Quark Flavour Physics

1. Draw Feynman diagrams for decays $\pi^- \to \mu^- \overline{\nu}_\mu$ and $K^- \to \mu^- \overline{\nu}_\mu$. The branching fractions of two are measured to be $\mathcal{B}(\pi^- \to \mu^- \overline{\nu}_\mu) = 0.999877 \pm 0.0000004$ and $\mathcal{B}(K^- \to \mu^- \overline{\nu}_\mu) = 0.6355 \pm 0.0011$. Decay rate of each decay is given by

$$\Gamma = |V_{uq}|^2 G_F^2 f_p^2 m_p m_\mu^2 (1 - m_\mu^2/m_p^2)^2 \tag{1}$$

where $f_\pi = (130.41 \pm 0.03 \pm 0.20) MeV$, $f_K = (156.1 \pm 0.2 \pm 0.8 \pm 0.2) MeV$ with masses being $m_\mu = 105.7$ MeV, $m_\pi = 139.57$ MeV and $m_K = 493.7$ MeV and lifetimes being $\tau(\pi^+) = 2.6033 \times 10^{-8}$ s and $\tau(K^+) = 1.2385 \times 10^{-8}$ s. Using this estimate Cabbibo angle.

2. Consider pure beam of long lived neutral kaons. As the K^0 and $\overline{K}^0$ interaction cross section with matter leads to interesting effect known as kaon regeneration. Essence of it is that after pure K_2 beam traverse block of matter, it contains again K_1 component. Denoting K^0 integrated cross section with block of matter as f and $\overline{K}^0$ as $\overline{f}$ find out amount of K_2 and K_1 component after pure K_2 beam traverses given block of matter.

3. Using discussed formalism, verify that $K_L \to 2\pi$ rate is indeed proportional to ϵ.

4. Neutral meson mixing is described by equation

$$i\frac{d}{dt}\begin{pmatrix} |B_s(t)\rangle \\ |\overline{B}_s(t)\rangle \end{pmatrix} = \left(\hat{M} - \frac{i}{2}\hat{\Gamma}\right)\begin{pmatrix} |B_s(t)\rangle \\ |\overline{B}_s(t)\rangle \end{pmatrix}.$$

Diagonalization leads to eigenstates with definite masses and lifetimes

$$\begin{aligned} |B^0_{sH}\rangle &= p\,|B_s\rangle + q\,|\overline{B}_s\rangle, \\ |B^0_{sL}\rangle &= p\,|B_s\rangle - q\,|\overline{B}_s\rangle, \end{aligned}$$

with p and q being complex numbers satisfying $|p|^2 + |q|^2 = 1$. Diagonalise matrix and find two mass states.

5. Which of the following decays can show CP violation in standard model. Draw Feynman diagrams and decide which type of CP violation. Decays to exhibit are:

   (a) $D^0 \to K^+ K^-$

   (b) $B^+ \to J/\psi K^+$

   (c) $B^0 \to J/\psi \rho$

   (d) $B^0_s \to \phi\phi$

   (e) $B^0 \to K^+ \pi^-$

(f) $B^+ \to [\pi^+\pi^-]_D K^+$ where $[\pi^+\pi^-]_D$ is combination of two pions consistent with originating from D^0 or $\overline{D}^0$.

(g) $B^+ \to [\pi^+\pi^-]_D K^-$

(h) $\Lambda_b^0 \to \Lambda_c^+ \pi^-$

(i) $\Lambda_b^0 \to \Lambda \pi^+ \pi^-$

6. What are differences in flavour tagging between e^+e^- machines at $\Upsilon(4S)$ energies and hadron colliders.

7. List physics sources of imperfection of flavour tagging. Consider also differences between e^+e^- machines at $\Upsilon(4S)$ energies and hadron colliders.

8. Why low energy e^+e^- colliders cannot compete with hadronic machines in studies of time evolution of B_s.

9. Imagine that there is a fourth family of quarks (t', b') with $m(t') > m(b')$, that is decoupled from the three SM families since $V_{t'b'} = 1$. Describe how the b' quark might be detected. If a strongly bound b'b'bar state exists, would it decay and if so, how?

10. Draw a Feynman diagram for the leptonic decay $D_s^+ \to \mu^+ \nu$. What property of the CKM matrix can be determined from the measurement of its branching fraction?

11. Draw a Feynman diagram for the rare decay $K_L \to \pi^0 \nu \overline{\nu}$. What property of the Unitarity Triangle can be determined from the measurement of its branching fraction?