UNIVERSITY OF CALIFORNIA, SANTA BARBARA
Department of Physics

Prof. S.B. Giddings | **Physics 229A** | Winter 2007

Gauge Theories

ASSIGNMENT #4

Due Thursday, February 8, 2007

1. Srednicki, problem 89.2 (including problem 88.6).
2. (Extension of HW 2.2) Show that the PMNS matrix can be written in terms of three angles and two phases.
3. MSW effect: Consider mixing of the first two neutrino generations. Solar neutrinos are produced in weak eigenstates (ν_e'), but these are non-trivial mixtures of mass eigenstates, in a simplification of three-neutrino mixing described in class.
   a) Find an evolution equation for the weak eigenstates for monochromatic (fixed E) neutrinos as a function of propagation *distance* L.
   b) Consider the four-Fermi interaction $\propto J^{\mu +} J_\mu^-$. It is easy to show that a vacuum expectation value $\langle e_L^\dagger \bar{\sigma}^\mu e_L \rangle = \delta_0^\mu N_e/2$, where N_e is the electron density in the sun, induces a correction to the evolution equation through the four-Fermi term. Using a Fierz rearrangement, find this correction.
   c) Parametrize the corrected evolution equation by a correction term in the equation from a), namely an additional contribution $A\nu_e'$ to $id\nu_e'/dL$. Suppose that in the center of the sun, where the neutrinos are produced, A is large as compared to $\Delta m^2/E$, and that A varies "slowly" as a function of L (distance from the center of the sun), to $A = 0$ at the surface. What is the amplitude of the neutrino to be a ν_e' when it reaches earth? (Justify any further approximations.)