Theories of Nuclear Composition

I. Proton-electron hypothesis

Before the discovery of neutron, it was assumed that nucleus contains both proton and electron. The spontaneously emitted negative particle from nucleus was wrongly assumed as the electrons. According to which, a nucleus of mass number A and atomic number Z contains A protns and $A-Z$ electrons so that an atom as a whole is electrically neutral. For example, in Sodium nucleus $_{11}Na^{23}$, there are 23 protons and $23-11=12$ electrons and there are 11 electrons in the orbit.

The later investigation showed that electron can not exist in the nucleus. Following are the supporting evidences:

1. **Nuclear size and energy:** The size of the nucleus is about $10^{-14}m$, *i.e.* uncertainty in its position is $\Delta x = 10^{-14}m$. According to uncertainty principle,

$$\Delta x \cdot \Delta p \geq \hbar$$
$$\Delta p \geq \frac{\frac{h}{2\pi}}{\Delta x} = \frac{1.054\times10^{-34}}{10^{-14}}$$
$$\Delta p \geq 1.1\times10^{-20}kgms^{-1}$$

An electron whose momentum is Δp given above, has its rest energy m_0c^2 Then,

$$E = pc$$
$$= 1.1\times10^{-20}\times3\times10^{8}$$
$$= 3.3\times10^{-12}J$$
$$= 20.63MeV$$

Thus the energy possessed by the electron emitted ny the nucleus should be equal to or more than $20.63MeV$, but experimentally it was observed that energy of these negative particles are 2 to 3 MeV. Hence electron can not exist inside a nucleus.

2. **Nuclear spin:** Proton and electron have half-spin. Thus nuclei with an even number of proton and electrons should have integral spins while those with an odd no. of electrons and protons should have half integral spins. Let us consider deuteron as an example. Deuteron nuclei consists of two protons and single electron. Hence the total nuclear spin should be 1/2 or 3/2. But experiment shows that the spin of the deuteron is 1, which again is in contrary to the hypothesis.

II. Proton- neutron hypothesis

After the discovery of neutron, a new hypothesis was devised, according to this, a nucleus of atomic number Z and mass no. A consists of Z-proton and $A-Z$ neutrons in the nucleus. There are Z electrons in the outer orbit. Hence the atom is as a whole electrically neutral.

- This assumption is able to explain the observed value of nuclear spin.
- There is no difficulty in explaining the existence of isotopes on this hypothesis. Isotopes of a given element differ only in the no. of neutrons they contain.

Meson Theory of Nuclear Forces

Mesons are intermediate mass particles. They are heavier than leptons but lighter than Baryons. Each meson consists of one quark and one anti quark.

According to meson theory of nuclear force, all nucleons consist of identical core surrounded by a cloud of one or more meson. Mesons may be neutral or may have positive or negative charge. Yukawa assumed that π meson is exchanged between the nucleons and this exchange is responsible for the nuclear binding forces, *i.e.* the forces that act betwee protons and between neutrons are the result of the exchange of neutral mesons (π^0) between them and the force between neutron and a proton is a result of the exchange of charged mesons between them.

Thus when neutron gets converted into proton a π^- meson is emitted

$$n \rightarrow p + \pi^-$$

The absorption of π^- meson by the proton converts it into a neutron.

$$p + \pi^- \rightarrow n$$

In the reverse process.

$$p \rightarrow n + \pi^+$$

$$n + \pi^+ \rightarrow p$$

Thus in the nucleus of an atom, attractive force exist between proton-proton, proton-neutron, and neutron-neutron. These forces of attraction are much larger than the electrostatic force of repulsion between proton-proton, thus giving the stability to nucleus.

Now, in order to calculate the mass of the meson, we consider the range of nuclear force is $R = 1.4 \times 10^{-15} m$

According to uncertainty principle, $\Delta E \cdot \Delta t \geq \hbar$ where ΔE and Δt are uncertainties in energy and time. Consider meson travels with speed of light c between the nucleons and let Δt be the time interval between emission of meson from one nucleon and the absorption by the other nucleon.

Then,

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

$$\therefore \Delta E = \frac{\frac{h}{2\pi}}{\Delta t} = \frac{hc}{2\pi R} \quad \Rightarrow mc^2 \geq \frac{hc}{2\pi R} \quad \Rightarrow m \geq \frac{h}{2\pi Rc}$$

Therefore in terms of electronic mass m_e

$$\frac{m}{m_e} = \frac{h}{m_e 2\pi Rc} \approx 275$$

$$m = 275 \times m_e$$

$$mass\ of\ meson \ \approx\ 275 \times mass\ of\ electrons$$