Lecture 14. *Tuesday 28^{th} April, 2020.* *Compiled: Tuesday 28^{th} April, 2020.*

When the Higghs was proposed, Weinberg and Salam showed that the required mass of the vector bosons and of the fermions can be acquired by the interaction with the H field. The potential of this field is:

$$V(\varphi) = -\mu^2|\varphi|^2 + \lambda\left(|\varphi|^2\right)^2 \tag{1}$$

The minimum of the potential is obtained by setting to zero the first derivative with respect to φ of the potential:

$$0 = -2\mu^2\varphi + 4\lambda\varphi|\varphi|^2 \implies |\varphi|^2 = \frac{\mu^2}{2\lambda} \tag{2}$$

If we compute the H field vacuum expectation value, we find:

$$v = \sqrt{2}\,\langle|\varphi|\rangle = \frac{\mu}{\sqrt{\lambda}} \tag{3}$$

It is different from zero and it spontaneously breaks the $SU(2)\times U(1)$ gauge symmetry. In the theory we need to introduce two coupling constants, g and g', related to the two gauge groups. Putting all together the previous facts, it is possible to show that:

- One of the 4 bosons of theory remains massless and it is the photon.
- Two bosons are charged with mass, namely:

$$M_W = g\frac{v}{\sqrt{2}} \tag{4}$$

- One boson is neutral and massive, with mass:

$$M_{Z^0} = \sqrt{g'^2 + g^2}\frac{v}{2} \tag{5}$$

- If we define the Weinberg angle θ_W, we have:

$$\tan\theta_W = \frac{g'}{g} \tag{6}$$

- It holds:

$$M_W = M_Z\cos\theta_W \tag{7}$$

$$e = g\sin\theta_W = g'\cos\theta_W \tag{8}$$

$W^{\pm}$ and Z^0 bosons couple to quarks and leptons. In order to describe these couplings two quantum numbers are needed: the **weak isospin** I and the **hypercharge** Y. The electric charge is then related to these quantities by:

$$Q = I_3 + \frac{Y}{2} \tag{9}$$

Experimentally, we see that left-handed particles couple to $W^{\pm}$ bosons, but right-handed particles have not this behaviour. Quarks and leptons are grouped:

- Left-handed $\implies$ doublet $\implies I = \frac{1}{2}$
- Right-handed $\implies$ singlet $\implies I = 0$

Therefore the correct representation is:

$$\begin{pmatrix}\nu_L \\ e_L^-\end{pmatrix}, e_R^- \qquad \begin{pmatrix}u_L \\ d_L\end{pmatrix}, u_R, d_R \tag{10}$$

0.1 Experimental electroweak tests

TODO