Homework #6: Nuclear Energy and Conservation

Note: The "Chart of Nuclides" web page gives an "Atomic Mass" in units of amu. DO NOT USE THIS NUMBER!!! We are studying the properties of NUCLEI, here, and the atomic mass also includes all the electrons in the atom. There are no electrons in the nucleus.

1. ${}_{15}\mathrm{P}^{32}$ decays by emitting an electron. Look up the properties of this decay process using the link to the table of the nuclides that is on the class web page.

a) According to the energy level diagram on the web page, what is the maximum kinetic energy of the electron that is emitted in this decay process? (Read this number off the diagram, and draw a copy of the diagram in your homework.)

b) Use the various conservation laws to determine the physical properties of the daughter nucleus *e.g.* Z number, B number, and rest energy. Do not calculate rest energy using the binding energy. Use the conservation of energy law to figure out what it should be. After that you can add protons and neutrons, and subtract binding energy, to check your prediction from the conservation of energy law.

2. In one type of nuclear bomb, U^{235} is induced to capture an extra neutron. The resulting nucleus is unstable, and splits into smaller fragments. One of the most common is xenon-140 and strontium-94 (plus two extra neutrons, that go on to hit other nuclei, resulting in a ever-increasing amount of energy being released. Hence, a bomb.). These nuclei themselves are unstable, and decay to cesium-140 and zirconium-94, respectively. These products are stable.

In the first atomic bomb, exploded over the Japanese city of Hiroshima on August 6th, 1945, two halves of a roughly 64 kg ball of Uranium were smashed together, causing 0.7 kg of the ball to undergo nuclear fission. Estimate how much energy was released in this explosion. Give answers in MeV, joules, and tons of TNT. (1 kiloton of TNT $\sim$4 TJ $= 4 \times 10^{12}$ J)

Remember you can just look at "before" and "after" and not try to calculate energies for every step along the way.

3. This problem has a fairly long introduction for two relatively simple questions at the end. The sun's total power output is approximately 4×10^{26} W. This energy ultimately originates from nuclear fusion occuring deep in its core. The most common fusion reaction in the sun involves smashing six protons together to make a He^4 nucleus. This occurs in three stages, because the odds of getting more than two particles moving that fast to be close enough to bond all at once are just too small to matter. First, two protons bond to form Deuterium. (Two protons together are unstable. How can they make stable Deuterium?) Then the Deuterium captures another proton to make He^3. These two steps happen twice,

and then the two resulting He^3 nuclei smash together to make He^4. So when you see the sun in the sky, think that all that light is coming from nuclear fusion!

(a) Using the relevant conservation laws (B, Z, Energy, family number, and momentum), write out the formulas for these three reactions and fill in the other particles I haven't mentioned.

(b) Compare the net change in energy and calculate how many times this process has to happen every second in the sun.

4. After the excited Barium-137 nucleus gives off its gamma ray (that you measured in the half-life lab), what is the recoil speed of the nucleus?

5. Ford Q4.15 (p. 85)

6. Plutonium 239 is an isotope that is useful for the kinds of chain reactions you need in a nuclear power plant (or a bomb). You can make Pu-239 from U-238 (the most abundant form of Uranium) by bombarding it with slow neutrons. Use the table of nuclides to explain how you might get from U-238 and a neutron to Pu-239. How much energy is released in this process per nucleus? A reactor that does this is called a "breeder reactor".

Due: Wednesday, October 7, 10:00 am