Problem Set 5

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Problem 1 figure 1

Which of the following reactions are allowed and which are forbidden by the conservation laws appropriate to weak interactions?

(a) $\nu_\mu + p \to \mu^+ + n$ (b) $\nu_e + p \to n + e^- + \pi^+$

(c) $\Lambda \to \pi^+ + e^- + \bar{\nu}_e$ (d) $K^+ \to \pi^0 + \mu^+ + \nu_\mu$

(e) $\nu_e + p \to e^- + \pi^+ + p$ (f) $\tau^+ \to \mu^+ + \bar{\nu}_\mu + \nu_\tau$

Figure 1: Problems 3.1

The following must be conserved:

- Lepton number.
- Baryon number.
- Charge.
- Energy and momentum.
- CPT

a) No: Lepton number is not conserved.

b) No: Charge is not conserved.

c) No: Baryon number is not conserved.

d) Yes.

e) Yes.

f) No: Lepton number is not conserved.

Problem 2 (3.3)

In Section 3.1.3 it is stated that electron neutrinos interact with electrons in a different way from muon and tauon neutrinos. Justify this remark by considering the lowest-order Feynman diagrams for $\nu_e + e^- \to \nu_e + e^-$ and $\nu_\mu + e^- \to \nu_\mu + e^-$

The electron neutrino can interact through both the neutral Z^0-boson and the W^--boson. The muon-neutrino can only interact with the electron through the neutral Z^0-boson, to conserve lepton number of each generation on each side of the vertices.

Problem 3 (3.5)

A KamLAND-type experiment detects $\bar{\nu}^{-}$ neutrinos at a distance of 200 m from a nuclear reactor and finds that the flux is $(90 \pm 10)\%$ of that expected if there were no oscillations. Assuming a two-component model with maximal mixing ($\theta = 45°$) and a mean neutrino energy of 3 MeV, use this result to estimate the squared mass difference of the $\bar{\nu}_e$ and its oscillating partner.

Problem 4 (3.6)

If the Sun is assumed to be a uniform spherical plasma consisting of nucleons, with radius 7 × 105 km and total mass 2 × 1030 kg, calculate the mean free path $\lambda = 1/\mathrm{n}\ \sigma$ of solar neutrinos from the dominant reaction (3.38) where n is the number of nucleons per unit volume and σ, the neutrino-nucleon ross-section, may be written $\sigma = 0.7\mathrm{EL}$ × 10−42 m2, where EL is the neutrino laboratory energy in GeV.

Problem 5 (1.3)

A proton and antiproton at rest in an S-state annihilate to produce $\pi^0\pi^0$ pairs. Show that this reaction cannot be a strong interaction.

$$p\bar{p} \to \pi^0\pi^0 \tag{1}$$

The left hand side has parity -1, but the right $+1$. This is not possible under the strong interaction.