Partice Physics: Problem Sheet 4
The Weak Force

1. Make sure you have done question 8 on last week’s sheet. (Question 6 is also interesting!)

2. Write down all possible decay modes of the $W^-$ boson into quarks and leptons. What is the strength of each of these vertices?

3. Draw the lowest order Feynman diagram for the decay of a tau into an electron and into a muon: $\tau^- \rightarrow e^- \bar{\nu}_e \nu_\tau$ and $\tau^- \rightarrow \mu^- \bar{\nu}_\mu \nu_\tau$, respectively. Discuss the corresponding matrix elements, decay rates and branching fractions.

4. By drawing the lowest order Feynman diagrams, show that both charged and neutral current contribute to neutrino electron scattering: $\nu_e + e^- \rightarrow \nu_e + e^-$. 

5. Estimate the total decay width, $\Gamma_Z$, and the lifetime of the $Z^0$ boson using:
   
   - The measurement of the total hadronic width: $\Gamma(Z \rightarrow \text{hadrons}) = 1744.4 \text{ MeV}$
   - The measurement of the width into charged leptons: $\Gamma(Z \rightarrow \ell^+\ell^-) = 84.0 \text{ MeV}$. ($\ell \equiv \{e, \mu, \tau\}$).
   - The prediction for the width into one flavour of neutrino: $\Gamma(Z \rightarrow \nu\bar{\nu}) = 167.0 \text{ MeV}$.

   Compare with the observed resonance width, $\Gamma_Z = 2495.2 \pm 2.3 \text{ MeV}$. What are the branching ratios of each of the decay modes?

6. Draw a quark level diagram for the weak decay $K^+ \rightarrow \pi^+\pi^0$. (See hints with question 6.)

7. Feynman diagrams
   In each of the following decays try to draw a quark level Feynman diagram and determine which interaction is responsible. The quark content of $D^{*+}$ is $c\bar{d}$; the quark content of $K^{*0}$ is $\bar{s}d$. The others are given on the particle properties sheet.

   \[
   D^{*+} \rightarrow D^0\pi^+ \quad \Sigma^0 \rightarrow \Lambda\gamma \\
   D^+ \rightarrow K^0\pi^+ \quad \tau^- \rightarrow \rho^-\nu_\tau \\
   K^{*0} \rightarrow K^+\pi^- \quad \pi^0 \rightarrow \gamma\gamma
   \]

   \text{Hints:} The photon only interacts electromagnetically and the neutrino only weak. First establish the relevant quark and lepton flavour quantum numbers of the initial and final states. Quark and lepton flavours are conserved at each vertex for the strong and electromagnetic processes, the weak charged current is flavour changing. Always draw the simplest possible diagrams.

   Do your answers agree with the observed lifetimes?