

## \* Meson theory of Nuclear forces (Yukawa's theory)

According to Meson theory of Nuclear forces the core of all nucleus is surrounded by a cloud of one or more mesons. Mesons are elementary particles which may be +ve, -ve or neutral.

Yukawa assumed that  $\pi$ -meson is exchanged bet<sup>n</sup> the nucleons and this exchange is responsible for the nuclear binding force.

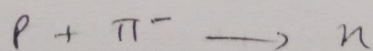
The forces bet<sup>n</sup> two neutrons and bet<sup>n</sup> two protons are the result of exchange of neutral mesons

( $\pi^0$ ) bet<sup>n</sup> them. The force bet<sup>n</sup> a neutron & or a proton is due to the exchange of charge mesons

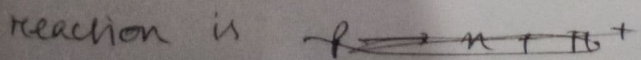
( $\pi^+$  or  $\pi^-$ ). A neutron emits

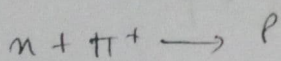
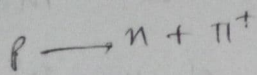
A neutron emits  $\pi^-$  meson and converted into a proton.  $n \rightarrow p + \pi^-$

on the other hand the absorption of  $\pi^-$  meson by the proton converts it into a neutron.



In the reverse process a proton emits a  $\pi^+$  meson becoming a neutron and neutron on the other hand receives these  $\pi^+$  meson to become a proton. This reaction is





Thus <sup>in</sup> the nucleus of an atom attractive

forces exist b/w the nucleons which is very much larger than the electrostatic force of repulsion bet<sup>n</sup> them, giving a stability to the nucleus. Just as a photon is a quantum of electromagnetic field, a meson is a quantum of nuclear field.

Yukawa considered the eq<sup>n</sup> for particle of mass  $m$  as

$$\left( \nabla^2 - \frac{m^2 c^2}{(\hbar/2\pi)^2} - \frac{1}{c^2} \frac{\partial^2}{\partial t^2} \right) \phi = 0 \longrightarrow (1)$$

This eq<sup>n</sup> is only valid for spinless particle.

Separating the time depending part, the radial part of eq<sup>n</sup> (1) can be written as

$$\left( \nabla^2 - \mu^2 \right) \phi(r) = 0 \longrightarrow (2)$$

where  $\mu = \frac{mc}{\hbar/2\pi}$

The sol<sup>n</sup> of eq<sup>n</sup> (2) is



$$\phi(r) = \frac{-g e^{-\mu r}}{r} \quad \text{--- (III)}$$

The potential bet<sup>n</sup> two ~~nucleas~~ <sup>nucleons</sup> is given by

$$V(r) = \frac{-\tilde{g} e^{-\mu r}}{r} \quad \text{--- (IV)}$$

here  $\tilde{g}$  is called the coupling constant

This made Yukawa predict the existence of pions as a quantum of nuclear force field.

[The range of pion field is  $\frac{h/2\pi}{m_{\pi}c} \approx 1.4 \text{ fm}$ ]

Q Show that the mass of the meson is equal to  $275 \times \text{mass of } e^{-}$

Sol<sup>n</sup>

On the basis of the range of a nuclear force and uncertainty principle it is possible to estimate the mass of a meson. According to uncertainty principle

$$\Delta E \Delta t \approx h = \frac{h}{2\pi}$$

where  $\Delta E \rightarrow$  uncertainty energy

$\Delta t \rightarrow$  uncertainty time

We know range of nuclear  $1.4 \times 10^{-15} \text{ m}$ . let us assume that the meson bet<sup>n</sup> nuclei at the speed of

light  $c$ . let  $\Delta t$  be the time interval  
between the emission of a meson and its  
absorption, then

$$\Delta t = \frac{R}{c}$$

therefore the min<sup>m</sup> meson mass is  
specified by

$$m \geq \frac{\hbar}{2\pi RC}$$

in terms of electron mass ( $m_e$ ) the  
mass of meson is

$$\begin{aligned} \frac{m}{m_e} &= \frac{\hbar/2\pi}{m_e RC} = \frac{1.054 \times 10^{-34}}{9.1 \times 10^{-31} \times 14 \times 10^{-15} \times 3 \times 10^8} \\ &= 0.0275 \times 10^4 \\ &= 275 \end{aligned}$$

$$\Rightarrow m = 275 m_e$$