PHY983 - Nuclear Astrophysics - Spring 2013
Homework set 3
Due: Friday, Feb 1, 2013, at beginning of class
Keywords: Nuclear masses, energy generation by nuclear reactions

1. A new mass formula has been proposed by http://arxiv.org/pdf/1211.2538.pdf. Download the data and compare with the EXPERIMENTAL data in the AME2012 compilation (see course website).
   a. [5pts] Calculate the simple rms deviation between experiment and theory and compare with the value given in the paper (ignore error bars here).
   b. [5 pts] Read section 2.1. in Moeller et al. 1993 (http://arxiv.org/pdf/nucl-th/9308022v1.pdf) and calculate the theoretical error (sigma_th for mu_th=0) of the new mass model using Eqs 9 and 11 in Moeller et al. 1993. This now includes the experimental error. Compare with the rms.
   c. [5 pts] The performance parameter of a mass model is how well it can predict unknown masses, not how well it can predict known masses. Find one possible criterion to judge whether the new mass model is suitable for extrapolating to more neutron rich nuclei and apply it.

2. Some neutron stars accrete matter at a rate of 10^{-8} solar masses per year from a companion star. After 1 hour nuclear reactions set in and power an X-ray burst. There are two cases depending on the composition of the accreted material:
   Helium burning X-ray bursts fuse helium into 56Ni via the net reaction
   $14\ {}^{4}\text{He} \rightarrow {}^{56}\text{Ni}$.
   If hydrogen is present, the net reaction is instead
   $10\ {}^{4}\text{He} + 66\ {}^{1}\text{H} \rightarrow {}^{106}\text{Cd} + 38\ e^{+} + 38\ \nu$
   a. [5 pts] How much energy per reaction is released in each case? (Answer in MeV per nucleon so divide the Q-value by 56 and 106, respectively).
   b. [3 pts] Which one is more efficient – hydrogen burning or helium burning? Why?
   c. [5 pts] Assuming burning is complete, in other words assuming the final compsoition is 100% ^{56}Ni or ^{106}Cd, respectively, how much energy in erg is produced by the burst in each case?

3. [10pts] Masses determine whether a nucleus is stable and which kind of decays are energetically possible.
   a. [6 pts] For ^{64}Cu, use the Wallet Cards to calculate the Q-values in MeV for
      - β^{+} decay,
      - β^{-} decay,
      - electron capture,
      - proton decay,
      - neutron decay,
      - α decay
   b. [2 pts] Based on your results, is ^{64}Cu stable, and if not, what is (are) the dominant decay mode(s) ? (justify)
   c. [6 pts] What is the atomic mass excess Δ for ^{64}Cu (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 ^{64}Cu mass. Is this accuracy sufficient to calculate Q-values reliably?