Partice Physics: Problem Sheet 3

Mesons & Baryons and the Strong Force

1. Which of these processes occur in nature?

   $$a)\ \pi^- p \to K^0 \Lambda^0$$
   $$b)\ \pi^- p \to \pi^0 \Lambda^0$$
   $$c)\ \pi^- p \to K^+ \Sigma^-$$
   $$d)\ \pi^- p \to \pi^+ \Sigma^-$$

   What quantum numbers are needed to solve this question? How are these related to the quark model?

2. Which of these processes occur in nature?

   $$a)\ \tau^- \to e^- \nu_e \bar{\nu}_\tau$$
   $$b)\ \tau^- \to e^- \bar{\nu}_e \nu_\tau$$
   $$c)\ \tau^- \to \pi^- \nu_\tau$$
   $$d)\ \tau^- \to \pi^- \pi^0 \nu_\tau$$

   What quantum numbers are needed to solve this question?

3. Verify the quark model predictions given in the lectures for the masses of the following mesons: π, K, ρ, ω, K^* and ϕ. Assume $m_u = m_d = 310$ MeV and $A = (2m_u)^2 \cdot 160$ MeV.

4. Draw a Feynman diagram for the scattering process $p\pi^+ \to \Delta^{++} \to p\pi^+$.

5. At very high beam momenta, 100 GeV/c, the total cross sections for $\pi^+ p$ and pp scattering is dominated by the exchange of a gluon between quarks inside the pions and protons. Draw a Feynman diagram for pp and $\pi^+ p$ scattering. Use the number of possible diagrams to calculate the ratio of cross sections $\frac{\sigma(\pi^+ p)}{\sigma(pp)}$.

6. The J/ψ meson was discovered through its electromagnetic decays into e^+e^- and $\mu^+\mu^-$. However, the J/ψ decays mainly through strong interactions such as: $J/\psi \to \pi^+\pi^-\pi^0$.

   Draw the Feynman diagram for this decay, and hence explain why, although most of the decays of J/ψ are due to the strong force, it has a relatively long lifetime.

   Hint: You have to consider both colour charge and parity. The J/ψ meson, has parity $\pi = -1$, gluons have parity $\pi = -1$.

7. What is meant by colour confinement?

8. Calculate the value of the cross section ratio, R:

   $$R(E_{CM}) = \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

   for:

   - $2 < E_{CM} < 4$, when u, d and s quarks can be produced.
   - $4 < E_{CM} < 10$, when c quarks can also be produced.
   - $10 < E_{CM} < 30$, when b quarks can also be produced.

   Compare these values, as best you can, to the values on the plot in lecture 6.

   What are the quark content of the J/ψ, $\psi(2S)$ and Υ states shown in the plot?