21.5: Problems

1. How would nuclear physics be different if the weak interactions didn't exist?
2. Suppose one started with 10^{20} radioactive atoms. How many half lives would one have to wait to be reasonably sure that none of the atoms were left?
3. One possible laboratory fusion reaction is $\mathrm{d}+\mathrm{d} \rightarrow \mathrm{a}+\mathrm{Q}$ where d represents a deuteron (Z = 1,A = 2), α an alpha particle, and Q the released energy. Given the binding energies for the deuteron (2.22 MeV) and for the alpha particle (28.30 MeV), find the energy released by this reaction. For the purposes of this problem you may ignore the rest energy of the electrons and their binding energy.
4. Fusion in the sun is a complicated process, but the net effect is the conversion of four protons into an alpha particle, or a helium-4 nucleus. This is what powers the sun.
    1. How much energy is released for every helium-4 nucleus created?
    2. How many and what kind of neutrinos or antineutrinos are released for every helium-4 nucleus created?
    3. At the earth's orbit we get about 1400 J m^{-2} s^{-1} from the sun. How many neutrinos or antineutrinos do we expect to get from the sun per square meter per second from solar fusion?
5. A neutrino has to pass within a distance $\mathrm{D} \approx \hbar /(\mathrm{Mc})$ of a quark to have a chance of $\mathrm{a}_{\mathrm{w}}^{2}$ to interact with it, where M is the mass of a W particle and a_{w} is the weak "fine structure constant".
    1. What is the area of the circular "target" centered on the quark through which the neutrino has to pass in order to interact with the quark?
    2. If the quarks are located in the nuclei of water molecules, how many quarks are there per molecule with which the neutrino can interact? Hint: The neutrino can only interact with d quarks in neutrons. Why?
    3. Imagine a cylindrical water tank of end cross-sectional area A and length L, with neutrinos passing through the tank in a direction parallel to the axis of the cylinder. How many quarks of the right kind are needed in the tank to give a neutrino passing through the tank a 50% probability of interacting with a quark?
    4. How big must L be in this case? Water has a density of about 1000 kg m^{-3}.
6. Suppose that fission of a uranium-235 nucleus induced by absorbing a slow neutron ultimately results in two equal nuclei and two neutrons.
    1. How much energy is released for each fissioned uranium-235 nucleus? Hint: The fission products must beta decay until they reach the line of stability on the N-Z plot. Thus, the final state consists of the two free neutrons, two nuclei with the same value of A as the fission products, but with some of the neutrons converted to protons, and the resulting electrons and neutrinos.
    2. How many neutrinos or antineutrinos are released per second by a 100 MW nuclear power plant?