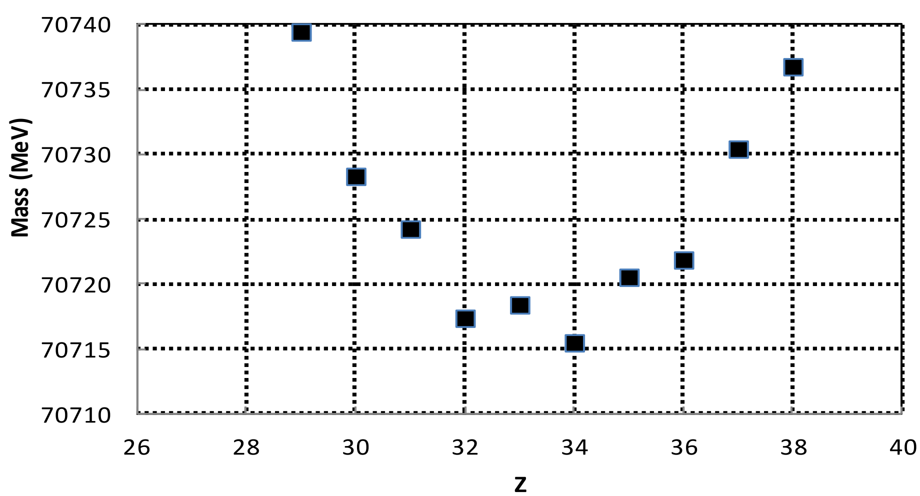
Nuclear Chemistry
Cumulative Exam
Wed. 19th 2012

This exam focuses on nuclear masses and binding energies. The exam will be graded out of 90 points with the point distribution indicated for each question.

1. A simple semiempirical mass equation for predicting the mass of a nucleus can be written as
$$M(Z,A)c^2 = [Z*M(^1H) + N*M(n)]c^2 - B_{tot}$$
The total binding energy of a nucleus with Z protons and a mass number A can be written as:
$$B_{tot}(Z,A) = a_1A - a_2A^{2/3} - a_3Z^2/A^{1/3} - a_4(A-2Z)^2/A \pm a_5/A^{1/2}$$
Where the constants a_1, a_2, a_3, a_4, a_5 have the values 15.56 MeV, 17.23 MeV, 0.7 MeV, 23.28 MeV, and 11 MeV, respectively.
    a. (15 points) Describe the physical significance of each of the five terms in the binding energy equation.
    b. (5 points) Based on the equation above explain the gradual shift toward larger N/Z ratios in stable nuclei as A increases.
    c. (5 points) What percentage of the total binding energy is accounted for by the surface term for $^{40}_{20}Ca$ and $^{238}_{92}U$?
    d. (5 points) Estimate the energy released when $^{238}_{92}U$ fissions into two equal mass nuclei neglecting pairing.
    e. (5 points) What is the mass of $^{40}_{20}Ca$ in amu using the following additional data; M(1H) = 1.00728 amu, M(n) = 1.00867 amu, the binding energy per nucleon for $^{40}_{20}Ca$ is 8.5513 MeV, 1 amu = 1.6606×10^{-27} kg, c = 2.99×10^8 m/s, 1 J = 6.24151×10^{12} MeV.

2. Shown below are the mass parabolas for the mass 76 nuclei ($_{29}Cu$, $_{30}Zn$, $_{31}Ga$, $_{32}Ge$, $_{33}As$, $_{34}Se$, $_{35}Br$, $_{36}Kr$, $_{37}Rb$, $_{38}Sr$).



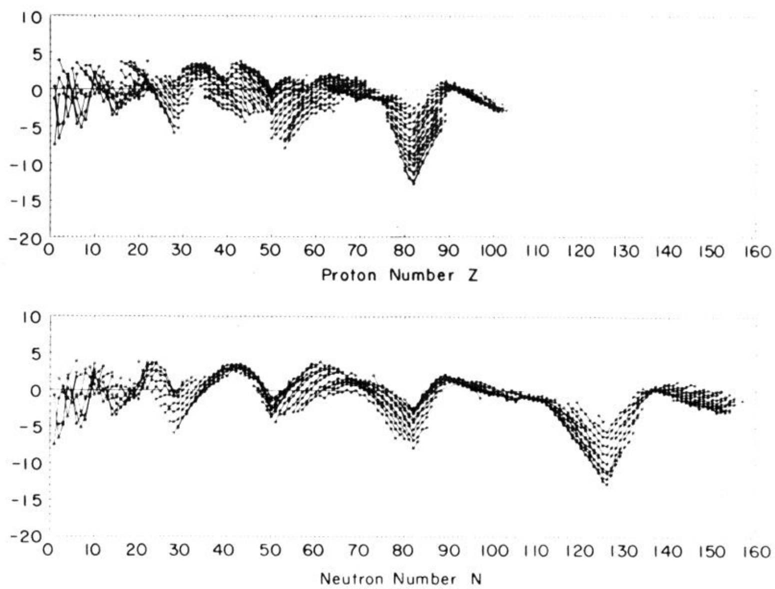
    a. (4 points) Which isotope(s) would you expect to be stable?
    b. (4 points) Which isotope(s) may decay by both β^+/EC and β^- decay?

c. (4 points) For which isotope(s) may double beta decay be experimentally observed?
d. (4 points) Explain the origin of the alternating large and small differences between neighboring masses.
e. (4 points) Derive a rough estimate for the pairing energy based on the mass parabola.

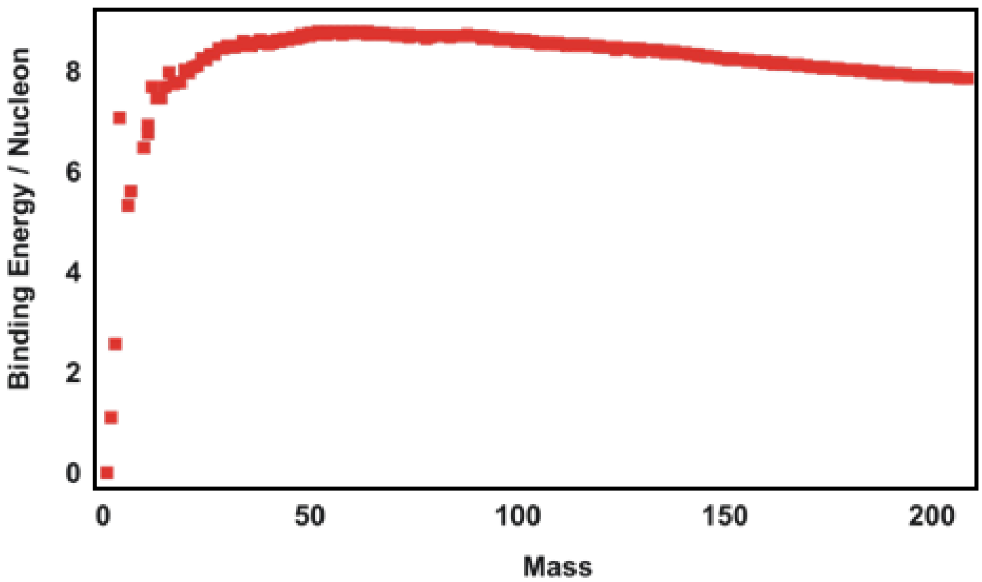
3. (5 points) Sketch the expected mass versus Z plot for an odd-A chain of isotopes. How and why does this plot differ from the one presented in question 2 for an even-A system?

4. (10 points) The figure below shows the deviation between measured and predicted masses (using the equations in question 1) as a function of mass number. Provide a simple explanation to account for the observed deviations.

Mass difference (MeV)



5. Shown below is the binding energy per nucleon as a function of mass.
    a. (5 points) What does the relatively flat binding energy per nucleon for A>10 tell you about the nuclear force?
    b. (5 points) Determine the mass at which the binding energy per nucleon peaks using the equation for total binding energy presented in question 1 under the assumption that Z = A/2 and no pairing.



6. He-3 is used in thermal neutron capture detectors and undergoes the following nuclear reaction:

$$^{3}He + n \rightarrow {}^{3}H + {}^{1}H$$

    a. (5 points) Determine the energy of the emitted triton (^{3}H) from the following data.
    b. (5 points) Is the reaction spontaneous?

The following data may be useful

	Mass Excess, Δ(MeV)		Mass Excess, Δ(MeV)
^{3}He	14.931	^{3}H	14.950
n	8.071	^{1}H	7.289