values)

$\langle l_z \rangle = \langle |\langle l \rangle|$

$\langle l \rangle = \hbar \sqrt{l(l+1)}$.

$\to$ Intrisic quantum # also known as spin quantum no

* For the complete description of an electronic state in an atom we require the introduction to new quantum no.

Intrinsic angular momentum ~ spin

Nucleus → Nucleus motion (spin proton $1/2$)

$\langle s^2 \rangle = \hbar^2 s(s+1)$

$\langle S_z \rangle = \hbar m_s$

$m_s = \pm 1/2$

$s = 1/2$ (numerical values)

$\uparrow\downarrow \pm 1/2$

$\uparrow +1/2$

$\downarrow -1/2$

• **Total Angular momentum (j) :-**

$j = l + s$

* $l = 1$ p-state

$\langle j^2 \rangle = \hbar^2 (j+1)$

$\langle j_z \rangle = \hbar m_j$

$m_j = m_l + m_s$

expectation value of j

$j = 1 \pm 1/2,\ 3/2,\ 1/2$

P state → $P_{1/2}$, $P_{3/2}$

• There are two types of coupling b/w spin and angular momentum.

(i) jj coupling.

$J = j_1 + j_2 + \dots\dots$

$j_1 = l_1 + s_1$

$j_2 = l_2 + s_2$

(ii) L.S coupling.

$L = l_1 + l_2 + \dots\dots \sum_{i=1} l_i$

$S = \sum_{i=1} S$

• Nuclear Angular Momentum:

If we have a nucleus in which 8 nuclons exist then vector sum of all the nucleons will give us the angular momentum of nucleus.

$$\boxed{I = S_p + S_n + l}$$

Isospin

Spin of Protons and neutrons (upward or Downward)

orbital angular momentum of nucleus as they move about the common centre of mass

Sp & Sn can be $\pm 1/2$

$I^2 = \hbar^2 I(I+1)$

$I_z = m\hbar \quad (m = -I \;\dots\; I)$

$2I + 1$ value

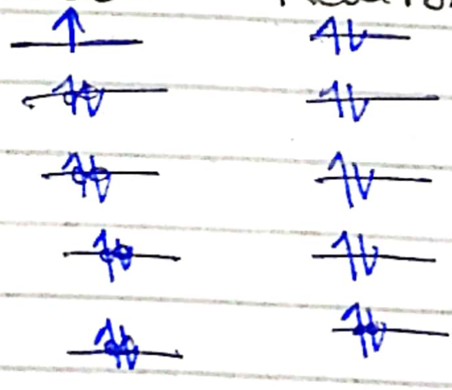
If we apply ordinary magnetic feild the nucleus splits into different states as in e case of atomic physics (Zeeman effect)(2j+1) but e need very very strong B feild for such plitting but such high B. feild does not exist but if splitting occurs.

Example:-

$^{19}_{9}F_{10}$

odd even

Proton Neutron



$\boxed{S = S_p + S_n}$

Ch#11 Review
Ch#12 → 2.5 Quantum Theory
2.6 Parity. (Study)
Ch# 3 → Nucleus Radius, Charge.

Parity:

Parity operation causes the replacement of co-ordinate with its -ve co-ordinates. It causes the reflection of all the co-ordinate through the centre.

$$\begin{aligned} r &\rightarrow -r \\ x &\rightarrow -x \\ y &\rightarrow -y \\ z &\rightarrow -z \end{aligned}$$

(Cartesian)

$$\begin{aligned} r &\rightarrow r \\ \theta &\rightarrow \pi-\theta \\ \phi &\rightarrow \phi+\pi \end{aligned} \qquad (r, \theta, \phi)$$

(Spherical)

- If a system/wave function on which the parity operator. If it remain unchange than we expect that none of the observable properties describing the system have changed as a result of reflection.

$$V(r) = V(-r)$$

$$|\psi(r)|^2 = |\psi(-r)|^2$$

$$|\psi(r)| = |\psi(-r)|$$

$$|\psi(r)| = \pm \psi(-r)$$

If $\psi(-r) = \psi(r)$ then it is even parity.

→ If
$\psi'(r) = -\psi(r)$ odd parity.

Mixed parity doesn't exist. either you have odd or even parity.

In spherical coordinates.

$$Y_{lm_l}(\pi-\theta, \phi+\pi) = (-1)^l Y_{m_l}(\theta, \phi).$$

$$V(r) \neq V(-r).$$

$$|\psi(r)|^2 = |\psi(-r)|^2$$

* Parity convert into Beta decay after Beta experment

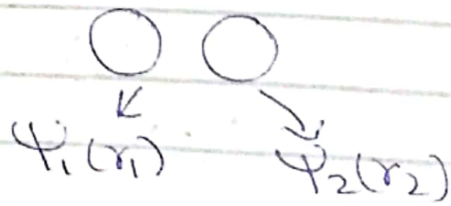
Parity is conserved in nuclear reaction its conservection.
In 1957 B-decay is failed

lecture

Quantum Statistics:-

if we have two Proton one with wavefunction ψ_1 and another with wavefunction ψ_2
Combined effect

$$\psi = \psi_1(r_1)\psi_2(r_2)$$



If these particles are interchanged then how we distinguish them and what

$\circledast$ $1/\sqrt{2}$ → Normalisation Factor

will be their combined wave function
* If Probability density is invariant under this interchange that means we have identical particles.

Combined wavefunction

$\psi_{12} \longrightarrow \psi_{21}$

$\psi_{12} \longrightarrow -\psi_{21}$ (Not identical particles)

* All combined wavefunctions representing identical particle must be either completely symmetric or completely Antisymmetric. No Mixed symmetry is allowed.

$$\psi_{12} = \frac{1}{\sqrt{2}}\left[\psi_1(x_1)\psi_2(x_2) \pm \psi_2(x_1)\psi_1(x_2)\right]$$

* All particles with integral spin (0, 1, 2, ...) have symmetric wave function whereas particles with half integral spins ($1/2$, $3/2$, $5/2$ ...) antisymmetric wave function

?

2.7 Article from book

2.8 Article (Not included).

→ Problems only from 3rd Chapter.

→ Exercise Examples of 1st, 2 Chapter. (Mass spectrometer problems)

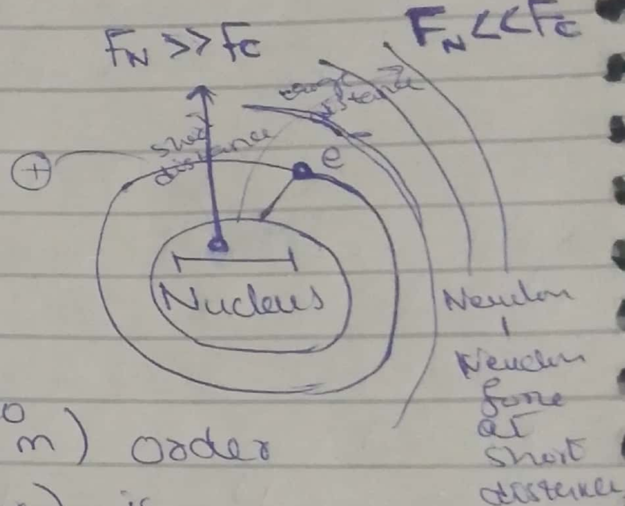
CamScanner

Properties Mentioned on Page # 80 — imp Understanding of Deutron imp in ~~Nuclear~~ Physics

Ch # 4: The force b/w the nucleons

* The Force with which the nucleons (protons & neutrons) are bounded is known as Nucleon. Nucleon force
* Nuclear force is the force that results b/c of nucleon. Nucleon force

Properties:-



1. → At short distance it is stronger as compared to the coulumb force (force among protons).

→ At long distance ($\sim 10^{-10}$ m) order of nuclei this force (nuclear) is dominating as compare to the coulomb force of attraction.

2. → At large distance nuclear force become weak and it 10^{-10} m decreases as the distance from the nucleus increases.

3. →

(N–N)

* Nucleon – Nucleon/Nuclear force is independent of charge.
* Nucleon – Nucleon force is spin dependent. (Spin are parallel or Antiparallel)

CamScanner

- Up → Anticlockwise
- Down → clockwise direction

(3) Nucleon-Nucleon force includes a repulsive term which keeps the nucleus at a certain distance/average separation.

(4) The nucleon-nucleon force has non-central or tensor component, as it is non-central so Orbital Angular Momentum in case of nucleon-nucleon force/Nuclear force

→ Orbital Angular Momentum is R Dependent

$mvr = n\hbar$ 

→ In hydrogen we have

↓ 1 proton ↓ 1 electron.

↓ hydrogen nucleus.

↓ 1 proton + 1 neutron

Simplest in periodic table.

Now this is not hydrogen atom this is isotope of hydrogen

^2H ~ Deuteron

↓ 1 neutron + 1 proton.

(•) Nuclear Physicist → Deuteron b/c it is simplest nucleus to understand nucleon-nucleon interaction.

* Deutron
  ↳ No excited state existance.

Binding Energy:- (For deutron)

* The B.E of deutron is measured precisely which can be determined in three different ways
* By spectroscopy :- we directly measure/determine the mass of deutron.

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

$$B.E = [m(p) + m(n) - m(^2H)]c^2$$

$$B.E = [m(^1H) + m(n) - m(^2H)]c^2$$

Ⓣ End of book Table Mass of Nuclear Properties.

$$B.E = [1.0078254 + 1.008665 - 2.014102]c^2$$

B.E for deutron :- 2.223228 MeV.

Spectroscopy:-
B.E = 2.2463 ± 0.00004 MeV. (Theoretical determined value)

Photo

Lec #

Methods for Finding Binding Energy:-

Three different techniques for finding Binding Energy values.

(i) Spectroscopy. (previous page) ⟶ $2.22463 \pm 0.00004\,MeV$

(ii) Mass doublet Method.

(iii) Photodissociation.

(ii)

$m(C_6H_{12}) - m(C_6D_6) = (9.289710 \pm 0.000024) \times 10^{-3}\,u$

$m(C_5D_{12}) - m(C_6D_6) = (84.616626 \pm 0.000090) \times 10^{-3}\,u$

From the 1st difference we find by using ^1H mass equals to $1.007825037\,u$.

$$\left.\begin{aligned} m(^2H) &= 2.014101789 \pm 0.000000021\,u \\ m(^2H) &= 2.014101771 \pm 0.000000015\,u \end{aligned}\right\} D \to {}^2_1H$$

(iii)

$$\gamma + {}^2H \longrightarrow {}^1H + {}^1n$$

$$B.E(^2H) = \Delta mc^2 - \gamma$$

$$= 2.224 \pm 0.002\ MeV.$$

* Very less error observed in Mass spectroscopy. So Best Method for Determination is Mass Spectroscopy for mass of Deutron.

■ Spin and Parity of Deutron:

The total angular momentum I of the Deutron should have three components.

* Spin of Proton S_p
* Spin of Neutron S_n
* Orbital Angular momentum l

$$I = S_p + S_n + l.$$

- Measured Spin of Deutron is 1

$$I = 1$$

- S_n and S_p can be either parallel or antiparallel.

$$S_n = \pm 1/2$$
$$S_p = \pm 1/2.$$

$S_p = +1/2 \quad S_n = +1/2 \quad l = 0$

$I = S_p + S_n + l$

$I = 1/2 + 1/2 + 0 = 1$ → {spin parallel}

$I = +1/2 - 1/2 + 1 = 1$ → {spin Antiparallel $l = 1$}

$I = -1/2 - 1/2 + 2 = 1$ → {parallel spin $l = 2$}

$I = -1/2 + 1/2 + 1 = 1$ → {Antiparallel with $l = 1$}.

* Deutron Measure spin is 1. that when l is 1 for ancher result is 1

Note

$\uparrow\uparrow \; l = 0$	$I = 1$
$\uparrow\downarrow \; l = 1$	$I = 1$
$\downarrow\downarrow \; l = 2$	$I = 1$

→ Deuteron consist an Integral number : I.

Book and Table Atomic Mass is basically Nuclear mass

$r \rightarrow -r$ Parity.

Parity is a useful concept both in nuclear physics and Quantum Mechanics. Parity help us to explain the types of function. (either it is symmetric or it is Antisymmetric)

$$\text{Parity} = (-1)^l$$

$l = 0, 1, 2.$

→ $S = \cancel{0}\ 1$

$l = 0, 2$

If $l=0$	$P = (-1)^0 = 1$	Even Parity
$l=1$	$P = (-1)^1 = -1$	Odd Parity
$l=2$	$P = (-1)^2 = 1$	Even Parity

→ It is measured or experimentally determined that deutron has even parity

→ Should be Able to learn book Table (end page)

<u>example</u>

Abundance or half life

	Z	A	Atomic Mass (u)		I^{π}
H	1	1	1.007825	99.985%	$1/2^+$
		2	2.014102	0.015%	1^+
		3	3.016049	12.34(8)	$1/2^+$

Conclusion

Deutron :-

Simplest, composed of 1p & 1n, even parity,

→ Tunelling effect
(in #4 not included.

■ Magnetic Dipole Moment
Electric Quadrapole Moment

■ Monopole :-

q A single charge moving alone.

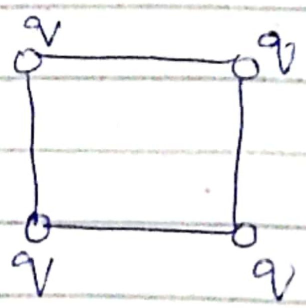
Ze

Angular Momentum

→ Nucleons present then dipole, monopole can exist

Spin motion of nucleon. | Orbital motion of nucleon.

Dipole



Quadrapole.

Nucleon spin then

Nucleus is spinning

- Both have Electric and Magnetic effects.

→ **Magnetic Dipole Moment** is represented as

$\mu = iA$

Consider a circular loop current carrying i and enclosing some area A

$$\mu = iA \rightarrow (1)$$

$$i = q/t = e/t \rightarrow (2)$$

$$S = vt$$

$$t = S/v$$

$$S = 2\pi r$$

$$t = \frac{2\pi r}{v} \rightarrow (3)$$

Using (3) in (2)

$$i = \frac{ev}{2\pi r} \rightarrow (4)$$

Using (4) in (1)

$$\mu = \frac{ev}{2\pi r} A$$

$$A = \pi r^2$$

$$\mu = \frac{ev}{2\cancel{\pi}\cancel{r}} \cancel{\pi} r \cancel{2}$$

$$\boxed{\mu = \frac{evr}{2}}$$

For circle as proton is moving

jahn pa sirf charges han wahn ye force ho ge jahan centre force ho ge vahn Tensors hon ge.

X and ÷ by m

$$\mu = \frac{e(Vrm)}{2m}$$

$$mvr = n\hbar$$

$$vr = \frac{n\hbar}{m}$$

$$L = n\hbar$$

$$\mu = \frac{eL}{2m}$$

$$n = 1$$

$$\boxed{\mu_B = \frac{e\hbar}{2m}}$$

Bohr Magneton.

m = electron.

μ_B = Bohr Magneton

Nucleus = $\mu_N = \frac{e\hbar}{2M}$ (Nuclear Magneton)

$$\boxed{\mu_B >> \mu_N}$$

Lure 7

→ $\boxed{\mu = l\mu_N}$ μ is not non central b/c μ depend on area.

NUCLEAR ANGULAR MOMENTUM AND SPIN

→ The total angular momentum of a nucleus containing. A nucleons would be a vector sum of the angular momenta of all nucleons.

The total angular momentum is called the nuclear spin represented by I

$I^2 = \hbar^2 I(I+1)$, $I_z = m\hbar$, $m: -I \ldots +I$

→ If we have even number of nucleons (so there will be an even number of half integral component that gives total I as an integer

→ Even A-nuclei I = Integral

and for such nuclei which p an odd number of nucleons total I will be half-integral

So odd A-nuclei I=half-Integral

Nucleon	
Neutron	Proton
1/2	1/2

→ If we known the wave function of every nucleon we can determine the nuclear parity by multiplying together the particles of each of the A-nucleons

→ We can end up with a result of π that is either positive or negative

J^{π} parity: $\pi = \pi_1 \pi_2 \ldots \ldots \pi_A$ → Total parity

Parity can be either positive or negative their is no direct theoretical relationship between I and π. For any value of I it is possible to have either $\pi = +ve$ or $\pi = -ve$.

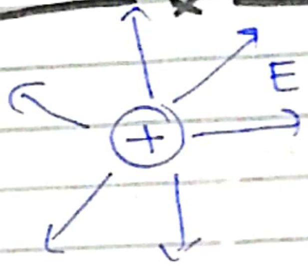
* Parity is intrinsic property.

→ Simplest Distribution of charges and current gives only the lowest order of multipole fields. A spherical charge dist gives only a monopole (columb) field The

Nucleons no ↑ ↓ size ↑ ↓ $R \propto A^{1/3}$ 1.2 fm

higher order fields all vanish

* A circular current loop gives only a magnetic dipole field.
As Nucleus is spherical in shape because of this we only have to calculate the lowest order Multipole moments to charaterize Electromagnetic properties of the nucleus.



$E = F/q$

$E = \frac{1}{4\pi\varepsilon_0} \frac{q}{r^2}$.

$\left(E \propto 1/r^3\right)$

order when dipole observed

For higher order it has larger values of r

.....

Quadrople

$E \propto 1/r^4$.

Heavy nuclear → Higher Dipoles.

→ Restriction on multipole moments comes from the spherical symmetry of the nucleus and it is related to the parity of the nucleus state.

Parity $= (-1)^L$; * if $L = 0$ $(-1)^0 = 1$

Electric Moment Formula.

$L = 0$ means monopole.

* if $L = 1$ $(-1)^1 = -1$

$L = 1$ means Dipole

* if $L = 2$ $(-1)^2 = 1$ Quadrapole

→ L. value linked with Multipole.

L = total Orbital Quantum number.

→ For Magnetic moment the parity is $(-1)^{L+1}$ {Magnetic Moment forms}

if $L=0$ $(-1)^{0+1} = -1$ Monopole
$L=1$ $(-1)^{1+1} = 1$ Dipole
$L=2$ $(-1)^{2+1} = -1$ Quadrupole

Form $\mu = iA$

$$i = e/t = \frac{e}{2\pi r/v}$$

$$\mu = \frac{e\,mvr}{2m} = \frac{e|L|}{2m} \rightarrow ①$$ Relation of magnetic moment

From eq ① we conclude that inside nucleus the magnetic dipole moment are produced due to L.

$$L = m_l \hbar$$

$$m_L = -l, \ldots\ldots, +l$$

$$\mu = \frac{e\hbar l}{2m_e} \rightarrow ②$$ Nuclear Magneton $= \mu_N$

$\mu_B =$ Bohr Magneton

* if electron ~~nucleons~~ mass is added that Bohr Magneton (μ_B)

$$\mu = e\hbar l/2m_p \rightarrow ②'$$

* if Protron mass is added than eq ② will have Nuclear Magneton (μ_N)

* Values

$$\mu_N = 3.1525 \times 10^{-8}\ eV/T$$

$$\mu_B = 5.7884 \times 10^{-5}\ eV/T$$

$\boxed{\mu_N \lll \mu_B}$ → b/c of difference in masses

$m_p >>> m_e$.

In Nuclear and Atomic Physics μ_B is dominant so mass of electron is taken while ignoring mass of proton
μ_B than m_e ; μ_N than m_p.

→ eq ① can be written as

$$\boxed{\mu = g_l \, l \, \mu_N} \rightarrow \text{Orbital Angular Moment}$$

where μ_N is Nuclear Magneton.

g_l is the g-factor associated with Orbital Angular momentum - l

For Proton $g_l = 1$

* Neutrons have no. of electric charge
So g_l is 0.

$$\mu_B = \frac{e\hbar l}{2m_p} \qquad l = 1$$

$$\mu_N = \frac{e\hbar l}{2m_p} \rightarrow \mu \qquad n = 1$$

→ Spin Magnetic moment

$$\boxed{\mu = g_s \, S \, \mu_N} \text{ spin magnetic moment}$$

$S = 1/2$ For proton, Neutron and electron.

→ where $g_s = 5.5856912 \pm 0.000022$ (for proton)
$g_s = 3.8260837 \pm 0.0000018$ (for Neutro

experimental values.

small values.

Neucleus → spin → overall spin → contribution
(neutron + proton spinning together)

So we have manute contribution which is so sma

Theoretically the value of $g_s = 2$ for proton.
$s = 1/2$

Q= Why the difference results in the value of g_s = ?

Protons → quarks(which has own spin)
Every particle has spin 1/2 so we have $g_s = 2$
Neutron → quark → charge accumulate 0

* This difference was first evidence for the existance of quarks.
* Some other particles are also present (inside) like π^+ meson, π^- meson, π^0 meson., Pi- meson.

Lec:-

Deutron

$l = 0$, $l = 2$ Even parity.
$l = 1$ odd parity → we didn't take it.

→ If $l = 0$ assumption is correct there should no orbital contribution to the magnetic moment ($\mu \propto l$) and we can assume that the total magnetic moment is simply the combination of the neutron and proton magnetic spin moment

For Deutrons-

$$\mu = \mu_A + \mu_P$$

$\mu_S = g_s S \mu_N$ {spin magnetic moment}.

$\mu = \mu_n + \mu_p$

$$\mu = \frac{g_{sn}\mu_N S_n}{\hbar} + \frac{g_{sp}\mu_N S_p}{\hbar} \rightarrow (1)$$

Maximum value of spin is $+1/2\,\hbar$

using eq (1)

$$\mu = \frac{1}{2} g_{sn}\mu_N + \frac{1}{2} g_{sp}\mu_N$$

$\therefore S_n = 1/2\,\hbar$

$$\mu = \frac{1}{2}(g_{sN} + g_{sp})\mu_N \quad (2)$$

$S_p = \frac{1}{2}\hbar$ max

$g_{sN} = -3.826084$

$g_{sp} = 5.585691$

$S_n = 1/2\,\hbar$

$S_p = -1/2\,\hbar$ min

$$\mu = \frac{1}{2}\mu_N(-3.826084 + 5.585691)$$

$$\mu = 0.879804\,\mu_N \rightarrow (3)$$

Experimental value is of magnetic moment for deutron is $0.8574376 = 0.0000004\,\mu_N \rightarrow (4)$

If we compare eq (3) and (4) we known that the two values are in good agreement with very small discropency (which may arise in the poosent discussion of deutron bcz of state {l = 2} d state).

$\Rightarrow$ wave function for deutron

$$\psi = a_s\,\psi(l=0) + a_d\,\psi(l=2)$$

a_s and a_d are the constant.

$\Rightarrow$ Calculate its magnetic moment

$$\mu = a_s^2\,\mu(l=0) + a_d^2\,\mu(l=2)$$

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$\mu(l=0)$ is calculated.

$\mu = 0.879804$

for $\mu(l=2) = \frac{1}{4}(3 - g_{sp} - g_{sN})\mu_N$.

gives the calculated value for the state ($l=2$) d- state.

$$\mu(l=2) = \frac{1}{4}(1.240393)\mu_N$$

$$\mu(l=2) = 0.31009825\mu_N$$

observed values

$a_s^2 = 0.96$ $a_d^2 = 0.04$

$\mu = 0.96\,\mu(l=0) + 0.04\,\mu(l=2)$

96% 4%

$l=0$ states contribution $= 96\%$

$l=2$ " " $= 4\%$

In Section 3.5

Lec:

Electric quadrapole moment:-

It is a parameter which describes the effective shape of the nucleus. The quadrapole moment in C.M is $e(3z^2 - r^2) = eQ \rightarrow (1)$

* If a particle move with spherical symmetry than on the average $z^2 = x^2 = y^2 = \frac{r^2}{3}$) and quadrapole moment vanishes.

Shape of Nucleus is spherical that is why only for spherical symmetry. (Electric quadrapole $Z=0$)

* If a particle moves in a classical flat orbit say in the xy plane then $z=0$
so from (1) $eQ = -er^2$
$\Rightarrow Q = -r^2$

* The Quadrapole moment in Quantum Mechanics is $eQ = \int \psi^* e(3z^2 - r^2)\psi\, dV \rightarrow (2)$

For a single proton and for a single neutron $Q=0$

* If $|\psi|^2$ is spherical symmetrical then $Q=0$
$\left[z^2 = \frac{r^2}{3}\right]$ in eq (2)

* If $|\psi|^2$ is concentrated in xy plane. ($z=0$) in eq (2)

$$Q = \int \psi^* (-r^2)\psi\, dV$$

$$Q = -\int \psi^* r^2 \psi\, dV$$

$$Q = -\langle r^2 \rangle$$

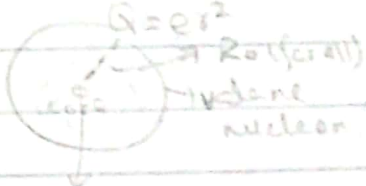
Here $\langle r^2 \rangle$ is the mean square radius of the orbit

* If $|\psi|^2$ is concentrated in the z plane
  $x, y = 0$ $\quad r = z$ then it mean
  $$Q = + \langle 2r^2 \rangle . \quad r = z$$
* Nucleons inside the nucleus are distributed in the form of core and valance nucleon
  Paired Nucleon $\longrightarrow$ Core $\longrightarrow$ Spherical in Shape.

Paired Nucleon move in spherically symmetric orbits so they do not contribute to Q.

◉ Nuclei 9 nucleons.
  - 8 nucleons $\rightarrow$ core.
  - 1 nucleons $\rightarrow$ valance nucleon.

▸ Orbit near the surface of the nucleus.



$$r = R_o A^{1/3}$$
$$R_o = 1.2 fm$$
$$A = \text{No. of nucleon.}$$

So $|eQ| \simeq e R_o^2 A^{2/3}$
$$|Q| \simeq R_o^2 A^{2/3}$$

Which ranges $6 \times 10^{-30} em^2$ for light nuclei. $50 \times 10^{-30} em^2$ for heavy nuclei

* The unit of $10^{-28} m^2$ is used frequently in nuclear physics/reactions are studied

$$1 \text{ barn} = 10^{-28} m^2$$
$$0.06 \, eb \text{ to } 0.5 eb$$

no contribution of inner nucleons as it is roughly spherical shape
Q = 0
so their quadrupole moment ...
A↑ Q↑
lighter and heavier nuclei have different values

1 barn = 10^{-24} cm^2.

This unit is convienient to measure quadrapole moment.

$\therefore eQ = r_0^2 A^{2/3}$
valid for unpaired.

* The observed Quadrapole moment for Deutron.
$l=0$ (s-state {spherical shape})
$l=2$ (d-state)

$Q = 0.00288 \pm 0.00002$ b
for $l=0$ wave function would have a vanishing quadrapole moment (b/c $l=0$ spherical symmetry)
* The mixed wave function for

$$\psi = a_s \psi(l=0) + a_d \psi(l=2) \rightarrow (1)$$

$$eQ = e\int \psi^* (3z^2 - r^2)\psi dV \rightarrow (2)$$

gives two contribution one is

Note

→ Book page # 75 Table 3.3 (check)

▸ Nuclei Quadrapole Moments.
Many of the nuclei given in table 3.3 fall within range of 0.06eb to 0.5eb. but several rare-earth nucleon ∴ paired nucleon (which is) → core also contribute in Quadrapole moment.

proportional to a_d^2 and another term is cross term that is proportional to $a_s a_d$. After performing the calculation by inserting ① eq in eq ② we get:-

$$Q = \frac{\sqrt{2}}{10} a_s a_d \langle r^2 \rangle_{sd} - \frac{1}{20} a_d^2 \langle r^2 \rangle_{dd}$$

where $\langle r^2 \rangle_{sd} = \int r^2 R_s(r) R_d(r) r^2 dr$ is the integral of r^2 over the radial wave function. Similarly $\langle r^2 \rangle_{dd}$. is defined similar to $\langle r^2 \rangle_{sd}$. & to calculate Q we must know about the deutron d-state wave function. and which is not directly measurable d state is consistent with 4% as deduced from magnetic moment. For the quadrapole moment the poor knowledge of the d-state wave function makes the deduced d-state mixture uncertain

$$(a_s \psi(l=0)) + (a_d \psi(l=2)) (a_s \psi^*(l=0)) + a_d \psi^*(l=2))$$

▶ Nucleon - Nucleon Scattering:-

The study of deutron gives some limited information about the nucleon-nucleon interaction because. there are no excited state.

We can only study the dynamics

of nucleon-nucleon interactions in the configuration of the deutron $l=0$ parallel spins

In order to study nucleon-nucleon scattering interaction in different confrigation we can perform nucleon-nucleon scattering experiments. In this an incident beam of nucleons is scattered from a target nucleon.

⇒ If the target is the nucleus with many nucleons then there will be several target nucleons within the range of nucleus potential for the incident nucleons. So there will be multiple scattering of single nucleon. which make complicated effect because of the multiple encounters. So in order to avoid that we select a target of hydrogen nuclei /atom so that the incident nucleon scattered from the individual proton present inside the nucleus of Hydrogen.

Article 4.2 :- If the probability of single encounter is small then the probability of multiple encounters will be negliable. Heavy nucleus have large no. of nucleons so there will be multiple encounter, the scattering process will be complex.

Light Nuclei $\rightarrow$ Small no. of nucleons. and scattering is not as complex as in heavy nuclei.

$\Rightarrow$ Nucleon - Nucleon scattering is identical to optical diffraction.
(pg No 86)
Nucleon - Nucleon scattering is analogues to optical diffraction. How.
pg # 86 (3 points)
$\rightarrow$ Classical approach.

Nucleon – Nucleon Scattering:-

Nucleon - Nucleon scattering $\xrightarrow[\text{CM}]{}$ Optical diffractio

Nucleon - Nucleon scattering $\xrightarrow[\text{QM}]{}$ Square well potential

Interaction of the incident particle with the particle in square well potential

Not only particle in box is imp but the coming particles are also imp.

$\rightarrow$ So when we are studing the scattering phenomena we are interacted with free incident particles with $E>0$

* Schrödinger eq by assuming $l=0$

* By considering that the incident nucleon is striking the target nucleon just at its surface that is the impact parameter is of the order of $R \simeq 1\,fm$
* If the incident nucleons are approaching with Velocity V. there angular momentum

mVR as in QM the angular momentum is quantized so,

$$mVR = l\hbar$$

If $l = 0$

$mVR << \hbar$

$$V << \frac{\hbar}{mR} \qquad \hbar = \frac{6.67 \times 10^{-34}}{2\pi}$$

$$T = \frac{1}{2}mv^2 << \frac{1}{2}\cancel{m}\frac{\hbar^2}{m^{\cancel{2}}R^2} << \frac{\hbar^2}{2mR^2} \simeq 20\,MeV$$

(Energy minimum incident)

In case if the value is used. $<< \frac{\hbar^2 c^3}{2mR^2} \simeq 20\,MeV$

Only that time particle is incident and possible if energy is less than 20MeV than case $l=0$ not possible scattering.

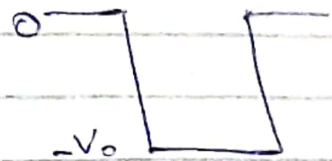
↳ phenomena known as low scattering phenomena and energy is 20MeV. ($l=0$)

* $E > 0$

when Energy is greater than zero to overcome a particle than possible

- $\delta = 0$ → low scattering phenomena → lighter nuclei → if heavy nuclei system become complicated

$$V(r) = -V_0 \qquad r < R$$
$$V(r) = 0 \qquad r > R$$



$$-\frac{\hbar^2}{2m}\frac{d^2u}{dr^2} + V(r)U(r) = EU(r)$$

$$U(r) = A\sin k_1 r + B\cos k_1 r \qquad \rightarrow \text{for } r < R$$
$$k_1 = \sqrt{\frac{2m(E+V_0)}{\hbar^2}}$$

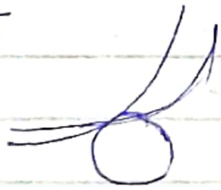
Boundary condition

$$U(r) = Ce^{-k_2 r} + De^{k_2 r}$$
$$k_2 = \sqrt{\frac{-2mE}{\hbar^2}} \qquad r > R =$$

(For $r > R$)

$$U(r) = C'\sin k_2 r + D'\cos k_2 r$$

σ



When u have different cross sections you have different angles.

(Read paragraph from book)
Nucleon-Nucleon scattering is Nuclear force. It is not just l dependent it is also spin dependent.

→ Contradiction between calculated cross-section (QM) and experimental cross section b/w Nucleon Nucleon interaction indicate that there is scattering missing → Spin part

$S = S_p + S_n$

$S = 1/2 + 1/2$

1 Triplet states. 0 singlet state.

For states determination: $2S+1$ (Multiplicity).

So we can conclude that Nucleon-Nucleon force is spin dependent.

Possible scattering:-

① p−p } Incident nucleon and target
② n−n } neuclon are same

③ p−n } Incident nucleon are different
④ n−P } from target nucleon.

Nature changes

Two charges interact so charges same than coloumb force is also present with Nuclear force.

⊙ Nuclear force is charge dependent

$F = \frac{K q_1 q_2}{r^2}$

if 1 zero Than Coloumb force zero and it has no cloumb force with nuclear force.

Lighter Nuclei	Heavy Nuclei
Less scattering rate	High scattering rate
Higher intensity. (after process scattered beam). (beam intensity after scattering)	Low Intensity
Mathematical formulation is simple.	Mathematical formulation is complex.

* When two nucleons come together they exert a nucleon-nucleon force.
* When energy is less than certain energy is there is no scattering.

Pg 200

Properties of Nuclear force:-

① The interaction b/w two nucleon consist to lowest order of an attractive central potential. square well potential fairly well fits with the observed data in case of nucleons.

$V_c(r)$.
↳ central potential (depend on r)

r is the inner nucleon distance
This is theorectically.

Now expermentally:- Nucleon-Nucleon parameter
↓
Scattering parameter → phase shift
↓
Exp data → Assume potential force
$V_c(r)$ V_c potential

② The nucleon-nucleon interaction is strongly spin dependent. → The observation results b/c of the failure to observe a singlet bound states of the deutron.

- Measure difference b/w singlet and triplet cross-section.
- Potential modification → Spin term include.

If we have two nucleons, one with spin S_1 and other with S_2 $S_{1/2}$. All combinations of S_1 and S_2 are not permitted

* Nuclear force must follow some symmetry which restrict the fo of potential
* Parity $(r \rightarrow -r)$ → conservation of angular momentum

$\downarrow$ coordinate reversal. $\quad \vec{L} = \vec{r} \times \vec{p}$

* the time reversal $(t \rightarrow -t)$ reaction are b
  IF those conditions are fulfill so from force we got a values
  Linear and angular momentum {they are reversed}

Combinations:- S_1 and S_2

$AS_1 + BS_2$

$$\left.\begin{array}{l} V_c(r) \sim S_1 \\ V_c(r) \sim S_2 \end{array}\right\} \rightarrow (1)$$

Linear combination: $AS_1 + BS_2$ when we put $t \rightarrow -t$ so there is negative sign so we take square

Time reversal conservation is imp for the nuclear force and for the central potential.

IF they (1) are present in potential they will violate the time reversal potential.

$S_1 \cdot S_2$ is the simplest term which include the spin of both nucleon.

S_1^2, S_2^2 are allowed in the expression of potential $V_c(r)$.

$S_1 . S_2$ for singlet state

$S_1 . S_2$ for triplet state

In order to find S_1, S_2 combination of singlet and triplet we have to evaluate the total spin which is $S = S_1 + S_2$ (total spin)

$$S = S_1 + S_2$$

$$S . S = (S_1 + S_2)(S_1 + S_2)$$

$$S^2 = S_1^2 + S_1 S_2 + S_2 S_1 + S_2^2$$

$$2 S_1 . S_2 = S^2 - S_1^2 - S_2^2$$

$$S_1 . S_2 = \frac{1}{2}\left[S^2 - S_1^2 - S_2^2\right].$$

As in Q.M $S^2 = S(S+1)\hbar^2 \rightarrow 1$

$$\langle S_1 S_2 \rangle = \left[\langle S^2 \rangle - \langle S_1^2 \rangle - \langle S_2^2 \rangle\right] \rightarrow 2$$

Use eq 1 in eq 2

$$\langle S_1 . S_2 \rangle = \frac{1}{2}\left[S(S+1) - S_1(S_1+1) - S_2(S_2+1)\right]\hbar^2 \quad 3$$

For singlet state $\underset{(2S+1)}{S = 0}$, $S_1 = 1/2$, $S_2 = 1/2$

Use in eq 3

$$\langle S_1 . S_2 \rangle = \frac{1}{2}\left[-\frac{1}{2}\left(1/2+1\right) - 1/2\left(1/2+1\right)\right]\hbar^2$$

$$'' = \frac{1}{2}\left[-3/4 - 3/4\right]\hbar^2$$

$$'' = \frac{1}{2}\left[-3/4\right]\hbar^2$$

$\langle S_1 \cdot S_2 \rangle = -\frac{3}{4}\hbar^2$

Similarly find the triplet state is nearly
$(2S+1)$ $\quad S_1 = 1/2,\ S_2 = 1/2,\ S = 1$

$\langle S_1 \cdot S_2 \rangle = \frac{1}{4}\hbar^2$ for triplet state

$S_1 \cdot S_2 \quad V_c(r)$ include in central potential term.

$$V(r) = -\left(\frac{S_1 \cdot S_2}{\hbar^2} - \frac{1}{4}\right) V_1(r) + \left(\frac{S_1 \cdot S_2}{\hbar^2} + \frac{3}{4}\right) V_3(r)$$

$V_1(r)$: singlet state potential
$V_3(r)$: triplet state potential

(3) The interaction potential includes a non central term know as a Tensor potential. Evidence for the tensor forces comes primarly from the observed quadrapole moment of the ground state of the deutron. As S-state ($l=0$) wave function is sphorically symmetric the electric quadrapole moment vanishes wave function with mixed l-state must form some non-central potential (tensor potential)

$$V_c(r) \longrightarrow V(\vec{r})$$

direction and magnitude.

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S_1^2, S_2^2 are allowed
potential $V_c(r)$
$S_2 . S_1$

Lec:

The Nucleon-Nucleon Interaction / Properties of nuclear force:-

① The nucleon-nucleon force is charge symmetric.
This means that the proton proton interaction is identical to the neutron-neutron interaction.
After correcting (means removing) the colomb force is proton proton interaction.
Here charge refers to the character of the nucleon (proton or neutron) and not to the electric charge.
→ Evidence in support to this comes from the equality of pp and nn scattering length. After applying the correction term in pp interaction. Some of its parameter are

$$\left.\begin{aligned} a &= -1.71 \pm 0.2\,fm. \\ r_0 &= 2.84 \pm 0.03\,fm. \end{aligned}\right\} \rightarrow ①$$

They are in good agreement with nn interaction

$$\left.\begin{aligned} a &= -16.6 \pm 0.5\,fm \\ r_0 &= 2.66 \pm 0.15\,fm. \end{aligned}\right\} ②$$

last point (symmetric) means n → p
Elaborate nn
pp
mai nucleon same
bhi force ho

① and ② support the charge symmetry
⑤ The nucleon - nucleon force is nearly charge
→ The nuclear forces nn, pp, pn are identical after correcting for the pp colomb force b/w two pp interaction

nn → just nuclear force
pp → $\boxed{\text{Colomb}}$ → we have to eliminate it and Nuclear both
pn → only nuclear force
Correcting term.

⑥ The nucleon-nucleon interaction becomes repulsive at short distances.
This conclusion follows from qualitative considerations of the nuclear density. as we add more nucleons the nucleus grows in such a way that its central density remains roughly constant and thus something is keeping the

7) The nucleon – nucleon interaction may also depend on the relative velocity or momentum of the nucleon.

Weak force $\longrightarrow$ $V(r)$ $\rightarrow$ Parity conservation. $r \rightarrow -r$

$\hookrightarrow$ Time reversal $t \rightarrow -t$

$V(r) \sim$ terms with linear power of p

terms with square power

$p \longrightarrow -p$ parity operator

$p \longrightarrow -p$ time reversal

In $V(r)$ terms with linear power of momentum are not included b/c Parity and time reversal invariance is violated

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$\vec{\sigma}\cdot\vec{p}$ or $\vec{\sigma}\times\vec{p}$ } → Parity conserved but time reversal is still violated.

Possible structure for this term is
$V(r)\,\vec{\sigma}\times\vec{p}\cdot\vec{S}$
where $S = S_1 + S_2$
Total spin of two nucleons.

Potential ke isse part jo ($\vec{L}\cdot\vec{S}$) se depend ha

$V_{LS}(r)\,\vec{L}\cdot\vec{S}$ → spin orbit potential term

(p) (n)
V_1 V_2

Time reversal ma spin change ho jaye ge up → down, down → up

* Although high order terms may be present but only first order term in p satisfies the symmetries of both parity and time reversal

Yukawa's theory of Nuclear force:-

1) Nuclear force → binding the Nucleus → proton + neutron.
2) Nucleus is about ~fm

p —— 1fm —— p

If we take two protons at a distance of 1fm

$$F = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2} = 230\,N$$

$e = 1.6 \times 10^{-19}\,C$

So the two protons are repelling each other with a force of 230 N large force

-> Then how it is possible that two protons are still present inside the nucleus. Even in some nucleus we have more than two proton in a tiny region of space

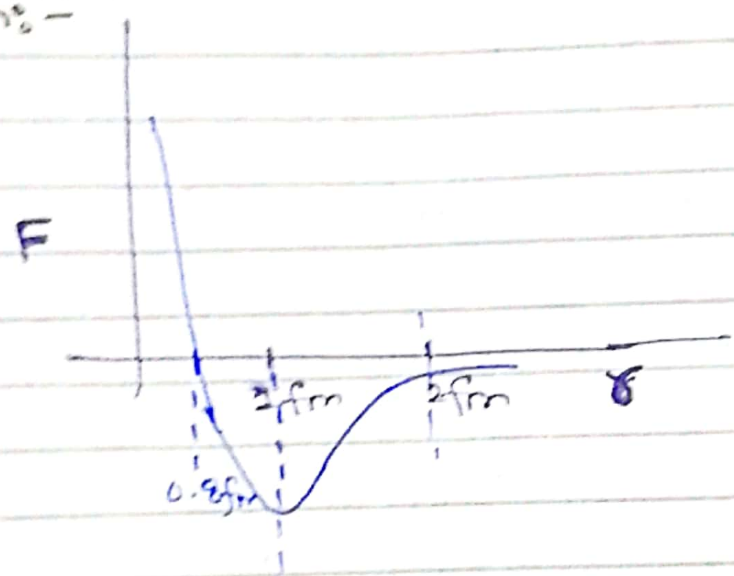
-> There is also another force other than coulomb repulsive force inside the nucleus and that is the nuclear force.
-> The nuclear force b/w the two protons at a distance of about 1 fm is around 2300 N. So it is 100 times more powerful than the repulsive force.

Q. Is Nuclear force only attractive ?
No but at shorter distances.

Question: Nucleus size, Two Protons repelling, Nucleus ka ander Nuclear force 100 times greater hoti hai.

As nuclear force is binding → Attractive but nuclear force is not just attractive it can be repulsive at short distances.
* So its nature of direction and repulsion for the nucleus force depends on the distance at which we are observing.

Graph:-



* At distance less than 0.8fm this nuclear force is Repulsive that means that it pushes the nucleons apart.

* At distance from 0.8fm - 2fm the nuclear force is attractive.

* For the distance more than 2fm the force become negliable.

① One of the successful theories describing the behaviour of nuclear force was given by a Japanese scientist Hideki Yukawa in 1935.
② This theory is known as Yukawa's theory of nuclear force or meson theory.

According to the theory:--

(i) Nuclear force exist as a result of exchange of particles.
(ii) The Neutron and Protons are continously emitting or absorbing another particle that is π-meson.

→ Whenever the near by neutron or Proton emit or absorb a particle this leads to a force which is nuclear force.

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