PHY357 Assignment 5, Due April 13, 2006

This is a the final version of your last assignment.

1. (a) In an experiment using 14g of selenium which contains 97% (by weight) ${}^{85}_{34}\mathrm{Se}$, 35 events associated with the double beta-decay process

   $${}^{85}_{34}\mathrm{Se} \rightarrow {}^{82}_{36}\mathrm{Kr} + 2e^- + 2\bar{\nu}_e$$

   were observed over a period of 7960 hours. Assuming a detector efficiency of 6.2% estimate the mean lifetime for this decay.

   (b) Estimate the statistical uncertainty on the this determination. If you don't know how to do this, look in a book on basic experimental techniques, and read the section on counting statistics (for instance, section 8-5 of *Introduction to Nuclear Physics* by H. Enge) or look at a statistics book, for example *Statistics for Nuclear and Particle Physics* by Louis Lyons.

   How long would the experiment need to run to measure the lifetime to a precision of 3% ?

   (c) If the above double-β decay *without* the emission of neutrinos were possible, what would be the experimental signature ? [The possible existence of these neutrinoless double-β decays are the subject of considerable interest at the moment. There are proposals for such experiments to be sited in the SNOLAB facility, which is an underground lab facility begin constructed at the current SNO site in Inco's Creighton Mine in Sudbury].

2. Using what you know so far about nuclear structure, estimate the average number of β-stable isotopes of elements up to and including ${}^{83}_{209}\mathrm{Bi}$? (I hope it goes without saying that you should explain how you arrived at your estimate).

3. Space probes that are expected to operate for long periods of time often use ${}^{238}\mathrm{Pu}$ as a power source. ${}^{238}\mathrm{Pu}$ undergoes α-decay with a lifetime of 127 years, producing ${}^{234}\mathrm{U}$ which has a much longer lifetime of 3.5×10^5 years,

   $${}^{238}\mathrm{Pu} \rightarrow {}^{234}\mathrm{U} + \alpha.$$

   (a) What is the energy of the α-particle created in this process ?

   (b) The energy of the α particles can be used to create heat which is then converted into electricity using a radio-thermal generator (RTG), with some efficiency.

   The Voyager 2 spaces probe was launched in August, 1977 and reached Saturn four years later in August of 1981. Saturn's separation from the sun is about 9.5 AU (astronnomincal units, which equal the distance from the earth to the sun). How much plutonium would an RTG on Voyager 2 require at launch time, in order to be delivering 395 W of power at the time it reached Saturn, assuming the efficiency for the conversion is 5.5% ? How large a piece is this if it is shaped as a sphere ?

   (c) How much power would have been available by the time the probe reached Neptune in August, 1989 ?

   (d) For how long could the RTG continue to deliver at least 300 W of power, assuming that the conversion efficiency does not change with time ?

4. In our March 30^{th} tutorial we showed (or at least outlined how to show) that for large A and Z the energy released when a nucleus emits an α-particle is given by:

$$Q_\alpha = -4a_V + a_S \frac{8}{3}\frac{1}{A^{1/3}} + 4a_C \frac{Z}{A^{1/3}}(1 - \frac{Z}{3A}) - 4a_A(A-2Z)^2/A^2 + B_\alpha$$

   where the coefficients are those of the semi-empirical mass formula and B_α is the binding energy of an α-particle. Show this again, but not in the way we did in tutorial. This time treat the binding energy $B(A,Z)$ as a continuous (differentiable) function of A and Z; write the expression for Q_α in terms of the relevant derivatives, and show that you get the above expression. For roughly what value of A does the energy release become positive ?

5. In our discussion of the liquid-drop model for the nucleus, we illustrated the basis for the asymmetry term in the semi-empirical mass formula based on a model in which the nucleus is viewed as two distinct potential wells, one each for protons and neutrons, that have identical energy levels (in the absence of the Coulomb interaction, which is moved to a separate term in the equation). From this we argued for the form of the asymmetry term, as it appears in the semi-empirical mass formula. Let's now look at this another way.

   The total kinetic energy of n fermions in a potential well of radius R, can be shown to be proportional to $n^{5/3}/R^2$. Using this result, compare the cases of a nucleus with Z proton and N neutrons to the case where $N = Z = A/2$ and from this derive the form of the asymmetry term.

Question 6 on next pg.

6. The three figures below show the energy level diagrams for three $A = 27$ isobars. For each of these, interpret the spin parities of the ground state and first few excited states within the context of the shell model. Two of the three have the same sequence, while the third differs. Explain this.

^{27}Mg

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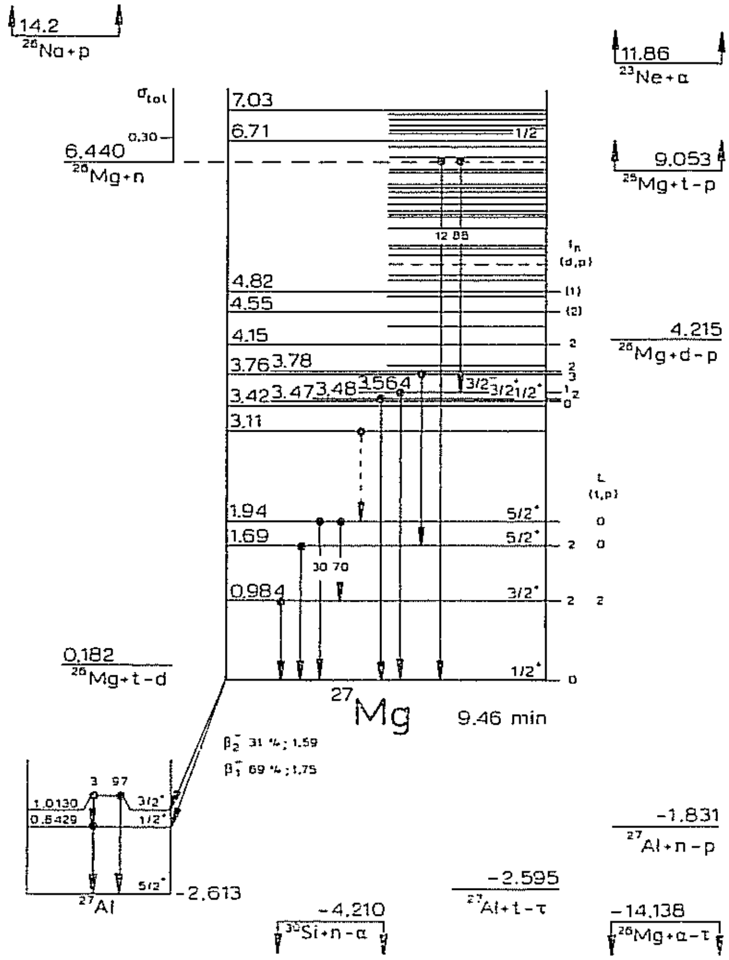

Fig. 27.1. Energy levels of ^{27}Mg.

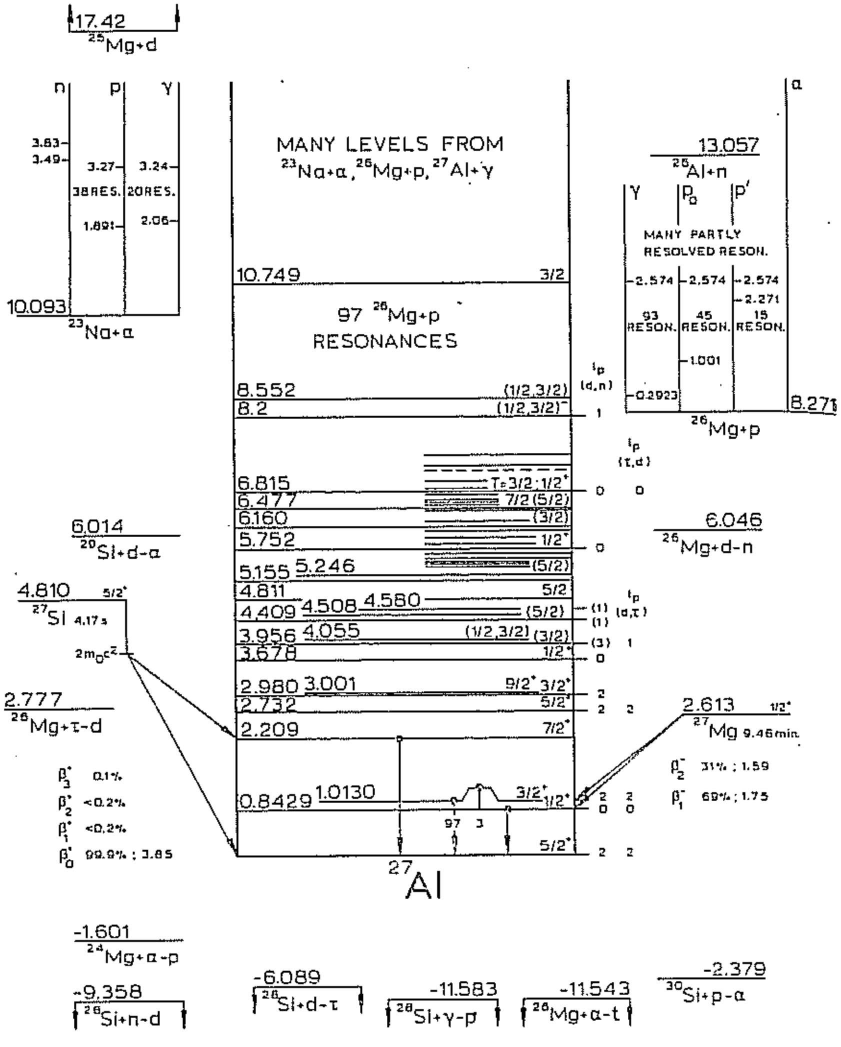

Fig. 27.2. Energy levels of ^{27}Al; for γ decay of resonance levels and bound states, see figs. 27.3 and 27.4, respectively.

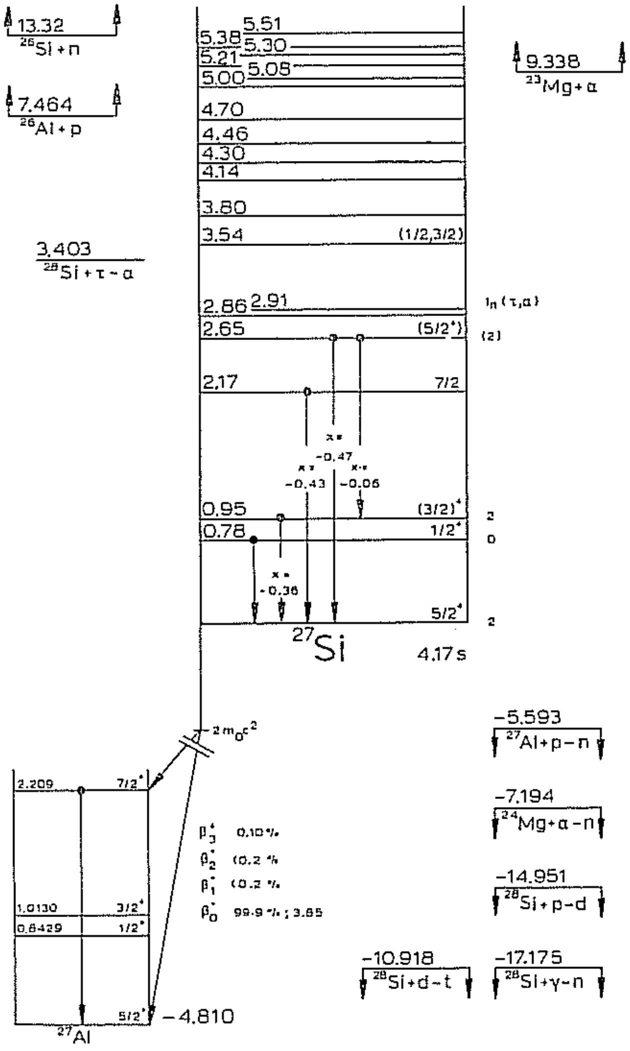

Fig. 27.5. Energy levels of ^{27}Si.