
Particle Physics Seminar
Isospin Symmetry and its Implications
-By Kushagra Nigam
Venue :- L202
Date :- 29/4/14
Time :- 5:15 pm

Goals Of Seminar

- To understand the structure of atom and nucleus before discovery of neutron.
- To study the birth of neutron and how it lead to formulation of isospin symmetry.
- To illustrate the model of nucleus after isospin formulation.
- To illustrate the implications of isospin and its relation with quark model.

Model of atom before Chadwick

- Before 1925, atomic model was manly based on Bohr-Sommerfeld Theory.

n	l	m
Size	Shape	Orientation

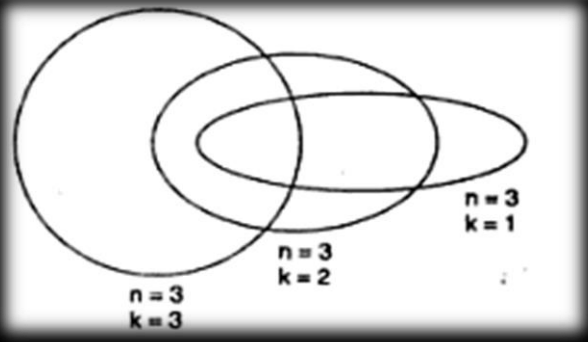
- In 1925, Pauli showed that for a complete characterization of electronic levels a fourth quantum number was needed – Spin s

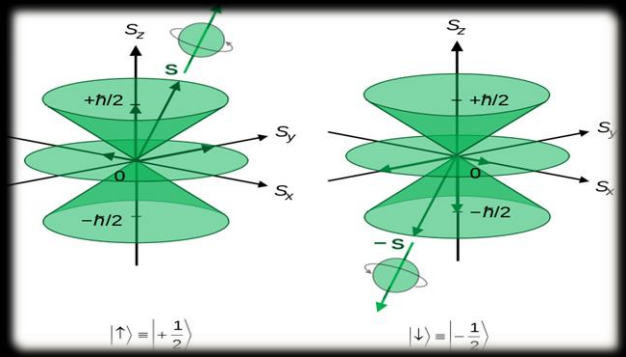
- Pauli Mathematically described Spin using Pauli Matrices.

$$\sigma_x = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \quad \sigma_y = \begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix} \quad \sigma_z = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$$

$$1 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

n	l	m	s
Size	Shape	Orientation	Spin





Timeline

- n - 1913 - Bohr
- l - 1914 - Sommerfeld
- m - 1914 - Sommerfeld
- s - 1925 - Pauli

Nuclear Structure without Neutrons

Facts before 1932:

- A-Mass No. Z- Atomic No.
- Mass of any nucleus is approximately Am_p.
- Nucleus was seem to behave as quantum mechanical system.
- Strong forces bind nuclear constituents.
- The charge on nucleus is given as Ze.
- Nucleus has A protons and Z-A electrons.

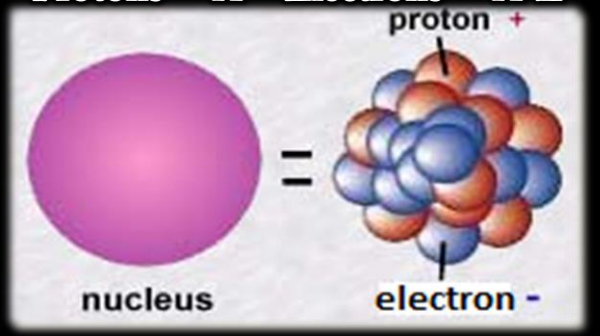
Problems Faced with this model:

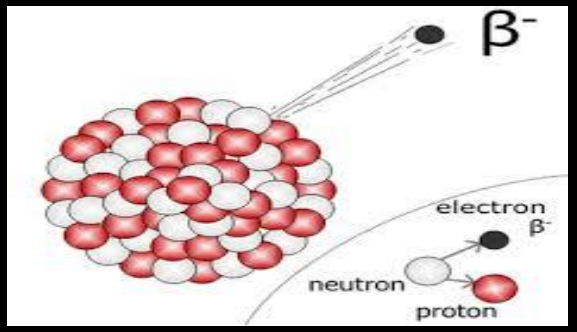
- **Consider Beta Decay Process:**

$$\underset{N}{{}^{A}X} \longrightarrow \underset{N-1}{{}^{A}Y} + \underset{-1}{{}^{0}e} + \nu + E$$

Charge	Energy	Ang. Mom.
Conserved	Violated	Violated

Protons = A Electrons = A-Z





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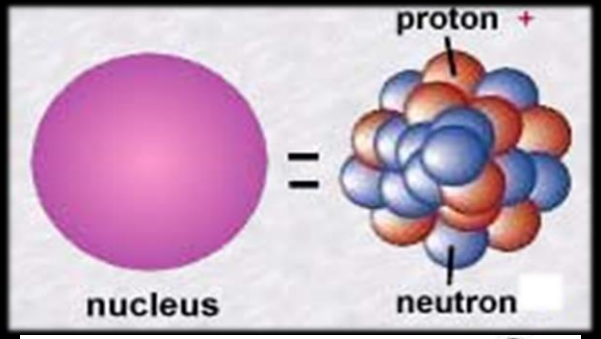
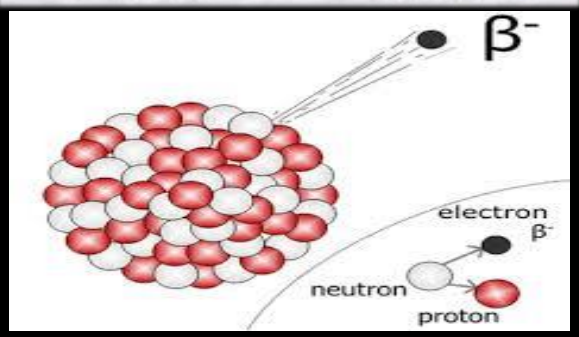
Discovery of Neutron

Post Neutron Discovery Scenario:

- **Problem of β – Decay got separated from nuclear structure.**
- **New model of nucleus had Z protons and A-Z neutrons.**
- **Heisenberg Develops a new Quantum Mechanical Model of Nucleus.**

Protons = Z Neutrons = A-Z





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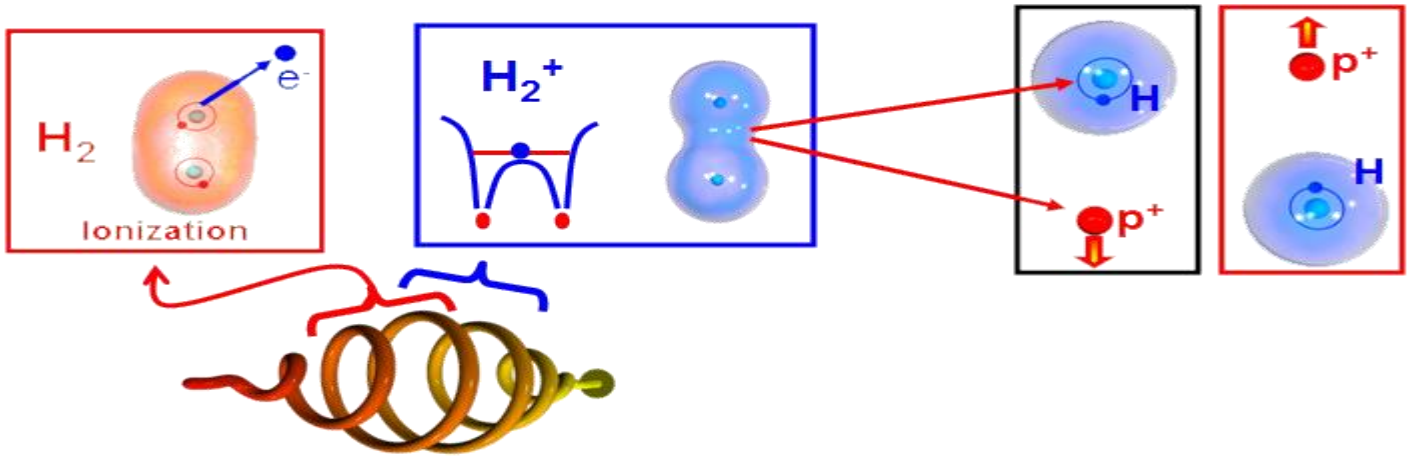
- **Neutron – 1932 Chadwick**

Homopolar Binding Model

Consider the following picture of H_2^+ ion:

r_1	r_2	Atomic States
$\oplus$	$\ominus\oplus$	$\|A>$
$\oplus\ominus$	$\oplus$	$\|B>$



Consider Similar Picture for Nucleus:

r_1	r_2	Nuclear States
$\oplus$	$\circledcirc$	$\|N_a>$
$\circledcirc$	$\oplus$	$\|N_b>$

Isospin Formulation By Heisenberg

r_1	r_2	Nuclear States
⊕	⊙	$\|N_a>$
⊙	⊕	$\|N_b>$

$$|I = 1; I_3 = 1> = pp$$

$$|I = 1; I_3 = 0> = \sqrt{\frac{1}{2}}\,(pn + np)$$

$$|I = 1; I_3 = -1> = nn$$

$$|I = 0; I_3 = 0> = \sqrt{\frac{1}{2}}\,(pn - np)$$

Points to note:

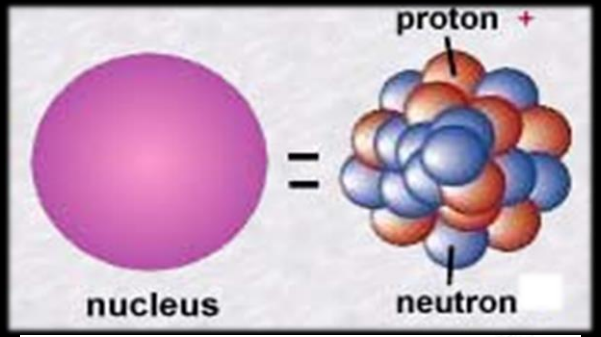
i) Isospin is not spin in quantum mechanical sense.

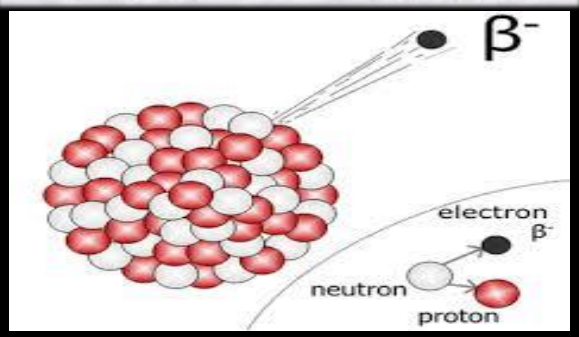
ii) It does not have units of angular mom.

iii) Particles are given isospin value based on the increasing charge.

iv) No. of members in an isospin multiplet depends on the number of different charged states.

Protons = Z Neutrons = A-Z





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- 1932 – Isospin - Heisenberg

Implications of Isospin Formalism

i) Pion discovery : π^+ π^0 π^- -> Isospin triplet
I=1 I_3: 1 0 -1

ii) K mesons :$(K^+, K^0), (K^-, \overline{K^0})$ -> Isospin doub.
I= 1/2 I_3: 1/2 -1/2

iii) Sigma Baryons : (Ξ^+, Ξ^0, Ξ^-) -> Isospin triplet
I= 1 I_3: 1 0 -1

iv) Delta Baryons : $(\Delta^{++}, \Delta^+, \Delta^0, \Delta^-)$ -> Isospin quartlet
I= 3/2 I_3: 3/2 1/2 -1/2 -3/2

WHAT CONCLUSION CAN BE DRAWN FROM ABOVE DISCOVERIES??

i) There is an underlying substructure common to all the above baryons and mesons.

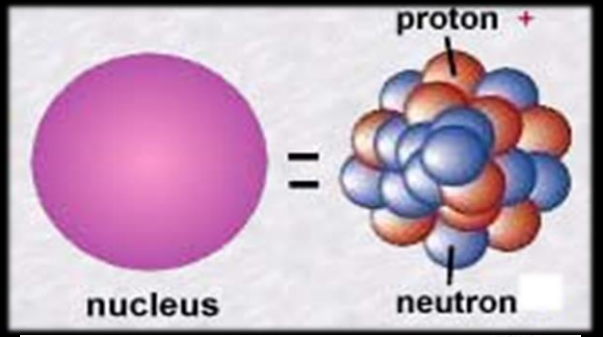
ii) This leads us to consider quark model consisting of u and d quarks that have very similar masse but different charge. For example

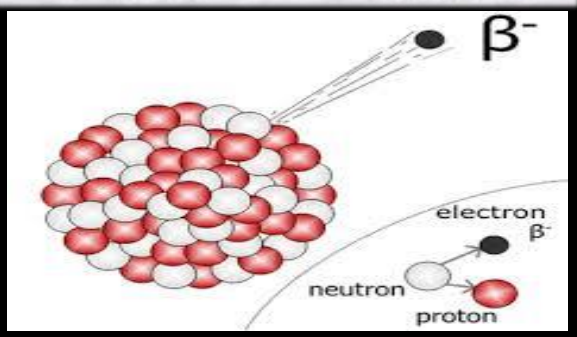
Δ^{++}	Δ^+	Δ^0	Δ^-
uuu	uud	udd	ddd

iii) Isospin of a particle in quark model is related to up and down content.

$$I_3 = \frac{1}{2}\left[\left(n_u - n_{\bar{u}}\right) - \left(n_d - n_{\bar{d}}\right)\right]$$

Protons = Z Neutrons = A-Z





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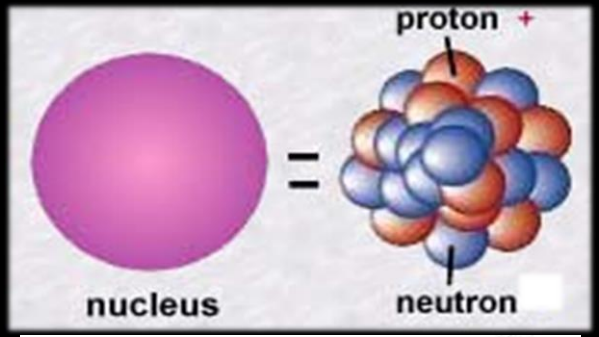
- 1932 – Isospin - Heisenberg
- 1947 – Pion Discovery

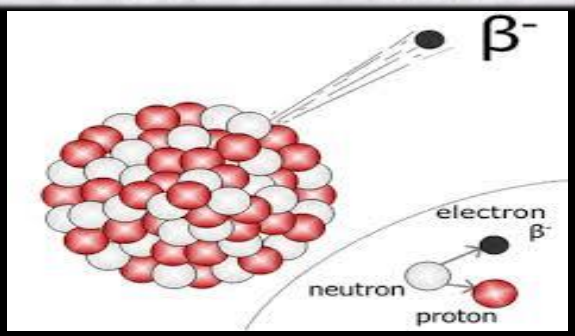
Conclusion

- What started as a two state problem by Pauli led Heisenberg to formulate Isospin model of nucleus.

- Isospin model further became generalized to multiplets which led to quark model of particle physics.

Protons = Z Neutrons = A-Z





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Any Questions?

Black Board Mode