In Search for the "Higgs"

A Laymans Intro to the Standard Theory of Particle Physics

by Seppo Nurmi, 2009 (still a draft version ...)

Preface

This is a short recollection of the main ideas contained in what is called the "Standard Theory of Particle Physics". I will outline the Glashow-Salam-Weinberg electroweak theory and its connection to the Higgs particles. I will also take up the quark theory and chromodynamics. And not forgetting quantum electrodynamics, the modern theory of electromagnetism. The rice of the theory starts in 1960ies and was somewhat mature in1980ties. It has not changed much during the last 30 yeras, telling us that the basis of the theory seems now quite stable and well confirmed. There are, though, unsolved problems left. Many ideas has also been presented for solving them, but all of them have not yet been entirely confirmed or generally accepted.

What is given here is a simplified presentation of the "Standard Theory of Particle Physics", showing the main principles but leaving out details, and not showing vector indices and so on, things that make reading of math slow and diffcult, and in stead tryning to give a nice and easy to grasp mathematical picture. Although I am an amateur and not a physicist of profession, or maybe just for that reason, I feeled that there is need for such a presentation. Nobody seems to have done it before on an easy level of math. The reader should be aware that it is meant to be a short glimse of the basic ideas, and not as a perfect theoretical treatment, what is it not. Nevertheless, I am grateful for any feedback, also for errors and misunderstandings that certainly can be foud here.

Introduction

The oldest theory we could call physical in some meaning was the one of the five elements. It was not only known by ancient greeks, but even earlier in India and Japan. The greek elements are: Earth, Water, Air, Fire, and Idea. The fifth element is better known in its later latin form, Quintessense, or Aether. This theory has infuenced western thinkig all through the Medieval time till the Renessaince. All material things were assumed be made of the four first elements in different proportions. The fifth element represented spiritual concepts: ideas, soul, and heaven. In the Medieval time icluding also the heavenly bodies, everything from Moon and above.

What was thought was that there was two different physical domains obeying different laws. The heavenly bodies in the heavenly domains were believed to prefer circular movement, whereas the earthy things would prefer vertical movement. The first unification of physical laws was that of Isaac Newton. In his theory what was above Moon and on Earth were made to obey the same physical laws. These we now know as the Newtons laws of calssical physics. The unification of physical laws is generally important because a real understanding of physics rises from the unification. Next unification was Maxwell putting together electricty and magnetism in one, the theory of electromagnetism. Most of our modern technology is dependent of this unification.

The next step was the atomic theory. The idea of the atoms comes from angient greeks, but in a more scientific form the idea rised again from chemistry in sixteenth century. Mixing properties in chemical combounds pointed to that direction, but it was not physically proven until the second half of seventeeth century. The number of different atoms, "chemical elements", then increased rapidly till there were more than ninety of them. They were then ordered in the periodic table, and that gave the hint that there must be some kind of systematic principle beyond the table. The atoms then eventually losed they role as the most elementary constituents of matter. Then came the discovery of radioactivity. Radioactive decay proved that atoms could split up. The constituenst of atoms, the "elementary particles" were found, of which electron was the first one. The atomic nucleus was dicovered, and the particles that made it up: the nuclear particles, protons and neutrons.

From the photo-electric effect, how ligt affeceted electrons in a metal, was deduced that also light is made of particles. Eistein, who suggeted the theory, called them photons. This and investigating of the problems of electromagnetic energy absorbtion, and the stability of atoms lead to postulation of quantum theory. It was a work of many, Bohr, Planck, Schördinger, Heisenberg, Dirac, Pauli, Born and others.

It was not erlier than now the photons could really be understood, and the systematics in the table of chemical elements could be explained. It was now explained due to an interaction between the particles and the electromagnetic force, obeying the newly dicoverd strange logic of quantum mechanics.

How the electrons in an atom behave was now well understood, but how the atomic nucleus was held together could not be understood at all using electro-magnetism. Necessarily there must be some other kind of forces between the particles in the atomic nucleus. This was the dawn of the nuclear physics. Study of particle collisions become an important tool. Soon and quite unexpactedly new particles were found that no theory still existed for. Particle physics was born.

From start of the particle physics in thirties to the seventies the "zoo" of what was then called "elementary particles" had increased to several hundreds in number. It became more and more obvious that not all of them could be really elementary. There were a shorter period in sixties when an idea was tried that all particles were made of each other in some intricate circular way. This theory was called "nuclear democracy" (the name was propably inspired by the then popular political democracy movement). Also was tried an idea that the particle properties could be calculated from collision or particle splitting conditions alone, called S-matrix (scattering-matrix) theory. None of these once quite popular theories have shown any greater success.

The same time a more conventional idea was rising stronger: some of the particles, but not all, were made of inner constituents, "partons" was one name suggested, but which now are called "quarks". Nuclens, protons and neutrons, were made of quarks called "up" and "down" (not so fanciful names). This approach turned up to be succesful, making predictions that quite immediately could be confirmed. Mayby one of the most important for the success of the theory was the prediction that there msut exist one more quarks, the charm-quark, and "charmed" particles. Then one more was predicted and corresponding particles containg it was found, the "top" quark.

Quarks themselves can not be seen alone, but the new quarks appear as contituents in other particles whose existence was predicted. These particles were found by the particle research laboratories: CERN in Europe, and Fermilab in USA in 1970ies - 1980ies. Quark theory thus was experimentally confirmed. The quark theory now is only one part of the larger theory, which in lack of a better name is called "The Standand Theory of Particle Physics" or simply "Standard Theory". There was more particles required by the consistency of the Standard Theory. Some of them were the "weak bosons", whose existence was also confirmed by the same large accelerator laboratories.

Note 1: The shorter name is a bit confusing, because thre are at least three different "standard theories". The "Standard Theory of Particle Physics" we are talking of now, the "Standard Theory of Astrophysics", which is of stars and why they shine, and the "Standard Theory of Cosmology", which is of the birth of the universe, the Big Bang ad such things.

There are, though, predictions of the "Standard Theory" that have not yet been confirmed. "Higgs" particles are such hypothetical particles, and one of them is the Higgs boson (named after the english physicist Peter Higgs). The role of the Higgs particles is for a part explaining the masses of the other particles. The "search" of them is what the title of this article talks about.

the new giant particle accelerator LHC (Large Hadron Collider) of the European particle research laboratory CERN will soon be ready for operation. It will accelerate two particle beams in opposite direction to higher energies that ever has been done before, and them smash them together. The energy is calculated to be large enough creating and seeing these elusive Higgs particles. Some time this year, or next (2010), we might know if they exist, or if the theory needs a major revision.

Note 2: when we refer to "explaining mass" it might sound like Higgs particles had something to do with gravitation, but so it is not. Mass has also other effects than weight, mass also means inertia. Particles with nonzero rest-mass need to be accelerated to gain speed, and for that reason massive (= non-zero rest-mass) particles can not (according to Einstein's Special Theory of Relativity) reach the velocity of light c. Massless particles always have the speed c already when created. For a particle having a rest-mass or not is an important property that has consequences for the theory. E.g. neutrinos were originally assumed massless, but most recent experiments suggest that they have a tiny rest-mass. The Standard Theory theory thus was in need to be modified, and has lately been modified accordingly. LHC is expected to show if more modications are necessary.

There is a principle in need to a short description: mixed particle states. It is a way of making new particles of other particles, but it is not the same as making new particles of constituenst like quarks. In quantum mechanics there is an other way too, because particles are also waves. Pick a string of a guitarr. There will be all kind of tunes very shortly initially, but only the resonant tunes survive and can be heard as a note. Every guitarr tone, though, consists of a number of resonant overtunes mixed in certain properties. The same way particle waves mix, but only the resonant combinations survive and can be measured physically. Physicist jargong is talking of particles as "resonances", because they often show up like that in experiments, as resonance peaks in the particle energy spectrum.

The Particle Zoo

The first particle found and was the electron, and its electric charge, the elementary charge, was mesured already in nineteenth century. That was before the "quantum era". The first quantum particle suggested was photon, the quantum of electromagnetic radiation, such as radio waves, light and X-rays. When radioactivity first was discovered, with the primitive analysing methods then available it was realized there were three different kinds of it, given names simply with greek letters: alpha, beta and gamma rays.

Alpha rays were later found to be free Helium ions, or rather Helium nuclei, after discovery of the atomic nucleus. Beta rays turned out to be rapid electrons, and the gamma rays were found to like very high frequency X-rays, that is, they were highly enegetic photons. The first nuclear particle found was the proton, which alone is also the Hydrogen nucleus. The other nuclear particle neutron was found somewhat later. Very ligth neutral particles, neutrinos, where hyptetized and also (quite much) later found.

The radioactive rays around us are not only from decaying instable isotopes in earth, there are also cosmic rays from outer space. Analyzing the cosmic rays rapidly lead to more particles, like myons and pions. Other sources used for the search were nuclear reactors, and particle accelrators. In an accelerator known particles are accelerated to high velocities, that is, high energies. Letting them collide with a target more particles are generated, some of them of earlier unknown species.

The number of different particles increased rapidly, and needed to be explained. That was the start of the Standard Theory of particle physics. There was no single physicst who invented it. In tead it rises from a work of a whole community, hundreds, or thousands of physicists around the world.

In lack of a working theory the particles were first quite crudely classified after their mass. Light particles were called "leptons", heavy paricles "hadrons". The later were further divided into medium heavy "mesons", and the heavy ones "baryons". Super heavy baryons were sometims called "hyperons". This crude classification first put some particles in wrong boxes. Myons e.g were first put among the mesons, but are now counted to the leptons. Nevertheless, it turned out that there was a logic hidden in the particle masses.

On the most basic level the particles are now divided in two main classes, "fermions" and "bosons". Fermions are named after the Italian physicist Enrico Fermi, who developed a theory of their common behavior (together with Dirac and Pauli).

The first known fermions were the electrons and the protons. Fermions have the common property that they keep alone, take only "one seat" (quantum state) each (they obey the "Pauli exclusion principle"), and are so forced to occupy volume in space and form structures. Bosons are quite different from the fermions, because they thrive close together and form fields. The first particles of boson-type found where the photons of light, investigated by the Indian physicist Satyendranath Bose (together with Albert Einstein), and the particle type was named after Bose.

Particles			
Fermions			Bosons
Leptons	Hadrons		
	Mesons	Baryons	

Above the particle classification and subdivision in types. This classification was done long before the quark theory. The particles found were only a few of type leptons and bosons, but a plenty of mesons and baryons, several hundred of them of very differnt masses an properties. The number of "elementary particles" were now wastly more than the chemical elemets, which were to be explained originally. It became obvious that in any case hadrons (mesons and baryons) could not be elementary. Later they were explaned consisting of a few constituent particles, the quarks. Mesons of two quarts each, and baryons of three quarks each.

Generally all particles have an antiparticle, which is a basic particle symmetry, although the particles, what is known in present day, wastly dominate in number. Together these "elementary" fermions and bosons (and their antiparticles) form the whole basis for all (yet known) particles in the nature.

Other particle properties are such as electric charge, spin, parity, lepton numbers, and baryon number. These are quantum properties, also the electric charge because it is quantized. Spin is an quantum level rotation property. Parity is a quantum level symmetry property. The other quantum properties turn up when particle collisions are studied. It is a kind of bookeeping numbers that seems to be preserved in collisions, limiting the possible outcome in types of particles. Some of them are reasonably well explained in the Standard Theory, some are still not.

The main task for the Standard Theory is explaining all these particles, they properties and quantum numbers, and the force couplig strengths, which has been only partly successful till today. The coupling strengths are very important in the theory. There are found to be only four basic forces: gravitation, electromagnetism, and the weak and strong nuclear forces.

One of the most odd things in nature is that the forces show up vastly different strengts. Why it is so is not yet fully understood. If electromagnetism is set 1 in strength, the "strong force" is 100 times stronger, the "weak force" is really weak, only 10^{-11} = 0.000 000 000 01 in the comparation, but gravitation is still much weaker 10^{-36} = 0.000 000 000 000 000 000 000 000 000 000 000 001, all counted per particle. It is only because gravitation always adds up, and things like planets and stars consist of a tremendous number of particles, gravitation becomes so strong on macroscopic level. Still on particle level it is the weakest force of them all, too a weak to be measured in particle processes.

Forces and the Bosons

Fields, or "forces" as they are often called, then keep the fermion structures together, and sometimes are responsible of splitting them too, as is case in the radioactive decay. A theory of boson fields is with a common term called a "quantum field theory". The Standard Theory of particle physics consists of three separate quantum field theories, that are somewhat loosely connected:

1. Quantum Electrodynamics (QED), which is the theory of electromagnetism. This was historically the first of the quantum field theories. Note that this modern theory (by Feynman, Schwinger, and Tomonaga) goes the opposite way as the classical theory of electromagnetism (Maxwell's equations). Photons, the quanta of electromagnetic waves, are the starting point to QED and explain the fields, whereas in Maxwell's theory electromagnetic waves were a consequence of the fields.

2. Quantum Chromodynamics (QCD), the field theory of quarks and "strong" nuclear forces. It is somewhat similar to the QED-theory above, but in stead of two opposite charges we have here three "opposite" charges of "color fields", a bit odd construction reminiscent of the visual colors by its logical structure. The bosons of the strong force are called gluons.

3. Electroweak Theory. There seemed to be a "week" nuclear force responsible of splitting certain radioactive atomic nuclei (mostly a beta decay process), that worked much slower than splitting nuclei by the strong nuclear force (e.g. alpha decay), or by electromagnetic processes (gamma decay). Quite inexpectedly, a theory was found that unified the weak forces, not with the strong nuclear force that would been the first thought, but with the electromagnetic force.

There is a dream of unification of all the forces above, so that they would form one and only theory, a "grand unified theory" (or GUT for short). The standard theory is an attempt for such unification. Nevertheless, it is not complete, but there are still certain "holes", or uncertain details, left in it.

There is also the fourth force, gravitation. The unification above is due to quantum field theories, but there is still no satisfactory quantum theory for gravitation. Although it is uncertain if a satisfactory theory of quantum gravity ever can be put together, the field boson is given the name "graviton", and it has supposed to have certain expected properties. (One well known person working with quantum gravity is Stephen Hawking). The dream of putting together all four forces is called "theory of everything" (TOE for short).

N.B. Einstein's geometrical gravitation theory, also called General Relativity, works fine and explains gravitation on large scale cosmological level. But the trouble is that it is not a quantum theory, and there is thus very little hope unifying all the four forces using the methods of the Standard Theory.

QED

The basic idea is that quantum theory allows existence of particles in vacuum. Vacuum as a quantum mechanical state is like any other energy state. The uncertainty principle (of Heisenberg) does not allow perfect emptiness, because then both energy and velocity would zeroes all the time, which violates the uncertainty law. This is really the most important law of physics, and it is well verified.

The uncertainty law tells then that energy can be created from emptiness for very short times (but it does not allow using this to energy production, the old energy law still holds in longer periods, which means longer times than some billionths of second). There is a quantum hiss of myriads of very short-lived particles (of all kind but QED only concentrates on the photons).

These "sub uncertainty level" particles in empty space are called "virtual particles". It is like a "see of virtual particles" where the real particles, that have enough energy to exist longer times, are "swimming around". The mathematics is quite intricate but the effect from virtual photons sums up to the electrical and magnetical fields. There is an opposite way of seeing it, which is how it was originally set up: not only are energy states of particles in a force field quantized, but the field itself is quantized too (called originally "second quantization", or "field quantization").

These two ways to see the field theory are basically identical and only two sides of the same thing. The scope of this article is setting up the simplified math for particle relations. Because there is only one boson in QED, the photon, we can not set up any particle equations here.

There are kind troubles in the QED, as is case in all quantum field theories. Calculations in certain situations lead to infinities in infinite (divergent) serie sums. So it is when trying to calculate electric charges or particle masses. Because the theories in other situations worked well and explained the quantum nature of the involved fields well, physicists foud ways to circumvent the infinities. Such a reducing away the infinities, is called a "renormalization". If a theory does not give limited results it should be "renormalizable" at least.

The best way to see renormalization is (according the duch pysicist Gerard t' Hooft, my rephrasing): field theories are only asymptotic and not mathematically exact. Because the physical forces ("interactions") are not zero the infinite sums of such interactions can not become zero either. That's why one should not claim the theory to hold when adding infinitely many force terms. When a theory is renormalizable then there is an effective cut-off of the summing that gives a reasonably good fitting into reality. It is the best we can do to day. The theory may still be quite accurate but not "infinitively" accurate.

Basic Fermions

To day there are assumed ton be only a few particles that are espected to be truly elementary: the leptons, the quarks, and the bosons. Hadrons, subdivided to Mesons and baryons, have been proved to be made of quarks. Below a table of the leptons and the quarks, which together are all the fundamental fermions.

Leptons			Quarks		
ν_e	ν_μ	ν_τ	u	c	t
electron-neutrino	myon-neutrino	taon-neutrino	up-quark	charm-quark	top-quark
e	ν_μ	ν_τ	d	s	b
electron	myon	taon	down-quark	strange-quark	bottom-quark

The higher row: electron neutrino, mu neutrino, tau neutrino, up quark, charmed quark, and top quark. The lower row: electron, mu lepton, tau lepton, down quark, strange quark, and bottom (beauty) quark. The group of six at left are all the leptons, the six at right all the quarks.

There is a strong experimental and theoretical evidence to the believe that there are no more basic levels of this "fermion" kind to be found. There are thus only these three "families" of both leptons and quarks, and there are two generations in each. Moreover, which is not shown, every one of the fermions (of course) have their corresponding antiparticle (an antiparticle is usually denoted by drawing a stroke above the particle symbol).

The particles on the higher row can transform to particles to the lower, and vice versa, by emitting or absorption of a W-particle (weak boson). Following the strange but powerfully exact quantum logic it is possible to mix particles and so remake them into some other particles.

The identity of quantum particles is entirely not fixed, but we can mix together particles and so form new ones that have partly the properties of the original ones. The mixing is expressed mathematically by a "linear combination" (simply addition together with multiplication by some positive or negative constants) of their respective wave functions. Here as an example a possible resonant mix between the down quark and the strange quark?. I let here the particle symbols represent the corresponding wave function (here d is down quark, s is strange quark, d' and s' are new mixed particle states, and θ_c is a purely hypothetical "mixing angle" or Cabibbo-angle? appearing in the Standard Theory):

$$d' = d \cdot \cos\theta_c + s \cdot \sin\theta_c$$

$$s' = -d \cdot \cos\theta_c + s \cdot \sin\theta_c$$

Mixing of particles in quantum physics is not the same as putting particles together as pairs. It is more like adding of waves as was explained earlier. The mix is still only one particle but with properties mid between the original ones. What is mixed is the quantum physical wave functions that carry the particle properties. In this simplified description I do not explicitely write down the whole expressions of the wave functions, but express them with algebraic paricle symbols only. It will give a taste of the mathemathical play, without plunging into the more tedious details.

Note: Compare to polarization of light waves, h = horizontal polarization component, v = vertical polarization component. The polarization components in this analogy correspond to the particle wave functions. After tilting the system in angle q the new horizontal and vertical polarization components become a mix of the original ones, got by simple trigonometric:

$$h' = h\cos\theta + v\sin\theta$$

$$v' = -h\sin\theta + v\cos\theta$$

But one can also have right and left circumpolarized components, that do not depend on the tilt:

$$c_{Right} = \frac{1}{\sqrt{2}}(h + i\cdot v)$$

$$c_{Left} = \frac{1}{\sqrt{2}}(h - i\cdot v)$$

The Salaam-Weinberg electro-weak theory

The theory consists of mixing of the Electromagnetic and Weak Forces, thus logically connecting them to eachother. The trouble was originally that theory claimed massless particles but the particles detected (except photon) had heavy masses. This theory was originally devised in order to circumvent that problem. The starting point is assuming two fundamental massless particles, we denote A and B, which are all not the particles really observed, but form the mathematical base to build further with (Note: varied notation, in stead of A and B, may be used in literature by different authors).

The two electrically neutral field particles, photon and the weak neutral boson, are then expressed as the mixed states of the two base particles (bosons):

$$\gamma = B\cdot\cos\theta_w + A\cdot\sin\theta_w$$

$$Z = -B\cdot\sin\theta_w + A\cdot\cos\theta_w$$

Here the mixing coefficients are given in form of sinus and cosine of the Weinberg angle, experimentally determined $\approx 29°$. It is assumed to be a fundamental constant of nature. There is currently no conclusive explanation for it, but it is deeply connected with the particle masses, as will be seen.

Note also that the former, the photon is massless (as far as is known), but the Z-particle has a heavy mass, as have the charged W-particles (see below). The analogy to polarization says that the theory is starting from the original massless particles thus obeying the necessary symmetry to be reasonably well working. The measured system is then "tilted" from this ideal situation, the symmetry is "spontaneously broken", and the particles gain mass (see below the Higgs mechanism).

For setting together the charged neutral bosons take the two more massless, and chargeless, base particles W^1 and W^2 . We get the charged weak bosons as ("charge polarized") linear combinations of them. These two particles have been detected and have masses, despite that the theoretical constituents have not:

(Elbaz ch. 19, 3.3, Wikipedia "Standard model")

$$W^+ = \frac{1}{\sqrt{2}}\left(W^1 - i\cdot W^2\right) \qquad \sqrt{2}\cdot\left(W^- + W^+\right) = W^1$$

$$W^- = \frac{1}{\sqrt{2}}\left(W^1 + i\cdot W^2\right) \qquad \sqrt{2}\cdot\left(W^- - W^+\right) = W^2$$

> Note: one can also see terms like "neutral current" for Z, and "charged currents" for W^{+-}. Like electrons, any particle can make up a "current", but the use of the term in the Standard Theory mostly is reminiscent from an earlier theoretical framework called "current algebra".

The independent generators in this field theory are four in number. The usual mathematical method is using group theory in classification.

- First is the particle B that forms a group of its own, a singlet or SU(1) group.

- Then we have W^0 = A, W^1, W^2 forming a two-parameter special unitary group, SU(2) group, with three generators.

The group classification comes from pure mathematics and is an effective analyzing tool; it is an often seen terminology, that is why mentioned it, but we do not need to know more of the mathematical group theory here.

The three "group generator" particles are usually given as W^1, W^2, and W^3, where the third one is not taken A but a mix of A and Z:

$$W^3 = -A \cdot \sin\theta_w + Z \cdot \cos\theta_w$$

Couplings express the strength of the corresponding force between the particles. Assuming two fundamental electroweak coupling constants g and g', where the former is the lepton coupling to the W's (which all are assumed have identical coupling), the later is the lepton coupling to B. Electron's and neutrino's couplings to γ and Z become from the mixings above (using this very simplified logic):

ν: s coupling to γ $$C_{\nu\gamma} = ½ \cdot \left(-g' \cdot \cos\theta_w + g \cdot \sin\theta_w\right)$$

ν: s coupling to Z $$C_{\nu Z} = ½ \cdot \left(g' \cdot \cos\theta_w + g \cdot \sin\theta_w\right)$$

e: s coupling to γ $$C_{e\gamma} = ½ \cdot \left(-g' \cdot \cos\theta_w + g \cdot \sin\theta_w\right)$$

e: s coupling to Z $$C_{eZ} = ½ \cdot \left(g' \cdot \cos\theta_w + g \cdot \sin\theta_w\right)$$

A neutrino ν is electrically neutral. Therefore its coupling to γ must disappear

$$2 \cdot C_{\nu\gamma} = -g' \cdot \cos\theta_w + g \cdot \sin\theta_w = 0$$

Although A and B are particles that carry the weak interaction, and therefore would react with the neutrino ν, the mix that makes the photon γ does not. In the theory the interactions with the component particles are assumed to "take out eachother" exactly. Now, from this formula we get following relation between the couplings and the Weinberg angle:

$$\tan\theta_w = \frac{g'}{g}$$

then follows $$\cos\theta_w = \frac{g}{\sqrt{g^2 + g'^2}}$$

and $$\sin\theta_w = \frac{g'}{\sqrt{g^2 + g'^2}}$$

The coupling between e^- and γ must be the charge of an electron (negative sign because we think the negative electron but we could have taken the positron and positive coupling in stead, the result in end is the same)

$$-C_{e\gamma} = -\tfrac{1}{2}\cdot\left(-g'\cdot\cos\theta_w + g\cdot\sin\theta_w\right) = -e$$

Then follows from this eq. and the earlier one

$$e = g\cdot\sin\theta_w = g'\cdot\cos\theta_w$$

Further, ν:s coupling to Z

$$C_{\nu Z} = \tfrac{1}{2}\cdot\left(g'\cdot\cos\theta_w + g\cdot\sin\theta_w\right) = \tfrac{1}{2}\cdot e\cdot\left(\tan\theta_w + \cot\theta_w\right)$$

and e:s coupling to Z

$$C_{eZ} = \tfrac{1}{2}\cdot\left(g'\cdot\cos\theta_w - g\cdot\sin\theta_w\right) = \tfrac{1}{2}\cdot e\cdot\left(\tan\theta_w - \cot\theta_w\right)$$

Additionally then there is the coupling from e, ν to the charged W's

$$C_{eW} = C_{\nu W} = \frac{g}{\sqrt{2}} = \frac{e}{\sqrt{2}\cdot\sin\theta_w}$$

Notably it is equally strong for an electron (charged) as for a neutrino (neutral), showing a unification of the weak and electromagnetic forces at this level. Elecron and neutrino look the same for the electroweak force as mediated by the boson W.

Charge (Kaku 336) is given by

$$Q = T_3 + \frac{Y}{2}$$

For an left-hand electron and a neutrino (doublet)

$T_3 = 1$ or $T_3 = -1$ and $Y = -2$

For a right-hand electron

$T_3 = 0$ $Y = -2$

The handness is called "chirality", it is coupled to the spin of the particles. There are no right-handed neurinos, if neurinos are massless (and anti-neutrinos are all right-handed). But if neutrinos have even tiny rest-masses then there should be found right-handed neutrinos (and left-handed anti-neutrinos). Because neutrinos then had velocities less then c we can in theory pass by such a neurino, and for such bypassing observer the lefthanded neutrino would appear going backwards and becomes a right-handed one. The question, though, is still open. (Neurinos have, though, lately been shown to have at tiny mass.)

Higgs-mechanism

As an analogy, in a refracting media photon gets an apparent velocity less than the velocity of light in vacuum. This is due to absorption of photons by electrons in the media. Photons then also have an apparent rest mass m_γ . Here ω_p is so called plasma frequency, n_e is electron density in the media, and m_e is the mass of an electron.

$$m_\gamma^2 \cdot c^4 = \left(\frac{h}{2\pi} \cdot \omega_p\right)^2 = \left(\frac{h}{2\pi}\right)^2 \cdot \frac{n_e}{\varepsilon_o \cdot m_e} \cdot e^2$$

The basic assumption is that the bosons W and Z (in the Weinberg-Salaam theory above) are originally massless and move with velocity of light, but that vacuum is filled with a medium that makes the particle field to advance more slowly. This medium is assumed to be electrically neutral: a kind of see of electrically neutral zero-spin particles and antiparticles, denoted N (here obviously not meaning nucleons). These virtual N-bosons are created in particle-antiparticle pairs all the time and recombine to nil short thereafter.

W (boson) + N (boson) ---> E (fermion?) ---> N (boson) + W (boson)

A charged W-particle can be absorbed by a N, that then transforms to an electron like charged ½-spin fermion E. That particle can emit an W and transform back to N. W^+ are absorbed by N and W^- by anti-N. We identify the particles in the Weinberg-Salaam theory as

$A = W^0$ B $N = W^1$ $E = W^2$ W^2 is a boson??

The apparent mass of W depends on the probability of the absorbtion. It is proportional the the coupling strength, which here is

$$\frac{g}{\sqrt{2}}$$

The mass-energy is then related to the quadrature of this. Here K is a constant that is among other things related to the density of N-particles in the vacuum-see.

$$m_W{}^2 = \frac{K \cdot g^2}{2}$$

The neutral A or B too can be absorbed by N-particles, but N do not transform but continue as N. Such an exited N-particle can again emit neutral A or B, but it does not remember which one it first absorbed, so what is effectively emitted is a mix of neutral A and B. The coupling coefficient for B is

$$\frac{g'}{\sqrt{2}}$$

The mixed state then, using (6.6.13) and (6.6.14), has the coupling

$$\frac{g}{2} \cdot A - \frac{g'}{2} \cdot B = \frac{\sqrt{g^2 + g'^2}}{2} \cdot \left(\cos\,\theta_W \cdot A - \sin\,\theta_W \cdot B\right) = \frac{\sqrt{g^2 + g'^2}}{2} \cdot Z$$

So whichever of A or B was absorbed by the N-particles, what comes out is always a mix that corresponds to the Z-particle. This is also true if the absorbed particle already was a mix of A and B. A Z-mix stays therefore as a Z-particle, and advances in space with a reduced velocity as if it was a particle with a given (apparent) rest-mass. The mass of the Z-particle is given by the coupling strength to the N-particles. K is again the density of the absorbing particles. Z can be absorbed both by N an anti-N-particles, that is why we have an extra factor 2 .

$$m_Z{}^2 = K \cdot \left(\frac{g \cdot \cos\,\theta_W + g' \cdot \sin\,\theta_W}{2}\right)^2 \cdot 2 = \frac{K}{2} \cdot \left(\frac{g}{\cos\,\theta_W}\right)^2$$

the K is the same than in eq. above, so

$$m_Z = \frac{m_W}{\cos\,\theta_W}$$

The situation above with the Z-particle is similar to that for a photon. Experimental result give approximately, expressed in GeV/c^2

(from Partcle Data Group, 2006.)

$$m_w = 80.4 \qquad m_z = 91.2$$

$$\theta_w = \operatorname{acos}\left(\frac{m_w}{m_z}\right) = 28.167 \cdot \text{degrees}$$

Note that the particles labeled A, B, W^0, W^1, W^2, W^3 are theoretical contructs, they do not show up in experiments, and their properties can not be directly measured. It is in stead the mixed states of these that turn up in the real world: γ , Z, W^-, W^+ , photon, the neutral weak boson, and the negitively and positively charged weak bosons.

Note also that Z is not identical to W^0. The later notation happened to be reserved as an alternative to the one also called A, there is a theoretical logic in it although a bit far-fetched. Any way, the neutral pal to the charged W's was labeled Z, and is in particle listings often written Z^0. Nobody yet knows if any of the Higgs or any mix with them will turn up in the real world.

Because now vacuum is filled with medium that can carry impulses, the situation is the same as in any medium: quantized waves should be possible. Such a quanta are called Higgs particles, "Higgs bosons".

Quark theory

The fundamental leptons and quarks can also appear in mixed forms. Here some such expressions for mixing of the quarks, were θ_c is the Cabibbo angle (about 13 degrees):

$$d' = d \cdot \cos \theta_c + s \cdot \sin \theta_c$$

$$s' = -d \cdot \cos \theta_c + s \cdot \sin \theta_c$$

Expressing the universality of the quark states, these pairs couple to weak bosons with nearly same strength. We can further write for s-quark the mixed state (Cabibbo 1963):

$$s = d' \cdot C + s' \cdot \sqrt{1 - C^2}$$

where

$$C = \sin\theta_c \qquad C = 0.225 \qquad C^2 = 0.051 \qquad 1 - C^2 = 0.949$$

This above explains why e.g. Λ-hyperon (quark combination uds) does not decay in the usual rate in weak interaction, but is some 20 times slower that that:

- First note that this decay does not preserve strangeness. The s-quark reacts through the mixed state, which in most part (95%) consists of the, in case of (uds) nearly stable, s' state.

- It is then only the more rare d' state that, with the reasonably lower probability $C^2 \approx 1/20$, can transform into u-quark by emitting a W^- particle (This then eventually decays into an electron and an antineutrino in a very short time.)

For the most usual 3-quark couplings we have the Cabibbo-Kobayashi-Maskawa (CKM) matrix:

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{td} & V_{td} \end{pmatrix} \cdot \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$\sum_{j=u,c,t} \left(V_{ij} \cdot V_{ik}^{*} \right) = \delta_{jk}$$

KM phase: $\varphi = f(\phi_1, \phi_2, \phi_3)$ 3 real angles, i phase factor

KM phase to be determined from CP violation in B-decays ($b \rightarrow u$)

$$\text{degrees} \equiv \frac{\pi}{180} \qquad \theta_c \equiv \frac{13 \cdot \pi}{180}$$

This whole article is still a draft ... and there are a number of question marks left.

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