Physics Beyond the Standard Model — Exercise Sheet 7

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1. **Neutrino Dirac mass revisited:**
   When both Dirac and Majorana mass terms are present in the Lagrangian we have

$$\mathcal{L}_{DM} = D\bar{\psi}_L\psi_R + A\bar{\psi}^c_L\psi_L + B\bar{\psi}^c_R\psi_R + \text{h.c.}\,.$$

   a) Expressed this mass terms in terms of the two Majorano fields:

$$\chi = \psi_L + \psi^c_L\,, \omega = \psi_R + \psi^c_R\,.$$

   b)Find out the mass eigenstates and the diagonalization condition.
   c) Show that the usual four-component Dirac field formalism can be recovered in the limit of $A = B = 0$.

2. **Lepton flavour violation $\mu \to e\gamma$:**
The $\mu \to e\gamma$ process is forbidden in the SM with massless neutrino. However when neutrinos are massive we can obtain non-zero amplitude for this transition.
a) Find out corresponding Feynman diagrams.
b)Write down the amplitude of the diagram with $WW\gamma$ vertex. Express it with neutrino mass eigenstates.

$$\nu_\alpha = \sum_i U_{\alpha i}\nu_i \,, \alpha = e,\, \mu,\, \tau \,; i = 1,\, 2,\, 3\,.$$

c)Find out that the branching ratio is

$$B(\mu \to e\gamma) \equiv \frac{\Gamma(\mu \to e\gamma)}{\Gamma(\mu \to e\nu\bar{\nu})} = \frac{3\alpha}{32\pi}\Big(\sum_i U^*_{ei}U_{\mu i}\frac{m_i^2}{M_W^2}\Big)^2 .$$