Date: 10h00, 24 April 2019 30 hr Project

PH4204: High Energy Physics

Duen: 16h00, 25 April 2019 Weight: 16%

1. **SM with two doublet:** For a $SU(2) \otimes U(1)$ gauge theory (i.e. SM) we have two scalar doublets Φ_1 and Φ_2 with hypercharges $+1$ and -1 respectively. Their electrically neutral componetnts get a vacuum expectation value (VEV) v_1 and v_2 respectively.
   (a) Find the mass of $A^{\pm}$ boson in terms of two VEVs.
   (b) Find the expressions for Z bosons and show that γ in terms of A_3 and B and show that γ remains mass-less.
   (c) Find the Z bosons coupling to both e_L and e_R.
   (d) Write down the mass terms of *down-type* fermions using Φ_1 and for the *up-type* fermions using Φ_2.
   (e) Find the Z and γ bosons coupling to both d_L and d_R, where d is the *down-quark*. How is it different from the SM case.
2. **SM with a doublet and a triplet:** For a $SU(2) \otimes U(1)$ gauge theory (i.e. SM) we have a scalar doublets Φ_1 and triplet scalar Φ_2 with hypercharges $+1$ and $+2$, respectively. Their electrically neutral componetnts get a vacuum expectation value (VEV) v_1 and v_2 respectively.
   (a) Find the mass of $A^{\pm}$ boson in terms of two VEVs.
   (b) Find the expressions for Z bosons and show that γ in terms of A_3 and B and show that γ remains mass-less.
   (c) Find the relation between $v_1,\ v_2$ and gauge couplings such that mass of Z boson becomes same as the mass of $A^{\pm}$.
3. **SM with a triplet:** For a $SU(2) \otimes U(1)$ gauge theory (i.e. SM) we have a scalar triplet Φ in place of a doublet with a hypercharges $+1$. One of the tree component gets a vacuum expectation value (VEV) v (to be tried for all three component one by one).
   (a) Find the mass of $A^{\pm}$ boson, A_3 boson and B boson for three choices of the VEV.
   (b) Which choice of VEV leads to the masses for all gauge bosons leaving A_3 mass-less and why does this happen.
   (c) Is it possible to have a mass-less photon candidate in this model? Explain your answer.
4. **Model with $SU(3)$ symmetry and two triplet scalar:** For a $SU(3)$ gauge theory we have two scalar triplet $\Phi = \{\phi_1, \phi_2, \phi_3\}^T$ and $\Psi = \{\psi_1, \psi_2, \psi_3\}^T$. The component ϕ_3 gets a vacuum expectation value (VEV) v and ψ_2 gets a VEV u.
   (a) Find the masses of all eight gauge bosons.
   (b) Which gauge bosons remain mass-less and why? What is the left over symmetry of the theory after scalars gets a VEV.