Nuclear and Particle Physics
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Module - 10
Gauge Symmetry
Lecture - 06
QCD, Electroweak Symmetry

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Now, let us go to the other interaction which is basically the weak interaction we already listed the elementary particles known to us.

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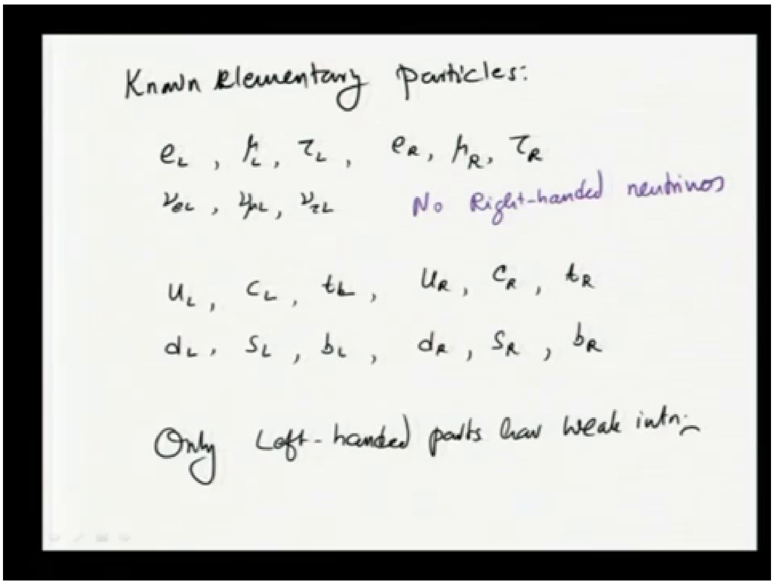

Let us write down again then here elementary particles, we have electron let us explicitly write down the left handed and right handed ones and we have mu e L corresponding to an electron, we have left handed muon mu L corresponding neutrino left handed tau lepton and mu tau L and we have a right handed electron, there is no right handed neutrino corresponding to that we have right handed muon, we have right handed tau particle.

And we do not have any no right handed neutrinos this is because they are not found in experiments, we are not found right handed neutrinos we have only found left handed neutrinos and right handed and the neutrinos in beta decays and other weak interactions.

What about the quarks we have u L, d L, c L the charm quark strange quark left handed, top quark left handed, bottom quark left handed we also have right handed quarks all of them c R, s R top and bottom all of them and again what is observed is that only left handed particles take part in weak interactions, this is an observation experimental observation.

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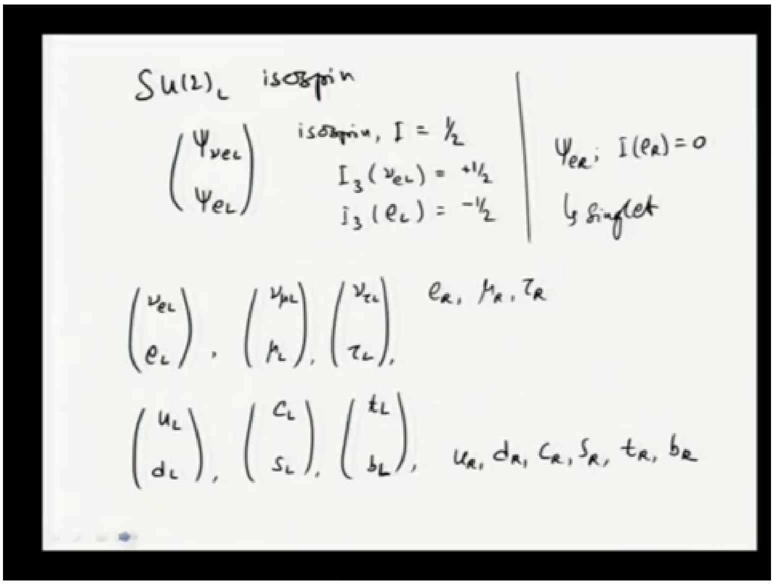

Now, to confirm to that, we consider the weak interaction and the gauge transformation corresponding to the gauge weak interaction, the gauge group is identified after some studies as s u 2 gauge group. S u 2 since only the left handed particles transform under s u 2 weak interactions I consider we will write the gauge group as s u 2 L, L just be noting that we made to remind us that only left handed particles take part in this and we can club this particles together.

Psi corresponding to the left hand (Refer Time: 04:34) psi corresponding to the electron can be clubbed together and considered as a doublet under s u 2 L whereas, the right handed field has no such partner and the wave function corresponding to around the field corresponding to that is a singlet under s u 2 L, when I say singlet which means that it is invariant or do not take part in the interaction corresponding to a s u 2 L which is weak interaction.

This is also similar to the isospin that we had discussed earlier in the case of the flavor isospin for example, we considered the proton and neutron has 2 different protections of same object which we could call as nucleon, we could consider something called isospin and the isospin of nucleon is half and plus half projection of that is proton minus of projection of that is neutron.

Now, in exactly the same way we can consider here the s u 2 L isospin or the weak isospin this is completely different from the isospin that we had considered in the case of strong interactions, but let us call it isospin because that is basically a standard terminology now. So, under isospin we can categorize these fields and we just now mentioned that the wave or the field corresponding to nu e L and e L transform as a doublet which means isospin of this is equal to let me denote this by I equal to 1 by 2 and isospin 3 the third component of nu e L is equal to plus half and that of electron is minus half.

Whereas when we consider psi e r we have a singlet and the isospin of e R is equal to 0 and isospin third component is also equal to 0 that is why we call this singlet, singlet under su 2 L. Similarly other fields also can be clubbed. So, let us write that down I will forget about the psi for the time being because the notation is becoming too much and I mean more and more complicated or clumsy if I write all the levels.

So, I will forget about psi here write only the notation nu e L e L just to denote the corresponding fields similarly we have nu mu L and nu tau L the left hand roots and all others e R mu R and tau R singlet us and in the case of quarks you will we will club u L and d L, c L and s L top left handed and bottom left handed.

Right handed fields are all singlet us t R let me start from the beginning u R, d R, c R, s R, t R, b R all these are singlet us. So, this is how we club this then write this explicitly ask the in terms of the multiplet us under s u 2 L that is one thing. Now study is lot of investigation had gone into understanding the weak interactions using the gauge symmetry similar to the quantum chromodynamics for strong interactions and quantum electrodynamics for the electromagnetic interactions.

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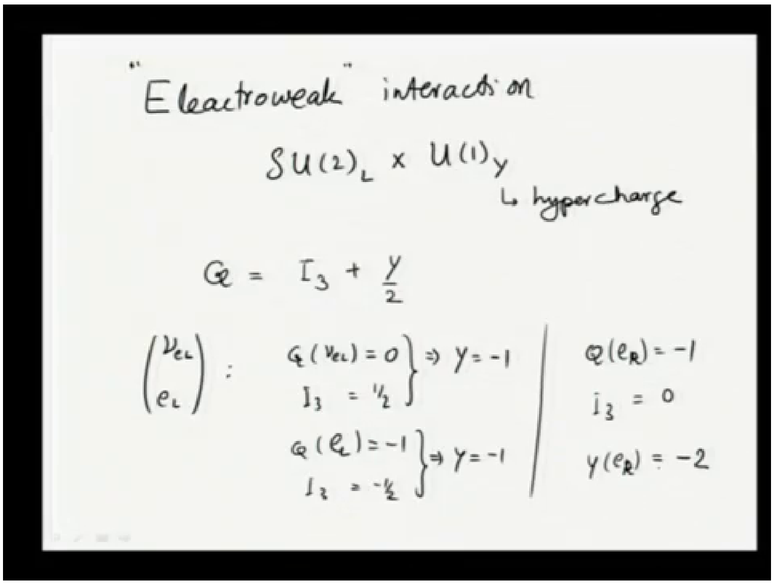

We will not go into the history or the details of all those studies, but discuss only the n product end at the end we see that we have to consider the electric electromagnetic interaction and the weak interaction together let us call it electro weak interaction, some kind of a unification between the electromagnetic and the weak interaction has to be considered for consistency and the gauge group that we should consider is not just s u 2, but a direct product of s u 2 and u 1.

Let us call this interaction or the charge corresponding to that as hyper charge s u 2 is the same as isospin weak isospin whereas, while, but the weak itself is now to be considered as to be understood as used under electroweak interactions there is a mix up between s u 2 isospin and hyper charge in both electromagnetic interaction as well as weak interaction. Such unification is not very unfamiliar to us if you remember your school days you will see that magnetism and electric electrostatics and electricity are taught different as different topics.

Especially the magneto statics and electrostatics, we have electric fields giving rise to all electrostatics propose and dynamics under that similarly we have magnetic field b giving rise to magneto static, but at high energies or for moving charged particles when the motion is or the velocity of the particle is large enough. So, that we cannot neglect the effects due to this motion then we cannot separate the electricity and magnetism from each other we have to consider electromagnetic theory or electromagnetic interactions between charged particles and Maxwell’s equation for us.

You see that induced electric changing electric field induces magnetic field the changing magnetic field induces electric field etcetera and then clubbing all these together you realize that you have to discuss electromagnetic interactions rather than electric and magnetic interactions separately. Unification of weak and electromagnetic interactions is another step in this direction. So, we can think about weak and electromagnetic interaction has unified considered to be a unified theory at sufficiently large energies thinking in terms of moving charged particles has larger energy compared to charged particle addressed.

So, we will not go into a further motivations in this direction, but tell that this is what we are going to consider then symmetry group consider it is s u 2 cross u 1, L to denote that only the left handed particles are going to be affected by transformation under s u 2 and y to denote that the charge corresponding to u 1 is what called hyper charged denoted by y, how do we assign this hyper charge, there is a consistent way of doing it this is due to the fact that we need to get the electrodynamics from this we will see that later.

That we have to actually describe the photons from this one right because this includes electrodynamics what are photons as I said photon now is a mixture of s u 2 L and u 1 by gauge fields it will be seen later clearly, but that tells us that the corresponding charges whatever charges are also related this relation is given by the charge of electromagnetic interaction q is equal to I 3 the third projection of isospin which is the charge corresponding to s u 2 plus y by 2 where y is the hyper charge.

Now, let us look at left handed electron and neutrino doublet q of nu e L is equal to 0, we know that it is a neutral particle I 3 of this is plus half and that is sufficient to fix y to be equal to minus 1. If I take y equal to minus 1, I have minus 1 by 2 in the second term of the relation above and I 3 is plus 1 by 2 total is 0 similarly for electron Q is known to be equal to minus 1, I 3 is equal to minus half which again gives you y equal to minus 1.

This indeed should be so, this is because the all the multiplieds s u 2 multiplied will have the same hyper charged while we will see how y is. So, when we write down the transformations this is also the reason that we have written the neutral component as the first component I 3 equal to half and the negatively charged e as the I 3 equal to minus half, to start with we would have wondered if you were keenly observing it why I wrote nu first hand and then e l second hand what would happen.

If the other way around if it was the other way around, if it is the other way around this relation would change that is the only thing, but if we stick to this conventional relation then basically we have this basically this way of representing the doublet there is no other way of representing the doublet here.

You will also see that because I 3 changes by one unit when you go from one component to another component nu e 2 e in the same multiplied the charge should also reduce or change by one unit when you go from one unit to one component to other component. So, that is always the case this is because the multiplet has the same hyper charged and whenever you change I 3 by 1 unit Q should will be changing by one unit, what about the right hand electron charge is the same as minus 1 I 3 is equal to 0 therefore, y of e L is equal to minus 2.

So, that is a there is a difference in the hyper charged assignment of sorry this is the right handed electron that we are talking about, there is a difference in the hyper charge of electron which is right handed and electron which is left handed. So, there is a difference between the left handed and the right handed electron, the charges in terms of the hyper charge there is a quantum number which makes left handed and right handed electron distinguishable which is the hyper charge and also the isospin of course, the isospin is another these 2 charges these 2 quantum numbers this allow us to distinguish or help us distinguish the left handed and the right handed particles.

That is indeed is the basic reason why they interact differently under weak interactions which is a combination of s u 2 L and u 1 by now the electromagnetic charge or electric charge of electron is minus 1 irrespective of whether it is right handed or left handed. This is the reason why we cannot distinguish the left handed and the right handed electrons under electromagnetic interaction, but they are distinguishable under weak interaction. The same story goes through for other particles as well like you can so for the other leptons muons and the tau lepton and the corresponding neutrinos the story is exactly the same replication of this, for quarks because their electric charge is now different.

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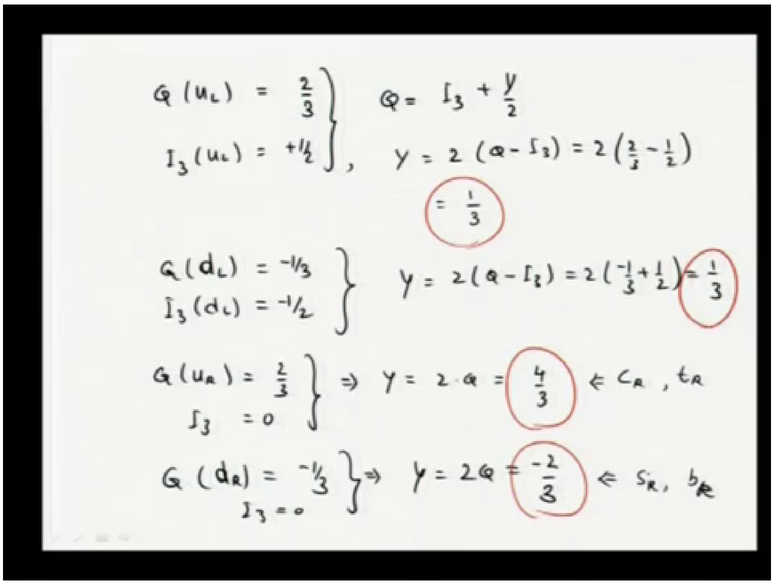

Let us consider you well up type lefts charge left up type quark has a charge of plus 2 by 3 and isospin third component is equal to plus half and that tells us that y is equal to. So, relation let me write here this Q equal to I 3 plus y by 2 or y is equal to 2 Q minus I 3 which is equal to 2 times 2 by 3 minus 1 by 2 which is equal to 1 by 6 2 into 1 by 6 is 1 by 3.

Similarly, for down type quacks I 3 is equal to minus half charge is equal to minus 1 by 3 y equal to again it should be equal to 1 by 3 let us see Q minus I 3 which is equal to minus 1 by 2 into minus 1 by 3 plus 1 by 2 which is again equal to 1 by 3 which should indeed be.

Right handed Q of right handed charged quark u right handed is 2 by 3, I 3 equal to 0 that gives y equal to twice Q which is equal to 4 by 3 and similarly for down type right handed it is 1 by 3 I 3 equal to 0 that will give you y equal to minus 2 by 3. So, these are the hyper charged assignments of the quark doublet and the quark singlet us.

The up type quark right handed will have all the quark doublet us left handed will have 1 by 3 as their hyper charged and right handed up quark c R and t R all have hyper charge 4 by 3 and down type quark s quark and b quark all right handed have hyper charged minus 2 by 3 all right. So, this is done we know what is the what are the hyper charges, what are the isospins of all these particles, now we are in a position to construct the Lagrangian which is invariant and a the s u 2 cross u 1 transformation we will follow a similar when approach similar to what we had done in the case of is QED and strong interaction QCD; we will do that in the next class.