Physics 222 CID ___________

Homework 27

Score ________ / 30

1. (6 pts) Lets calculate the energy released through the proton-proton cycle. (a) How much energy is released when two protons are converted into a deuteron (a $^{2}_{1}$H nucleus) plus a positron and a neutrino? Remember that for β^+ decay we have to keep track of electrons and positrons carefully and not just blindly plug in atomic masses for nuclear masses! (b) What is Q when a proton combines with a deuteron to form a $^{3}_{2}$He nucleus? (c) How much energy is released when two $^{3}_{2}$He nuclei combine to form an alpha particle plus two free protons? (d) Sum up these energies to find the total energy released by the proton-proton cycle. Remember to add twice the energy released in the parts of the cycle which happen in duplicate. (e) Now calculate directly the difference in rest energy between 6 free protons and an alpha particle plus 2 protons and two positrons. You should have gotten the same result as the book for parts (d) and (e) - but there is something that the book neglected. After one cycle you've got a couple positrons hanging around with a couple of left over electrons. And you know that nothing good happens when young positrons hang out indiscriminately with particles of the opposite charge. Eventually they are going to annihilate each other, releasing an additional 4×0.511 MeV, which really should count as part of the energy released in the proton-proton cycle.

2. (3 pts) Consider the combination of the Coulomb repulsion and the nuclear force attraction and make an argument as to why D-D and D-T reactions make tokamak fusion reactors more feasible than P-P reactions.

3. (3 pts) What is the difference between "breakeven" and "ignition"?

4. (4 pts) Assuming that the fission of a uranium 235 nucleus releases about 200 MeV on average, how much energy per kilogram could I get from the fission of pure uranium 235?

5. (4 pts) (a) Assuming that the fusion of two deuterons results in an average energy release of 3.7 MeV, how much energy per kilogram could I get from the D-D reactions in a pure gas of deuterium? (b) How much energy per kilogram of water can I get from D-D reactions. Assume that the water has the natural isotopic abundance of deuterium as listed in the appendix of your text.

6. (4 pts) Different types of decay are caused by the different forces. For a particular force to cause a decay, the decaying particle and all of the "products" of the decay must interact via that force. If there are two forces which they all interact with, the stronger of the two will most likely cause the decay before the weaker one gets around to it. What force is responsible for the following decays? (a) $n \to p + e^- + \bar{\nu}_e$. (b) $\pi^0 \to \gamma + \gamma$. (c) $\Omega^- \to \Xi^0 + \pi^-$. (d) $\Xi^- \to \Lambda^0 + \pi^-$.

7. (3 pts) Explain why the process $p \to n + e^+ + \nu_e$ can occur in certain nucleons but cannot occur in free space (i.e. a free proton cannot decay this way).

8. (3 pts) The neutrinos created when pions decay into muons never induce inverse beta decay. Explain why this is a hint of the existence of a conservation law.

Extra problems I recommend you work (not to be turned in)

- A π^+ and a π^- at rest annihilate to create two gamma-ray photons. (a) Why must there be more than one photon? (b) Give an argument as to why the energies of the two photons must be the same. (c) What is the wavelength and energy of the photons? (d) Now consider what happens when only the π^+ is at rest, with the π^- moving at a finite velocity before they collide and annihilate. Explain why more than one photon must be emitted regardless of the velocity of the π^-.