

Physics 661  
Problem Set 2

Due: 2 pm, Wednesday, November 1, 2017

1. In an experiment using a reactor as the source, the observed rate of  $\bar{\nu}_e$  reactions at a distance of 250 m from the reactor core is found to be  $0.95 \pm 0.10$  of that expected. If the mean effective antineutrino energy is 5 MeV, what limits would this place on a possible neutrino mass difference, assuming a mixing angle  $\theta = 45^\circ$ ?
2. If the Sun is assumed to be a uniform spherical plasma consisting of nucleons, with radius  $7 \times 10^5$  km and total mass  $2 \times 10^{30}$  kg, calculate the mean free path  $\lambda = 1/n\sigma$  of solar neutrinos from the dominant reaction  $p + p \rightarrow d + e^+ + \nu_e$ . Here  $n$  is the number of nucleons per unit volume and  $\sigma$ , the neutrino-nucleon cross-section, may be written  $\sigma = 0.7E_L \times 10^{-42} \text{m}^2$ , where  $E_L$  is the neutrino laboratory energy in GeV.
3. The deuteron,  $d$ , is a neutron-proton bound state with spin  $J=1$  and positive parity. (a.) Show that the reaction  $\pi^- + d \rightarrow n + n + \pi^0$  cannot occur for pions at rest. (b.) Explain why this reaction can occur when the collision energy increases.
4. Show that a scalar meson cannot decay to three pseudoscalar mesons in a parity-conserving process.
5. Both the neutral mesons  $\rho^0(770)$ , with  $J = 1$ , and  $f^0(1275)$ , with  $J = 2$ , decay to  $\pi^+\pi^-$ . What are their  $C$  and  $P$  parities? State which of the decays  $\rho^0 \rightarrow \pi^0\gamma$  and  $f^0 \rightarrow \pi^0\gamma$  is or are allowed, and estimate the branching ratio.
6. Discuss the possible decay modes of the  $\Omega^-$  hyperon allowed by the conservation laws, and show that weak decay is the only possibility.
7. The state  $J/\psi(3100)$  has a full width  $\Gamma = 87$  keV and 88% of the decays are to a hadronic final state. Assume that the hadronic decay proceeds via three gluons,  $\psi \rightarrow 3G$ , with a rate given by the same formula as that for triplet positronium decay

$$\Gamma(3\gamma) = \frac{2(\pi^2 - 9)}{9\pi} \alpha^6 m,$$

but with  $\frac{4}{3}\alpha_s$  replacing  $\alpha$ . Estimate a value for  $\alpha_s$  from this data.