CP Violation in Heavy Flavour Physics	**Dirac Equation, Symmetries**
Tutorial 1	2021

1. Postulate that the solutions of the Dirac Equation have form of the plane wave and a spinor: $\psi(x^\mu) = u(p^\mu)e^{-i(Et-\vec{p}\cdot\vec{x})}$ and write out the DE for spinors.
2. Use the previous result and find four solutions of Dirac Equation for a particle with momentum $\vec{p}$ and mass m.
3. Define the properties of Dirac spinors using their transformation properties i.e. apply $\hat{P}$ and $\hat{C}$ operator on any of u_i functions.
4. Show that for a particle/antiparticle with momentum $\vec{p} = (0,0,p)$ the u_1 and v_1 spinors represent spin up states and u_2 and v_2 spin down states.
5. Using the properties of the γ matrices and the definition of γ^5, show that: $(\gamma^5)^2 = 1$, $\gamma^{5\dagger} = \gamma^5$, $\{\gamma^5, \gamma^\mu\} = 0$ where $\gamma^5 \equiv i\gamma^0\gamma^1\gamma^2\gamma^3$.
6. Show that the chiral projection operators $P_L = \frac{1}{2}(1-\gamma_5)$ and $P_R = \frac{1}{2}(1+\gamma_5)$ satisfy: $P_L\, P_R = P_R\, P_L = 0,\quad P_L + P_R = 1,\quad P_L\, P_L = P_L,\quad P_R\, P_R = P_R,\quad P_L\, P_R = 0.$ These conditions prove that these operators are projectors (applying one of them twice gives the same result as applying it once and that applying both of them results in the null state.
7. Check what is the consequence of applying the $P_L = \frac{1}{2}(1-\gamma_5)$ and $P_R = \frac{1}{2}(1+\gamma_5)$ operators on the helicity states $\{u_R, u_L, v_L, v_R\}$ and interpret the result. You can use states when fermion has only p_z component of the momentum.

CP Violation in Heavy Flavour Physics	**CPV measurements**
Tutorial 2	2021

1. Find the time dependent probability of the transition of a kaon into an anti-kaon particle when CP is conserved and violated. Choose one out of four possibilities of the form:

$$P(\overline{K}^0, t) = |\langle \overline{K}^0 | K^0(t) \rangle|^2$$

2. Check by direct substitution that the following time dependent states:

$$|K_S^0(t)\rangle = e^{-\frac{i}{\hbar}\left(m_S - \frac{i}{2}\gamma_S\right)t} |K_S^0\rangle$$

$$|K_L^0(t)\rangle = e^{-\frac{i}{\hbar}\left(m_L - \frac{i}{2}\gamma_L\right)t} |K_L^0\rangle$$

are indeed solutions of the effective Schrodinger equation describing two state kaon system:

$$i\hbar \frac{\partial |\psi(t)\rangle}{\partial t} = \mathcal{H}_{eff} |\psi(t)\rangle$$

3. Calculate the e-values and e- states of the Hamiltonian matrix describing two state system of decaying kaons. Hint: use the partially finished calculation shown during the lecture.

4. What is the interpretation of off-diagonal elements of the Hamiltonian matrix.

1. Neutral meson P^0 and its antiparticle $\overline{P^0}$ decays to the same final state $f.$ Calculate:
   a) the decay rates

$$\Gamma_f = |\langle f|H|P^0(t)\rangle|^2 \text{ and } \bar{\Gamma}_f = \left|\langle f\middle|H\middle|\overline{P^0}(t)\rangle\right|^2$$

   b) the CP asymmetry of the form:

$$a_{CP}(t) = \frac{\Gamma_f - \bar{\Gamma}_f}{\Gamma_f + \bar{\Gamma}_f}$$

2. Show that CP asymmetry for the channel $B^0 \to J/\psi K_S$ ("golden channel") can be used to extract unitary angle β. Start with the asymmetry:

$$a_{CP}(t) = \frac{\Gamma(B^0 \to J/\psi K_S) - \Gamma(\overline{B^0} \to J/\psi K_S)}{\Gamma(B^0 \to J/\psi K_S) + \Gamma(\overline{B^0} \to J/\psi K_S)}$$

3. Write the equation describing the direct CPV in charged B-meson decay, for example $B^0 \to K^+\pi^-$.
4. Determine the sensitivity of CKM γ angle measurement in $B^0 \to D^0 K^{*0}$ decay.