Massachusetts Institute of Technology

Department of Physics

Course: 8.701 – Introduction to Nuclear and Particle Physics
Term: Fall 2020
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Discussion Problems
from recitation on **October 22th, 2020**

Problem 1:   Unitarity

Show that the CKM matrix is unitary for any real number θ_{12}, θ_{23}, θ_{13}, and δ, i.e. show that $(VV^\dagger)_{11} = 1$ and $(VV^\dagger)_{12} = 0$ and so on.

$$
VV^\dagger = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23}-c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23}-s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23}-c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23}-s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}
$$
$$
\times \begin{pmatrix} c_{12}c_{13} & -s_{12}c_{23}-c_{12}s_{23}s_{13}e^{-i\delta} & s_{12}s_{23}-c_{12}c_{23}s_{13}e^{-i\delta} \\ s_{12}c_{13} & c_{12}c_{23}-s_{12}s_{23}s_{13}e^{-i\delta} & -c_{12}s_{23}-s_{12}c_{23}s_{13}e^{-i\delta} \\ s_{13}e^{i\delta} & s_{23}c_{13} & c_{23}c_{13} \end{pmatrix}
$$

Problem 2:   CKM Parameter

Show that as long as the CKM matrix is unitary, the GIM mechanism for eliminating $K^0 \to \mu^+\mu^-$ works for three generations or any number of generations. Note: $u \to d + W^+$ carries a CKM factor V_{ud} and $d \to u + W^-$ carries a factor V_{ud}^*

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