Lecture- 3a

Conservation Laws :

Ref. :1- Atomic and nuclear physics
2nd Ed. Talittlefield

- 2-Introductory nuclear physics
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- **1.3\ Conservation Laws :**
- **1- Conservation Law of Energy and Charge:**
- Some particles are stable, others are unstable. The most important rule here is conservation of energy. In any reaction the final energy must be exactly equal to the initial energy. A particle of a given mass has a certain amount of energy, given by Einstein's equation $E = mc^2$.
- In asking if a particle can decay, one must first try to find a set of particles whose total mass is less than that of the particle under consideration. A particle with a mass of 100 MeV cannot decay into two particles with a total mass exceeding 100 MeV. The law of conservation of energy forbids this, and Nature is very strict about this law. For more massive particles there will usually be enough energy available, and therefore they tend to be unstable. Excess energy is carried away in the form of kinetic energies of the decay products.
- *Let us turn once more to neutron decay. The neutron has a mass of 939.57 MeV and it decays into a proton, an electron and an antineutrino*

- Neutron $\longrightarrow$ proton + electron + antineutrino
- The proton has a mass of 938.27 MeV, the electron 0.511 MeV and the antineutrino mass is very small or zero. One sees that the sum of the masses of the electron and the proton is 938.78 MeV, which is 0.79 MeV less than the neutron mass. From an energy point of view the decay can go, and *the excess* **energy is carried off in the form of kinetic energy of the proton, electron and antineutrino.**
- **However, the energy balance is not the whole story. Why for example is there an antineutrino in this reaction? And why is the proton stable**? It could, energy wise, decay into an electron and a neutrino, to name one possibility. Here enters an important concept, namely conservation of electric charge. Charge is always strictly conserved. Since the proton has a charge +ve to that of the electron, that decay, if it were to occur, would have a different charge in the initial state (the proton) as compared with the final state (an electron and an electrically neutral neutrino). Thus there may be conservation laws other than conservation of energy that forbid certain reactions. The law of conservation of charge was already a basic law of electromagnetism even before elementary particles were observed. There are several conservation laws on the level of elementary particles, and some of them remain verifiable macroscopically. Charge and energy are the foremost examples.

- On the elementary particle level electric charge has a very special feature: it occurs only in discrete quantities. Measuring the charge in units in which the charge of the electron is -1,one observes charges which are integers,or for quarks multiples of $\frac{1}{3}$
- In other words, charge is quantized. This allows us to formulate this conservation law slightly differently; the charge appears as a number, and counting the charge of any configuration amounts to adding the numbers of the various particles. Let us call that the charge number. **Conservation of electric charge means that the charge number of the initial state must be equal to that of the final state. For example, for neutron decay (neutron → proton + electron + antineutrino) the charge number of the initial state is zero, while for the outgoing state it is + 1 (proton) plus − 1(electron) which gives zero as well.** The charge quantum number is conserved.
- There are six different kinds, or ***flavors'*** of quarks:(u ,d, c, s ,t, b). These six particles may be arranged according to their masses into three pairs,
- with one member of each pair having a charge $\frac{2}{3}$ e and the other $-\frac{1}{3}$e, as shown in Table(2)

Table 2: Quarks and leptons.

Quarks			
$Q/e = \frac{2}{3}$	u	c	t
$Q/e = -\frac{1}{3}$	d	s	b
Leptons			
$Q/e = -1$	e	μ	τ
$Q/e = 0$	ν_e	ν_μ	ν_τ

- **While Leptons** Although quarks make up the bulk of observed mass in the universe, they are not the only elementary building block of particles with finite rest masses. ***Leptons,*** or light particles, are not made of quarks. They participate in electromagnetic and weak interactions but not in strong interaction. The number of different types of known leptons is also six and can also be arranged into three pairs, as shown in Table(**2).**
- The elcctron (e), the muon ***(μ) ,*** and the tau lepton ***(τ)*** carry a charge **-e** each , but the electron neutrino ***(v_e),*** the muon neutrino ***(v_μ)*** and the tau neutrino ***(ν_τ)*** are neutral.

The masses of leptons are much less than those **of** quarks, with $\mathbf{m_e c^2 = 0.511}$ MeV, $\mathbf{m_\mu c^2}$ = 106 MeV, and , $m_\tau c^2$ = 1784 MeV. The neutrinos are known to be much lighter and their rest masses may even be zero.

<u>Example:</u> in antiproton production,

$$\mathrm{p} + \mathrm{p} \rightarrow p + p + p + \bar{p}$$

q: +1 +1 = +1 +1 +1 -1

- **2-Lepton number conservation:**
- The lepton number is defined as L=+1 for **lepton particle** ,L=-1 for **lepton antiparticles** ,and L=0 for **all other particles**. The number of leptons is conserved in a reaction. **For example**, a free neutron decays with a lifetime of 886.7 $\pm$1.9 s through the reaction :
  - $n \rightarrow p + \bar{e} + \bar{\nu}_e$ ……. (1)
- L 0 = 0 + 1 +(-1)
- On the L.H.S. of equ.(1), only a neutron is present. Since there is no lepton, we can assign L = 0 as ***its lepton number***. On the R.H.S. of equ.(1), we have one electron, which carries a lepton number L= 1.

- An antiparticle is given a particle number of the same magnitude as the particle with which it is associated but with the opposite sign. This is necessary since an antiparticle can annihilate a particle to form a state with no particle. Hence, the lepton number of ($\bar{v}_e$) is(-1). The total lepton number on the R.H.S.of Eq.(1) is:
- L = 1 + (- 1) = 0. With these assignments, we find that the lepton number is conserved in the reaction.
- **Examples** of lepton numbers conservation ,consider the decay of the muon:
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- $\mu^- \rightarrow e^- + \bar{v}_e + v_\mu$
- Sol.
- $\mu^- \rightarrow e^- + \bar{v}_e + v_\mu$
- $\boldsymbol{L_e}$ **0 = +1 -1 + 0**
- $\boldsymbol{k^0 \rightarrow \pi^+ + e^- + \bar{v}_\mu}$
- $\boldsymbol{L_e}$ **0 = 0 + 1 - 1**