ELEMENTARY PARTICLES

I. INTRODUCTION:

Nucleons are held together inside the nucleus by something other than the gravitational or electrical force. Hence there must be a separate NUCLEAR force. However, electrons do not respond to this nuclear force, and yet they are involved in nuclear reactions such as beta decay. Hence we conclude that there are two nuclear forces. These two forces are called the **STRONG NUCLEAR FORCE** and **the WEAK NUCLEAR FORCE**.

This leads to the separation of particles into those that respond to the strong nuclear force and those that do not. Those that do not are called **LEPTONS**, and those that do are called **HADRONS**.

The leptons appear to be elementary in that we have not yet discovered any size or structure to these particles. However, the hadrons do have a size and appear to have a structure indicating that these particles are made up of smaller (more elementary) particles.

II. FLAVORS:

To explain all the different hadrons in terms of these more elementary particles, physicists have postulated the existence of particles they call **QUARKS** (the name is from a James Joyce novel). The elementary particles found so far are:

LEPTONS					QUARKS			
name		electric charge	weak charge	color charge	name	electric charge	weak charge	color charge
electron	e	-1	- ½	0	up	+ 2/3	+ ½	r/b/g
neutrino_e	ν_e	0	+ ½	0	down	- 1/3	- ½	r/b/g
muon	μ	-1	- ½	0	charm	+ 2/3	+ ½	r/b/g
neutrino_μ	ν_μ	0	+ ½	0	strange	- 1/3	- ½	r/b/g
tau	τ	-1	- ½	0	top (truth)	+ 2/3	+ ½	r/b/g
neutrino_τ	ν_τ	0	+ ½	0	bottom (beauty)	- 1/3	- ½	r/b/g

From now on, we'll abbreviate neutrino with ν, and all quarks with their first letter, e.g., u for up.

For each elementary particle there is an anti-particle with opposite charge (electric, weak, and color). We'll discuss the 'weak' charge in section V and the color charge in section III below.

It appears that the only difference between the three sets is one of mass (energy). For instance, the muon behaves exactly as an electron except the muon has a mass about 200 times that of the electron. The muon is unstable and will decay into an electron. The different types of elementary particles are called different **FLAVORS**.

III. COLORS:

For the electric force, some particles were neutral and some were not. We can explain all of electrodynamics using two charges: + & - . But for the nuclear force we need THREE kinds of **NUCLEAR CHARGE** which are called: red, green, and blue.

Obviously, since the leptons do not respond to the nuclear force, the NUCLEAR charge of the leptons is zero, or better yet: colorless.

IV. GLUONS:

The electric force is transmitted via photons; i.e., one charge affects another charge by exchanging photons with that charge. Another way of looking at it is that the charged particle sets up an electric field by emitting photons, and when those photons hit some other charge, they cause that charge to either be attracted or repelled. That is how the electric force is transmitted across space.

In the case of the nuclear force, we have not been able to separate individual quarks. It seems that the nuclear force between quarks is small when the quarks are confined within a certain region, but becomes very strong when the quarks try to go out of that region. The nuclear force actually increases in strength as the distance between colored quarks increases. If we stretch the quarks too far apart, it takes so much energy that a quark-antiquark pair is created which forms another hadron (more on this later).

What we think is that **GLUONS** are to the nuclear force what photons are to the electric force - that is, they are the carriers or mediators of the nuclear force.

Because of the nature of the gluons and the nuclear force, we think that we may never be able to isolate a single quark. And because of the way the nuclear force is, we think that all hadrons as well as all leptons must be either colorless or 'white' . What we mean is that we can form hadrons out of quarks in only two ways. One way is to have three quarks each with a different color (one with red, one with blue, one with green). We call this combination 'white'. The other way to have a hadron is for it to be colorless. We can have this if we have one quark with one color and another antiquark with the anticolor. Thus there are only two ways to have quarks bound together: in packets of three, or a quark-antiquark pair. The three quark particle is called a **BARYON**, the quark-antiquark pair is called a **MESON**. Of course the leptons are colorless as mentioned before.

HADRONS

BARYONS name	BARYONS quarks	MESONS name	MESONS quarks
proton	(u,u,d)	π^0	(u,anti-u)
neutron	(u,d,d)	π^0	(d,anti-d)
		π^+	(u,anti-d)
λ^0	(u,d,s)	π^-	(anti-u,d)
Σ^-	(d,d,s)	K^+	(u,anti-s)
xi^-	(s,s,d)	K^-	(anti-u,s)
xi^0	(s,s,u)	K^0	(d,anti-s)
Ω^-	(s,s,s)	D^+	(c,anti-d)

There is another difference between the nuclear force and the electric force. In the electric force, the photons (the mediators of the electric force) were themselves neutral. However, in the case of the nuclear force, the gluons (the mediators of the nuclear force) can themselves be charged (colored). Thus individual quarks can exchange color by exchanging gluons. This leads to eight types of gluons but only one type of photon. The types of gluons are: g-r, r-b, b-g, r-g, b-r, g-b; and two gluons that do not change the color of the quarks.

Another difference between the gluons and the photons is their rest mass. According to the Heisenburg Uncertainty Principle ($\Delta E*\Delta t \geq h/2\pi$) , photons have rest mass of zero (of course they are never at rest so they always have some mass according to $E = m c^2$) so they can have arbitrarily small energy and hence exist for an arbitrarily long time which leads to the fact that the electric force is infinite in range. However, since the nuclear force is short-ranged, the gluons must have a finite rest mass.

V. WEAK NUCLEAR FORCE:

In the weak nuclear force, particles exert forces on one another by exchanging another type of mediating particle called an **INTERMEDIATE VECTOR BOSON**. There are four particles that belong to this group: the W^+, W^-, W^0, Z^0. These mediating particles can carry an electric charge and a 'weak' charge.

name	electric charge	weak charge
W^+	+1	+1
W^-	-1	-1
W^0	0	0
Z^0	0	0

In exchanging these intermediate vector bosons, two particles can change their electric charge and their weak charge. When particles exchange their weak charge they in effect become different elementary particles which means they change flavors.

As an example, consider beta decay: a neutron consists of a combination of three quarks: (u,d,d). [Note that this combination of quarks give the neutron a 0 electric charge but a -½ weak charge]. The energy from the nucleus creates a photon which splits into a ν_e (neutrino) and anti-ν_e pair. The ν_e may exchange a W^+ (elec charge = +1,weak charge = +1) with one of the d quarks of the neutron. This changes the ν_e (elec charge = 0, weak charge = +½) into an electron (elec charge = -1, weak charge =-½) because by emitting the W^+ the ν_e loses +1 elec charge and loses +1 weak charge; and it changes the d quark (elec charge = -1/3, weak charge = -½) into an up quark (elec charge = +2/3, weak charge = +½) because the d quark absorbs the $W^{+.}$ This changes the neutron (u,d,d) into a proton (u,u,d). Note that we also have leaving the scene of the beta decay the anti-ν_e. Note that there is no exchange of color charge here so that this does not involve the strong nuclear force.

VI. EXAMPLES:

<u>STRONG</u> interaction

π^{-} + $proton^{+}$ $\rightarrow$ Λ^{0} + K^{0}

[in elementary particle groupings, this looks like]

(anti-u,d) + (u,u,d) $\rightarrow$ (u,d,s) + (d,anti-s)

** remark: (anti-u,u) becomes energy (via particle annihilation) which goes to creation of (anti-s,s).*

<u>WEAK</u> interaction

energy + proton $\rightarrow$ anti-electron + neutrino + neutron

[in elementary particle groupings, this looks like]

(anti-υ,υ) + (u,u,d) $\rightarrow$ anti-electron + υ + (u,d,d)

** remark: energy goes to (anti-υ,υ) and then anti-υ emits W^{-} to become an anti-electron and the u quark absorbs the W^{-} to become a d quark.*