RUDIMENTARY PARTICLE PHYSICS & LARGE HADRON COLLIDER

(Compiled by Dr. S. S. Tripathy, President, *The Uranium*)

The entire universe is made up of two types of elementary particles. Note that the proton and neutron are also further divisible to still smaller particles. In other words they are made up of elementary particles which are still smaller than them. These two types of elementary particles are

(a) QUARKS (b) LEPTONS

QUARKS :

There are six types of quarks.

(1) UP (U quark) (2) DOWN (D quark)
(3) CHARM (C quark) (4) STRANGE (S quark)
(5) TOP (T quark) (6) BOTTOM (B quark)

U, C and T quarks carry +2/3 units of charge while D, S adn B quarks carry –1/3 unit of charge.Quarks always remain in groups. Hence they are social entities.

LEPTONS:

There are 6 types of leptons.

(1) ELECTRON (e) (2) MUON (μ) (3) TAU (τ)
(4) ELECTRON NEUTRINO (ν_e) (5) MUON NEUTRINO(ν_μ) (6) TAU NEUTRINO (ν_τ)

Each of electron, muon and tau has –1 of charge and the corresponding neutrinos have no charge. So the electron about which you know so much is a lepton. Leptons always remain isolated(not in group), hence they are not social entitites.

[The beginners are advised not to confuse neutron with ***neutrino****. They are different. While neutron is a baryon(see later) made up of quarks, neutrinos are leptons]*

ANTIPARTICLES:

Every particle has its antiparticle. Particle and antiparticle are identical in all properties except one property. For charged particles, particle and antiparticles have opposite charges. Excepting three neutrinos, the antiparticles of all other elementary particles have opposite charges w.r.t their corresponding particles. For example, U quark has +2/3 charge, while anti U quark($\overline{U}$) has –2/3 charge and so on. *The antiparticles are denoted with bar sign above the symbol of their particles*. For neutrinos, the antiparticles too have no charge. But they differ in more than one properties, principal among them is difference in masses. We shall not discuss more about this here. Just remember that antiparticle is like the reflection of reflection of a particle which are identical in all respects except charge(valid for charged particles).

Note that there are six **antiquarks**.

(1) $\overline{U}$ (Anti U) (2) $\overline{D}$ (Anti D) (3) $\overline{C}$ (Anti C)
(4) $\overline{S}$ (Anti S) (5) $\overline{T}$ (Anti T) (6) $\overline{B}$ (Anti B)

There are also six **antileptons**.

(1) $\bar{e}$ (Anti e, this has +1 charge, commonly called a **positron** with symbol $_{+1}e^0$)

(2) $\bar{\mu}$ (Anti μ, this has also +1 charge)

(3) $\bar{\tau}$ (Anti τ, this has also +1 charge)

(4) $\overline{\nu_e}$ (Anti electron neutrino; commonly called anti neutrino. This has no charge but smaller mass than electron)

(5) $\overline{\nu_\mu}$ (Anti muon neutrino. It has no charge but has mass)

(6) $\overline{\nu_\tau}$ (Anti tau neutrio. it has also no charge but has mass)

So altogether there 12 particles (6 quarks and 6 leptons) and also 12 antiparticles(6 anti quarks and 6 antileptons). The entire universe has been formed from these 12 particle/antiparticle pairs. Antiparticles are unstable and hence do not exist freely. The common antiparticle which is emitted from some radioactive nuclides is positron i.e antielectron. The presence of all other antiparticles have been proved beyond any doubt now.

ANNIHILATION:

The interesting fact about particle-antiparticle is that when any particle comes in contact with its own antiparticle, both the two are destroyed and their mass is converted to energy. It has been already told that when a positron(antielectron) comes in contact with an electron, both electron and positron destry each other and we get two gamma photons moving in opposite directions. This is called annhilation process. The same is the case with any particle annihilating with its own antiparticle. Just like a particle has its antiparticle, a bigger particle like proton, helium atom etc.i.e a matter has its antiparticle.

Recently scientists have prepared **antiproton, antihydrogen and antihelium atoms**. They are extremely unstable having very small life periods. Scientists believe that every matter can have its antimatter, though not available, can be prepared.

It is believed that when the universe was formed by the **big bang**, equal number of matter and antimatter were formed. Immediately after this, matter and antimatter underwent annhilation to pure energy. But some matter was left out. In other words there was an imbalance between matter and antimatter after big bang. The universe we see is that left-out matter. So scientists believe that there must be the corresponding antimatter somewhere hidden which we do not find. Often you might have heard the fantasies/humour about this antimatter. *(Some are excited to believe that there must somewhere an ANTIWORLD where every matter here has an anti version. For example, Anti Sonia must be reading in an anti high school and eating anti ice cream and riding anti cycle and so on. If Sonia living in this world somehow comes in contact with Anti Sonia living in antiworld, can you imagine what will happen ? Both Sonia and antisonia will destroy each other and covert to pure energy !!! This is merely fantasy.)*

HADRONS:

Quarks always remain in groups, not isolated. They remain either as a combination of 2 quarks or 3 quarks. These combinations of quarks are called HADRONs. Hadrons are of two types.

(1) **BARYONS** : combination of 3 quarks

(2) **MESONS** :combination of 2 quarks.

E*xamples of Baryons* : Proton and Neutron which you know are baryons

PROTON : UUD (it is combination of two U quarks and one D quarks. So count the total charge. Is it not +1 ? +2/3 + 2/3 – 1/3 = +1

NEUTRON : UDD (its a combination of one U quark and two D quarks. Is it not netural ? +2/3 – 1/3 – 1/3 = 0

Examples of Mesons: There are many types of mesons out of which the **π mesons** also called **pions** are more common. There are three types of pions.

(1) **π^+ (positve pion)** : $U\overline{D}$ (it is combination of one U quark and and anti D quark.

(2) **π^- (negative pion)** : $D\overline{U}$ (it is a combination of one D quark and an anti U quark). Note that π^+ is the antiparticle of π^-.

(3) **π^0 (neutral pion)** : $U\overline{U}$ or $D\overline{D}$ (it is made up of U or D quark with its own antiparticle. Note that there is no annhiliation occuring there as long as a neutral pion is in life.

FUNCTION OF PIONS:

(1) **STABILITY OF NUCLEUS(MESON THEORY):**

The most important function of pions(pi mesons) is to bind the nucleons(neutrons and protons) to form a stable nuclues.

When a neutron emits a π^- , it is converted to a proton and when another proton absorbs a π^- , it is converted to a neutron. Similarly when proton emits a π^+, it is converted to a neutron and when another neutron absorbs a π^+ , it is converted to a proton. Hence the charged pi-mesons rapidly exchange beween proton to neutron and neutron to proton. Neutral pions also are exchanged between proton to neutron and vice versa. When a proton emits a π^0, it remains as a proton and when a neutron absorbs π^0 it remains as a nuetron. Theses rapid exhange of pions between the nucleons is responsible for the binding of nucleus and hence its stabililty.

In fact, when a D quark changes into a U quark in a neutron, it is converted to proton (during beta emission of a radioactive nuclide) (UDD changes to UUD), another particle called **W^- boson** is emitted first, which then decays to a beta particle and an antineutrino. The details about bosons will not be discussed now.

$$D \rightarrow U + W^- \qquad\qquad W^- \rightarrow {}_{-1}e^0 + \overline{\eta_e}$$

(2) Mesons are unstable particles. Pions and other mesons are present in atmosphere formed by the interaction cosmic rays with it. Pions decay into leptons and their neutrinos as follows. There are two modes of the decay of charged pions.

Muon emission: $\pi^+ \rightarrow \mu^+ + \eta_\mu \qquad\qquad \pi^- \rightarrow \mu^- + \overline{\eta_\mu}$

Electron emission:

$$\pi^+ \rightarrow e^+ + \eta_e \qquad\qquad \pi^- \rightarrow e^- + \overline{\eta_e}$$

Neutral pion decays by the following two ways

$$\pi^0 \rightarrow 2\gamma \qquad\qquad \pi^0 \rightarrow e^- + e^+ + \gamma$$

GLUONS: Gluons are chargeless and massless force carrier particles which bind the quarks in forming the mesons and baryons. There are eight gluons(see later).

FERMIONS: Particles containing odd number of elementary particles called as spin half particles(do not bother about the term spin half now). Examples are quarks, leptons, baryons.

BOSONS: Particles having even number elementary particles are called spin 1 particles(forget about spin 1 now). Mesons are bosons as they contain two quarks. Force carrier particles like photons, gluons, W and Z bosons are also included in this category.

FORCE CARRIER PARTICLES (Gauge bosons)

Photons, gluons, W and Z bosons are called force carrier particles and are also called gauge bosons as their inteactions are explained by a thoery called gauge theory. Photons carry electromagnetic interactions(between charged fermions) while W and Z bosons carry weak interactions responsible for radioactive decay, and gluons carry strong interaction of binding the quarks in forming the nucleons.

LARGE HADRON COLLIDER(LHC):

The mimicry of the big bang is being tried 100 m below ground near Geneva with a 27 Km(circumference) circular gigantic tunnel in the France-Switzerland border surrounding Alps mountain. The protons(handron) are allowed to collide with each other in opposite directions at a velocity close that of light so as to produce elementary particles and their antiparticles, bosons, gluons and other particles. Thus it will recreate conditions that existed during 1st billionth of a second after the big bang. Scientists from more than 100 nations are working for the mega project day and night to prove or disprove the big bang theory of creation of universe. The most important particle they expect to find is **HIGG'S BOSON**. Higg's boson is the hypthetical particle which was responsible, as they believe, to give mass to all particles(other than photons and gluons).. This is also call the ‘GOD PARTICLE”. After several LHC collisions by now, many new findings have been obtained. But scientists are almost sure of the presence of Higg's boson. The other particles they expect are **SUPPER SYMMETRIC PARTICLES.** which compose of 96% of universe called **DARK MATTER**. Astronauts have got the evidence of the existence of dark matter from the unusually high gravitational pull they experience which is not matching with the material universe.

LHC experiment consists of the following steps.

1. **Linear Accelerator** : The hydrogen gas is subjected to electron impact to break it into atoms and strip off one electron from each to covert them to protons. These protons then are allowed to enter the linear accelerator in which they are subjected to an electric field to get velocity nearly one third of light.

2. **Four Ring Circular Boosters**: The protons then enter into four circular boosters in which they are subjected to electric and magnetic field. Here they are compressed and get velocity 91.6% of light. Each ring has 157 m circumference. The protons then move to proton synchroton.

3. Pr**oton Synchroton**: Here again it is subjected to magnetic fields to increase its velocity to 99.9% of light. Note that when a particle travels with velocity nearly equal to that of light, if we give more energy to it, its relativistic mass will increase instead of velocity. Here protons become 25 times heavier than its rest mass. Proton synchroton is circular in shape having circumference of 628 m. Then protons move to super proton synchroton.

4. **Super Proton Synchroton** : Again protons are subjected to stronger magnetic fields to acquire more energy. Its energy becomes 450 GeV(Giga electron volt). Its mass increase much more. It is also circular in shape having 7 Km circumference. Finally protons move to LHC.

5 **Large Hadron Collider** : Ultimately the protons enter into LHC in two counter rotating beams, but not allowed to collide. They are subjected to more energy to acqure a value of 7 TeV(tera electron volt). The proton becomes 7000 times heavier than its rest mass here and rotate 11000 times a second. LHC has 27 Km circumference. After gaining the required energy here they are allowed to collide at 4 positions(Dectector) where the elementary particles, their antiparticles, bosons, gluons, super symmetric particles(that is believed to be present in **Dark Matter**), Higg's boson etc. etc. will be disocvered..

Higgs boson has already been almost discovered on 4th July 2012 at CERN.

HIGG'S BOSON(GOD PARTICLE): A particle (which has been recently discovered with almost certaintly) which is responsible to confer mass to massless particles. Elementary particles(other than photons and gluons) when pass by or interacts with the Higg's field will acquire mass by a complicated mechanism called Higgs mechanism. The strong point in favour of the existence of Higg's boson is the discovery of W and Z bosons which carry weak forces and are so massive while a photon which carries the electromagnetic force is massless. W and Z bosons are elementary particles that mediate weak forces in the radioactive decay of heavier nuclides. Their discovery has been a major success in the standard model of particle physics. W and Z boson are almost 100 times heavier than a proton and also heavier than an atom of iron. Is it not incredible !!!!!. W^- boson is involved during beta emission. When D quark changes to U quark during neutron to proton conversion, a W^- boson is emitted which subsequently decays to a beta particle and an antineutrino.

Properties of Higg's Boson: Mass: 125 GeV/c^2. It means it is 125 time heavier than a proton !!!!. It has zero spin.

Why the name "God Particle" ?

In 1993, Leon Leddermann, a Nobel Lauraeate in Particle physics wrote an article by name"If Universe is the answer , What is the Question ? " . He termed the elusive particle Higg's boson as "GODDAM PARTICLE" giving it a villianous nature. But the publisher of the journal changed the term GODDAMN PARTICLE" to "GOD PARTICLE" by removing the suffix DAMN. Henceforth, the world and particularly the non-scientific world knew this particle as "God Particle". Many particle physicists do not accept this term for Higgs boson as they say this particle is nothing to do with God. After the discovery of Higs's boson on 4th July 2012 at CERN, there was much hue and cry in the spiritual world. Many religious preachers vehemently opposed to the term "God Particle" for Higg's boson.

DARK ENERGY AND DARK MATTER:

Our universe consists of nearly 75% dark energy, 20% dark matter and only 5% matter that we see and experience. Dark matter is responsible to provide unusually high gravitational pull experienced by astronauts which is not in agreement with the material universe. Dark energy drives the galaxies away from each other. In other words helps in the expansion of the universe.

MORE ABOUT......

Quarks:

U, C and T quarks have isospin(isotopic spin) = + ½ while D, S and B have I = –½

Leptons:

e, μ and τ have I = – ½ while ν_e, ν_μ and ν_τ have I = +½

(Antiquarks and charged antileptons differ only in the sign of their charges and hence of their isospin(I) as compared to their correpoding particles..

Neutrinos(neutral leptons) and antineutrinos also have ½ isospin but their direction may be same or opposite. The neutrino-antineutrino differs in their chirality(mirror images of each other).

Hadrons: are white although individual quarks are coloured R/B/G.(but monochromatic). Baryon contains three quarks which are RBG type and thus is white. While a meson contains $q\bar{q}$ (quark and antiquark) are also white. The antiquark has the complimentary colour of the quark, hence the combination is white. (Note that the colour here is nothing to do with the actual light clours. Their implications are beyound our present scope).

<u>Massses of quarks</u>: U and D quarks are much lighter than a proton or a nuetron which are made up of the quarks. U = 2.4 MeV, D = 4.8 MeV. A proton/neutron has a mass equivalent to 1 GeV. A proton which is UUD should weigh 9.6 MeV, but actually it has mass of 1GeV. Hence most mass of proton and neutron comes from the energy possessed by gluons which bind the quarks together. Although gluons have zero rest mass, but the bond energy corresponds to 90.4 MeV. Note that bond energy is stored as mass in the baryons. But when the baryons break down to individual quarks and gluons, the latter do not carry any rest mass.

<u>Masses of other quarks:</u> C = 1.27 GeV, S = 104 MeV, T = 171.2 GeV, B = 4.2 GeV.

<u>Masses of leptons:</u> Neutrinos are much lighter compared to their corresponding charged leptons.

e = 0.511 **<u>M</u>**eV, ν_e = 2.2 eV; μ = 105.7 MeV ν_μ = 0.17 MeV

τ = 1.777 GeV ν_τ = 15.5 MeV

Gluons: There are eight gluons which are coloured.There are 6 bicoloured gluons and two white gluons.(Note that this colour is nothing to do with the actual light colours). Their implication is beyond our scope.

1. Red and anti-green(mangenta) gluon
2. Red and anti-blue(yellow) gluon
3. Blue and anti-green(magenta gluon
4. Blue and anti-red(cyan) gluon
5. Green and anti-blue(yellow) gluon
6. Green and anti-red(cyan) gluon
7. Red and anti-red(cyan) + green and anti-green(magneta = White Gluon
8. Red and anti-red(cyan) + green and anti-green(magneta + blue and anti-blue(yellow) = White gluon

Gluons are messangers of strong nuclear forces that bind atomic nuclei.

Fermions: These have isospin or intrinsic magnetic moment: I =+ or – ½ or multiples of ½ (half integral values). Elementary fermions having I values of 3/2, 5/2 etc.(other than 1/2) have not been discovered yet. These obey Fermi-Dirac statistics.

<u>Fermions of first family</u> : (1) electron and electron-neutriono under lepton category (2) U and D quarks under quark category. Higher families of fermions from lepton and quark categories are unstable and decay down to the first familiy fermions.

(Top quark is 3,30,000 times heavier than electron. Electron is far heavier than its neutrino)

Bosons: Bosons have I = 0, 1, 2 etc. (intregral values). All gauge bosons(photon, gluon, W and Z bosons), other atoms like $_2He^4$ (I=0) I = 1. Those bosons having I =0 are called <u>scalar bosons</u>(eg. He-4, π-mesons).

The bosons having I = 1 are called vector bosons(eg. photon, gluon, W and Z bosons). The recently discovered Higgs Boson is a scalar boson as its I = 0. They obey Bose-Einstein statistics.
W^- : I = –1 and charge also –1 while W^+ : I = +1 and charge +1 ; W = 80.4 GeV and Z = 91.2 GeV(These bosons are heavier than an atom of iron !!!!!!!) Life time of 3 X 10^{-25} sec(very unstable). Z^0 also have I = +1 or –1. Z boson is its own antiparticle.
(Higgs boson is the only elementary scalar boson so far known)

(IMP : Although pi-mesons are scalar bosons as their ground state I = 0 , the two particles remain in opposite spin according to Pauli's exclusion principle. But they go to the excited state of parallel spin and acquire I =1 and hence generally we write I = +1 for π^+, –1 for π^- and hence +ve and -ve pions are vector bosons too in the excited state.They are often called pseudo scalar bosons)

I : neutron : I = UDD = –½. proton : I = UUD = +½. deuterium I = 0
tritium : I =–½. $_2He^4$: I=0
So neutron, proton and tritium are fermions while deuterium and He(4) are bosons.

Graviton: The graviational field involves the hypothetical massless particle graviton having spin I = 2.

Higgs Mechanism: In particle physics, the Higgs mechanism is a kind of mass generation mechanism, a process that gives mass to elementary particles. According to this theory, particles gain mass by interacting with the Higgs field that permeates all space. More precisely, the Higgs mechanism endows gauge bosons(such as W and Z) with mass through absorption of Nambu–Goldstone bosons arising in spontaneous electroweak symmetry breaking.
The simplest implementation of the mechanism adds an extra Higgs field to the gauge theory. The spontaneous symmetry breaking of the underlying local symmetry triggers conversion of components of this Higgs field to Goldstone bosons which interact with (at least some of) the other fields in the theory, so as to produce mass terms for (at least some of) the gauge bosons. The particle corresponding to Higgs field with which the Goldstone boson interacts is Higgs boson(or the infmaous God Particle) which has been almost discovered on 4th July 2012. This is also called Brout–Englert–Higgs mechansim. Englert shared nobel prize with Higgs in 2013 in physics for the Higgs mechanims for acquring mass.
Analogy:
(1) Imagine there are large number of students in a hall and they spread out with large gaps between them. Suppose a very popular celebrity such as MS Dhoni(cricketer), Hirthik Roson or Karina Kapoor(Film stars) suddenly enter to that hall and pass bye. What willl then happen ? The students nearing the celebrity will come closer to him/her and become overwhelmed/surprised/sensitized in dismay and crowd near him to take autograph or interact personally. Similar thing happens when a massless particle come near Higgs boson(analogous to the celebrity) in Higgs field permeating the entire space which has the capacity to confer mass. But unless there is interaction with the Higgs boson and unless the massless particle becomes sensitized while coming near the Higgs boson, it cannot get mass from the Higgs field. It develops some sort of resistance when comes near the Higgs boson. At that time, it becomes receptive of acquiring mass from the Higgs field.
(2) Imagine, there is continuous drizzling in the sky. The fine rain drops are filled throughout the sky. This is analogous to Higgs field. Also in the sky are hanging many baloons filled with water with good gaps between them. These water filled balloons are analogous to Higgs bosons. When any dry particle will come to the drizzling sky, it is supposed to be wet and carry mass from the drizzling rain drops. Such a thing will not happen in this case. Those dry(analogous to massless) particles which will pass near the water filled baloons(Higgs boson) will intereact with it, will get a resistance, will be sensitized and at that moment it will be filled up by rain drops (Higgs field) and acquire mass. Although Higgs field confers mass to the massless particles, it is only after its interacts with the Higgs boson. However, photons and gluons are the two unfortunate particles which do not interact with Higgs boson and Higgs field and do not carry mass.

Mass and Energy :

The two terms are synonymous as they are interconvertible.

A particle having rest mass 'm' can acquire speed nearly equal to speed of light, it cannot get greater speed than this value. If more energy is supplied to it, then energy will be converted to its mass. Hence its mass increases. In other words the energy is stored without doing any thing else(means it is defunct). This stored energy(defunct) can be called mass. Similary, during nuclear processes, there is a mass defect, i.e some mass is lost in the form of energy. These are either called binding energy of nuclei or the decay energy of the nuclide or the fission/fusion energy of the reaction. These intercoversions are based on the famous Einstein's equation $E = mc^2$. Hence mass and energy are synomous. In particle physics, the mass(E/c^2) is often expressed as GeV/c^2 or MeV/c^2 in stead of Kg or g etc. The particle physicists are in a habit of using the unit GeV or MeV(i.e only energy unit) for both mass(omitting c^2 term) and energy. So mass and energy are more or less indistinguishable.

When big bang occurred, it was a bang of this stored or defunct energy(not the real mass). It is the bang of energy, not mass. After big bang, massless elementary particles were formed. These acquired mass later from the Higgs field by interacting with Higgs boson.

In LHC, similar siutation has been reproduced in the mini scale. Protons(handrons) were allowed to acquire high energy after four successive steps at LHC. An energy of 7 TeV is acquired by each proton. This is no longer the real mass of proton which is approximately 1 GeV. We say the proton becomes 7000 times heavier than its rest mass at LHC before collision. The real mass of proton does not increase. It is the relativistic mass which increases. It is in fact a stored form of energy, which we call mass. So when two such proton beam are allowed to collide, it is nothing but analogous to energy bang, not the real mass bang. The situation is exactly analogous to bing bang which took place during the creation of this universe.

Nuclear Forces:

The exchange of gluons(vector bosons) between quarks in a baryon produces very strong force. This is called strong nuclear force. Binding of nucleons by rapid exchange of mesons is also strong force but operates over very short distance(within 1 fm = 10^{-15} m). The strong nuclear force(gluon exchange within a nucleon) has a residual force(the force that holds the protons and neutrons together in the nucleus) that is inversely proportional to distance whereas its non-residual form(the force that keeps the quarks together in proton and neutron) reaches a maximum value and then neither decreases or increases with increase in distance). Secondly the non-residual force has a gauge boson, *gluon*, as its exchange particle whereas in its residual form the exchange particle is a meson(pion) consisting of a quark and an antiquark. Weak nuclear forces are responsible for nuclear decay particularly beta decay via the generation of W boson.

Meson theory which was based on **One Boson Exchange(OBE)** was popular in 1950's(Yukawa got Nobel prize in 1949 for meson theory) and also in 1960's. But in 1970's the fundamental theory of nuclear forces was considered to be **Quantum Chromo Dynamics**(QCD), not meson theory. Although meson theory was not discarded, but QCD was a better mathematical tool to explain the the nuclear forces. QCD was further augmented by **Effective Field Theory(EFT)** developed by the nobel laureate Steven Weinberg in 1990. Both QCD and EFT are beyond the scope of the present discussion on rudimentary particle physics for high school students as these are taught in degree level particle physics classes.

How π-mesons exchange between nucleons ?

Leaving aside its complicated quantum theory and the mathematics involved to explain how pions exchange between the nucleons to give rise to short ranged strong nuclear forces, we can present the concept in a very simple way comprehensible to a high school student. Though its a crude way to explain but can be considered very handy for young students.

When quark radiates a gluon, it often produces additional gluon as well as quark and antiquarks (opposite of annihilation) from its own energy. One gluon enters another quark and responsible for strong forces to bind the quarks to form a baryon. But the generation of an antiquark alongwith an existing quark in the baryon is responsible for the formation of pi-meson which is also bound by gluon.

Lets see how a proton(UUD) emits a +ve pion(π^+). π^+ consists of U and $\overline{D}$. From the energy of gluon, suppose a D, $\overline{D}$ pair results. One U quark present in proton and the $\overline{D}$ quark produced from gluon bound by another gluon becomes a π^+ meson and goes out of the proton. Thus the said proton is now left with UDD triplet and hence it is now a neutron. Similarly when this +ve pion enters into a neutron(UDD), $\overline{D}$ annihilates with a D to form energy of gluon and U joins with UD to make UUD combination, thus a proton is formed.

Lets see now how neutron(UDD) emits a -ve pion(π^-). π^- consists of D, $\overline{U}$ pair. From a gluon's energy a U, $\overline{U}$ pair is generated. One D quark present in neutron and $\overline{U}$ produced from gluon go out as π^- meson, leaving behind UUD. Thus a neutron is converted to a proton. Similarly when this π^- meson enters into a proton(UUD), $\overline{U}$ annihilates with U to give energy of gluon. and it is converted to UDD(neutron).

Similarly a neutral pion(π^0) can be exchanged between protons or between neutrons. A neutral pion can be U$\overline{U}$ or D$\overline{D}$, Both the type of neutral pions can be produced from a gluon. When the former type enters a proton, U of that proton annihilates with $\overline{U}$ from the neutral pion and hence proton remains as proton. Similarly when latter type of meson enters a neutron, D of that neutron annihilates with $\overline{D}$ from the neutral pion, hence neutron remains as neutron.

(Instruction to Readers: If any reader finds a single mistake in the contents of this article, please write to us in the email ID sudhansu.trips@gmail.com for correction)

$\overline{U}$