Particle Physics: Problem Sheet 2

Quantum Electrodynamics, Interaction with Matter, Accelerators, Detectors

1. 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.

2. Draw the lowest order Feynman diagram for electron-proton scattering $e^- p \to e^- p$. Discuss the corresponding scattering amplitude or Matrix element, $\mathcal{M}$. You may neglect the spins of the e^- and p.

   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.

3. 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. You may neglect the spins of the e^- and μ^-. Estimate the contribution of the second order diagrams to the Matrix element, $\mathcal{M}$, and cross section.

4. Cosmic ray muons are produced at the top of the atmosphere. How much energy does a muon with 5 GeV/c momentum lose by ionisation before reaching sea level? Hints: Treat the muon as minimum ionising and use $\frac{dE}{dx}|_{\text{min}} \approx 2.0 \frac{\text{MeV}}{\text{g cm}^{-2}}$. The mass thickness of the atmosphere, x, in g/cm^2, can be inferred from the pressure at sea level, $P = 1$ atm $= 10^5$ kgm^{-1}s^{-2}, by assuming the density to be constant.

5. A pion of mass 139.6 MeV/c^2 is traversing a glass window with refractive index of $n = 1.50$. What is the minimum pion momentum, p, in GeV/c (momentum threshold) at which the pion emits Cherenkov radiation? What is the maximum Cherenkov angle, θ_C, and what pion speed does it correspond to?

   Plot the Cherenkov angle as a function of the pion momentum.
   Hint: Use the relation $p = \beta\gamma mc$ and plot with logarithmic x-axis in the momentum range 0.1 GeV/c to 10 GeV/c.

6. Using the Born approximation, derive the matrix element for scattering of bosons in the Yukawa potential. Comment on your result.