PHY983 - Nuclear Astrophysics - Spring 2009
Homework set 3
Due: Friday, Feb 6, 2007, at beginning of class
Keywords: Nuclear masses, energy generation by nuclear reactions

NOTE: neglect electron binding energies throughout

1. In a simplified model, the rapid neutron capture process (r-process) produces heavy nuclei by a sequence of neutron captures and β^- decays starting at ^{56}Fe. To explore the energy generated by this process we consider the simplified and extreme assumption that the r-process converts ^{56}Fe into ^{238}U (the heaviest nucleus made by the r-process) via the net reaction:

   $$^{56}\text{Fe} + 182\ \text{n} \text{ --> } {}^{238}\text{U} + 66\ e^- + 66\ \nu\text{bar}_e$$

   a. [4 pts] Calculate the nuclear binding energy per nucleon in MeV for ^{56}Fe and ^{238}U using the atomic mass excess table provided by the Nuclear Wallet Cards (see http://www.nndc.bnl.gov/wallet/nwccurrent.html).
   b. [2 pts] Calculate the total binding energy per nucleon in MeV on the left side of the reaction equation and compare to ^{238}U (the right side). Does the process increase or decrease the binding energy of the reactants (left side) as a whole.
   c. [6 pts] Calculate the total energy generated by this simplified r-process (in ergs) assuming it produces 10^{-5} solar masses of r-process material (^{238}U) and compare to the typical total explosion energy of a core collapse supernova of 10^{53} ergs.
   (additional information not needed to solve the problem: in reality the r-process produces not just ^{238}U but many other nuclei between ^{56}Fe and ^{238}U, and it might also start beyond ^{56}Fe so the produced energy will be less)

2. [10pts] Masses determine whether a nucleus is stable and which kind of decays are energetically possible.
   a. [6 pts] For ^{56}Ni, calculate the Q-values in MeV for
      - β^+ decay,
      - β^- decay,
      - electron capture,
      - proton decay,
      - neutron decay,
      - α decay

      using the masses given in the nuclear wallet cards.
   b. [2 pts] Based on your results, is ^{56}Ni stable, and if not, what is (are) the dominant decay mode(s) ? (justify)
   c. [6 pts] What is the atomic mass excess Δ for ^{56}Ni (in MeV) that you would obtain from the Weizsaecker Liquid Drop formula discussed in class?
   d. [2 pts] How does it compare with the measured value? Give the difference in absolute MeV/c^2 and as fraction of the total ^{56}Ni mass. Is this accuracy sufficient to calculate Q-values such as the ones in problem 2.a reliably?