PHY140Y

Spring Term – Week 11 Discussion

29 March, 1999

1. The Sudbury Neutrino Detector consists of an acrylic vessel filled with 1,000 tonnes of heavy water (D_2O), situated in the Creighton INCO nickel mine, 2 km underground. This vessel is suspended in a large cavity filled with about 8,000 tonnes of light water (H_2O) and a large photomultiplier array that can detect all the β radiation and light that is created in nuclear reactions in the heavy and light water. The goal of the experiment is to measure the rate by which neutrino's (there are three types, or flavours, of neutrinos, ν_e, ν_μ and ν_τ) from the sun interact with the heavy water, but this rate is so low that any residual radioactive contamination in the heavy and light water may "mask" the signal from the neutrino interactions.

   (a) Estimate how many molecules of light and heavy water are contained in the cavity.

   (b) If there are N_{Rn} residual molecules of ^{222}Rn, which has a half-life of 3.82 days, estimate the rate of α's coming from the radon decay. Assume that the radon is in equilibrium, ie. the rate of decay is balanced by the rate at which radon enters the water from the mine air. This isotope of radon decays via the chain

   $$^{222}\text{Rn} \rightarrow^{218}\text{Po} + \alpha. \tag{1}$$

   (c) Thorium represents another large background. Thorium decays via the chain

   $$^{228}\text{Th} \rightarrow^{224}\text{Ra} + \alpha, \tag{2}$$

   with a half-life of 1.9 years. If we have N_{th} atoms of ^{228}Th in the heavy and light water, what is the rate of radiation coming from the thorium decays? Again, assume that the thorium is at equilibrium so that thorium enters the water at the same rate that it decays.

   (d) If the solar neutrino rate is expected to be about $N_\nu = 30$ (in events per day), give a relationship for N_{Rn} and N_{Th} so that the background rates from these reactions remain less than 10% of the expected solar neutrino rate.

   (e) What is the maximum level of thorium or radon contamination, expressed in fractional number of atoms, that SNO can tolerate?

   (f) The neutrino's interact in the heavy water several ways, but one of the most unique processes is via the "charged current reaction"

   $$\nu_e + d \rightarrow p + p + e^-, \tag{3}$$

   where d is a deuterium nucleus with a mass $M_d = 2.014102$ amu. Calculate the energy released or required to transform the deuterium nucleus into two protons and the β.