Physics 390: Homework 9

For full credit, show all your working. You may find Appendices A (nuclides) and D (fundamental constants) in the book useful for answering some questions.

1. **Stable nuclei:** Equation (11-14) in the handout gives the semi-empirical formula for the total energy of a nucleus to be:

$$E = Zm_pc^2 + Nm_nc^2 - [a_1A - a_2A^{2/3} - a_3Z^2A^{-1/3} - a_4(A-2Z)^2/A + a_5A^{-1/2}]c^2.$$

   (a) Show that, for a given value of A, the minimum energy occurs when

$$Z = \tfrac{1}{2}A\,\frac{4a_4 + m_n - m_p}{4a_4 + a_3A^{2/3}}.$$

   (b) Using the values of the constants given in the handout, determine the most stable nuclei with $A = 29$, 59, and 78. How do your results compare with the data in Appendix A of the book?

   (c) **Extra credit:** Make a computer plot of the stable line given by the formula above on N and Z axes and on the same plot show the known stable nuclides. A list of the stable nuclides is at `http://www.umich.edu/~mejn/courses/2010/phys390/stable.dat`.

2. Problem 11-19 from Tipler & Llewellyn.

3. **Radioactive decay:**

   (a) When we say that the atomic mass of ^{226}Ra, for example, is 226.0254, what units is that measured in? In other words, that's 226.0254 of what?

   (b) ^{226}Ra is an α emitter. Calculate the energy of the α particles from ^{226}Ra, assuming the kinetic energy of the recoiling nucleus to be negligible.

   (c) ^{228}Ra is a β^- emitter. Calculate the *maximum* energy an electron emitted by ^{228}Ra can have, again neglecting recoil. (Hint: Note that the atomic masses listed in the book really are *atomic* masses, including the electrons, not just the masses of the nuclei.)

4. **The sun:** The sun is powered by a nuclear fusion reaction called the *pp chain* in which, through a series of processes, four protons (in the form of hydrogen nuclei) are fused together into a helium, with the accompanying emission of two positrons and a bunch of neutrinos and γ rays. Most of the energy emerges in the form of γ radiation.

   (a) From the masses of the proton and the helium nucleus and the total luminosity of the sun, make an estimate of the number of kilograms of hydrogen the sun converts into helium per second.

   (b) Assuming that most of the mass of the sun is in the form of hydrogen, about how many years will the sun burn for before it collapses and becomes a white dwarf?