University of Toronto PHY357S

Problem Set 4

due Monday, 8 April 2002

(Late penalty is 10% per day, and no problem set is accepted after April 10.)

Each problem is of equal weight, but **not all problems may be marked**.

Note: The last lecture for this term (April 10) will be held in Room 408 instead of Room 137.

These problems are based on Martin and Shaw and on the lectures.

1) a) Martin & Shaw Problem 10.4
   b) Martin & Shaw Problem 10.5

2) Martin & Shaw Problem 11.2

3) The binding energy of an atomic nucleus with Z protons and N neutrons (atomic number A=N+Z) is approximately given for heavier nuclei by a semi-empirical formula:

$$E_b = C_{Volume}A - C_{Surface}A^{2/3} - C_{Coulomb}\frac{Z(Z-1)}{A^{1/3}} - C_{symmetry}\frac{(N-Z)^2}{A}$$

The origin of each term and the value of the constant coefficients are given below:

- The binding energy due to the short range strong nuclear force is almost entirely due to how many immediate neighbours a nucleon has, so if each nucleus has the same number of neighbours then this contribution to the binding energy is simply proportional to the number of nucleons in the nucleus.

$$C_{Volume} = 15.7\ MeV$$

- Nucleons on the surface have fewer neighbours, so the binding energy must be reduced by a term proportional to the surface area of a nucleus. If we assume a nucleus is spherical and of constant density, then the surface area is proportional to $4\pi A^{2/3}$.

$$C_{Surface} = 17.8\ MeV$$

- Protons repel each other and the corresponding potential energy is inversely proportional to the average distance between protons which is proportional to $A^{1/3}$.

$$C_{Coulomb} = 0.71\ MeV$$

- Nucleons are fermions, so the Pauli Exclusion Principle requires that you can't have two protons (or two neutrons) in the same quantum state. This means it costs less energy to make a nucleus which is symmetric in N and Z.

$$C_{symmetry} = 23.6\ \mathrm{MeV}$$

This formula roughly describes the data, but more terms must be added if more accuracy is required.

(a) Calculate and plot the neutron number which the formula predicts will give the most strongly bound nucleus as a function of atomic number A, for values from A=10 up to A=400.

(b) Assume that when a nucleus undergoes fission, it splits into two strongly bound nuclei and some free neutrons. (I define a "strongly bound" nucleus to be one on the line you plotted for part (a).) Assume the most likely fission products are those which result in the maximum energy release.. Use this **approximate** model to estimate the most likely number of neutrons produced and the most likely energy release for such fission of ${}^{239}_{94}Pu$.