Particle Physics: Problem Sheet 2
Quantum numbers and QED

1. What quantum numbers are associated with leptons? Are they conserved in strong, weak and electromagnetic interactions?

2. What quantum numbers are associated with quarks? Are they conserved in strong, weak and electromagnetic interactions?

3. What are the charge and quark flavour quantum numbers for the $\bar{\mathrm{u}}$, $\bar{\mathrm{d}}$ and $\bar{\mathrm{s}}$ quarks? What are the quantum numbers of the lambda anti-baryon, $\bar{\Lambda}^0$, and of the antiproton, $\bar{p}$?

4. The simplest vertex in QED is a fermion-fermion-photon vertex. Draw an example Feynman diagram for such a vertex. Write down *all* possible electromagnetic fermion-fermion-photon vertices.

5. Draw the lowest order Feynman diagram for electron-proton scattering $e^-p \to e^-p$. Discuss the corresponding scattering amplitude or Matrix element, $\mathcal{M}$.

   Show that the photon propagator is the origin of the $1/\sin^4(\frac{\theta}{2})$ dependence of the Rutherford cross section for $e^-p \to e^-p$ scattering.

6. Draw the lowest order Feynman diagrams for our favourite process: $e^+e^- \to \mu^+\mu^-$. Discuss the corresponding Matrix element, $\mathcal{M}(e^+e^- \to \mu^+\mu^-)$.

   A similar process can be used to create pairs of quarks, $e^+e^- \to \mathrm{q}\bar{\mathrm{q}}$. Discuss the corresponding Matrix element for this process, $\mathcal{M}(e^+e^- \to \mathrm{q}\bar{\mathrm{q}})$.

   What can you say about the ratio of the cross sections,

   $$\frac{\sigma(e^+e^- \to \mathrm{q}\bar{\mathrm{q}})}{\sigma(e^+e^- \to \mu^+\mu^-)}?$$

   Please note: this is not the whole answer to the problem! We'll look more at this process in the coming weeks.

7. Draw the lowest and second order Feynman diagrams for electron-muon scattering $e^-\mu^- \to e^-\mu^-$. Discuss the corresponding matrix element, $\mathcal{M}$, and cross section for the lowest order. Estimate the contribution of the second order diagrams to the cross section.

8. Some of what we have learned about QED is applicable to the weak force. The weak force can be propagated by the $W^\pm$-boson with mass $m_W = 80\ \mathrm{GeV}/c^2$. For example, nuclear beta decay can be described as $\mathrm{d} \to \mathrm{u}W^-$, followed by the decay of the W^- into $e^-\bar{\nu}_e$.

   Estimate the maximum range of the weak force propagated by the W-boson.

   What does the Yukawa potential look like for exchange of a W-boson? The coupling of the W-boson, is written as g_W.