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

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

Yukawa assumed that π-meson is exchanged bet^n the nucleons and this exchange is responsible for the nuclear binding force.

The forces bet^n two nutrons and bet^n two protons are the result of exchange of nutral mesons (π^0) bet^n them. The force bet^n a nutron ~~of~~ or a proton is due to the exchange of charge mesons (π^+ or π^-). ~~A nutron emits~~

A nutron emits π^- meson and converted into a proton. $n \longrightarrow P + \pi^-$

On ~~ther~~ other ~~H~~ hand the absorption of π^- meson by the proton converts its into a nutron.

$$P + \pi^- \longrightarrow n$$

In the reverse process a proton emits a π^+ meson becoming a nutron and nutron on the other hand receives these π^+ meson to become a proton. This reaction is ~~$P \rightarrow n + \pi^+$~~

$$p \longrightarrow n + \pi^+$$

$$n + \pi^+ \longrightarrow p$$

Thus in the nuclear of an atom attractive forces exist betn the nucleons which is very much larger then the electrostatic force of repulsion betn 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 eqn for particle of mass m as

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

This eqn is only valid for spinless particle. Separating the time depending part, the radial part of eqn (i) can be written as

$$(\nabla^2 - \mu^2)\,\phi(r) = 0 \longrightarrow (ii)$$

where $\mu = \dfrac{mc}{h/2\pi}$

The soln of eqn (2) is

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

The potential betn two ~~nucleas~~ nucleons is given by

$$V(r) = \frac{-g^2 e^{-\mu r}}{r} \text{ ——— (iv)}$$

Here g^2 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 $\frac{h/2\pi}{m_\pi c} \approx 1.4\ fm$]

Q Show that the mass of the meson is equal to 275 × mass of e^-

Soln

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

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

where $\Delta E \rightarrow$ uncertainity energy

$\Delta t \rightarrow$ uncertainity time

we know range of nuclear 1.4×10^{-15} m. let us assume that the meson betn nuclei at the speed of light c. let Δt be the time interval

betn the emission of a meson and its

absorption, then

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

therefor the min^m meson mass is

specified by $m \geqslant \frac{h}{2\pi} / Rc$

in terms of electron mass (m_e) the

mass of meson is

$$\frac{m}{m_e} = \frac{h/2\pi}{m_e Rc} = \frac{1.054 \times 10^{-34}}{9.1 \times 10^{-31} \times 1.4 \times 10^{-15} \times 3 \times 10^{8}}$$

$$= 0.0275 \times 10^{4}$$

$$= 275$$

$$\Rightarrow m = 275\, m_e$$