Exercises for Neutrino Physics: Theory and Experiment

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Sheet 6: Experiment

1. **Solar Neutrinos [10 Points]**

   In the core of the Sun, energy is released by the exotermic thermonuclear fusion of four protons into Helium:
   $$4p \longrightarrow {}^4\mathrm{He} + 2e^+ + 2\nu_e. \tag{1}$$

   (a) Calculate the total energy released in this reaction. Note that the positrons annihilate with electrons releasing additional energy.

   (b) Each neutrino takes away an average energy of 0.3 MeV. The remaining energy is radiated from the solar surface as electromagnetic radiation. The solar luminosity (the total power radiated by the Sun) is $l_{\mathrm{sol}} = 3.8 \cdot 10^{26}\,\mathrm{W}$.
   How many of the fusion reactions mentioned above take place per second? How much matter is converted into energy? (give the result in kg/s).

   (c) Estimate the total flux of solar neutrinos arriving at the Earth (distance Sun-Earth $d = 1.49 \cdot 10^8\,\mathrm{km}$). Do oscillations change this value?

   (d) A solar neutrino experiment measures a seasonal time variation of the neutrino flux of 6.7%, i.e. the measured rate in winter is 6.7% higher than in summer. How can this variation be explained?

2. **Gallium Neutrino Observatory: GNO results [10 Points]**

   Radiochemical neutrino experiments use isotopes with relatively high cross sections for inverse beta decay (neutrino capture of a proton). After some exposure time, the decay of the created unstable nuclei is measured to compute the number of neutrino events. For more information about the GNO experiment and its results you can read "Complete Results for Five Years of GNO Solar Neutrino Observations", Phys. Lett. B 616 (2005) 174 or hep-ex/0504037.

   (a) Which reaction is used for the neutrino capture? What is the threshold energy for the detection reaction?

   (b) How are the germanium nuclei detected?

   (c) What kind of background has to be considered?

   (d) The neutrino capture rate is usually given independent from the target mass in solar neutrino units (SNU). 1 SNU is equal to $1\nu_\mathrm{e}$ capture per 10^{36} target atoms per second.

The predicted rate for ^{71}Ga is 129 SNU. How many ^{71}Ge atoms are produced in GNO during the 28 day solar run?

(e) Give the differential equation for the number of ^{71}Ge nuclei in the target $N_{Ge}(t)$. Consider the creation with a constant production rate p and the decay of ^{71}Ge with the lifetime τ. What is the expected number of ^{71}Ge atoms in GNO at the end of a 28 day solar run?

(f) The measured rate by GNO is only $62.9 \pm 6.0\,\mathrm{SNU}$. What could be possible explanations for this derivation?