PHY3063 --- Enriched Modern Physics --- Spring 2019
Homework #6

Deadline: Thursday, April 18 10:25am.

1. The Russian ex-FSB officer Alexander Litvinenko was poisoned in 2006 with 10 μg of polonium-210, an α emitter that kills through radiation poisoning as molecules important to metabolism are ionized by the passage of the α particles. He died 3 weeks later.

(a) What is the nuclear decay process and what is the *Q* (that is, the amount of energy released) of the reaction in MeV? Show the full calculation.

(b) Find the kinetic energies (in MeV) of the α particle and the accompanying nucleus.

2. Refer to the previous problem.

(a) What was the initial activity of this dose of Po-210 in decays/sec?

(b) What fraction of the Po-210 sample decayed in the first 3 weeks?

(c) How many α particles were emitted in the first 3 weeks?

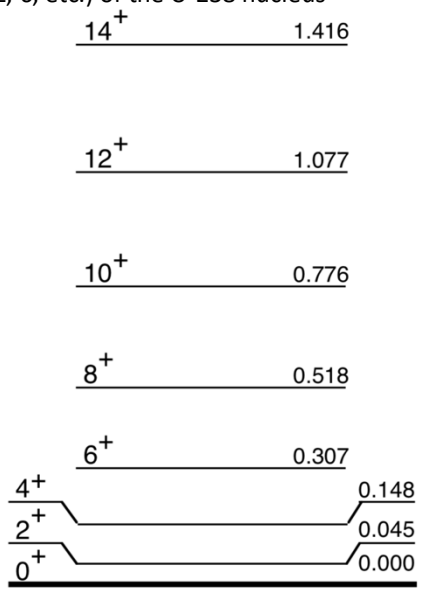
(d) If the average ionization energy of molecules in body cells is 2 eV, approximately how many molecules were ionized in the first 3 weeks?

3. A nucleus at rest decays into two particles 1 and 2 with total energy *Q* released. Show from energy and momentum conservation (non-relativistic) that their kinetic energies are

$$K_1 = \frac{m_2}{m_1 + m_2} Q \qquad\qquad K_2 = \frac{m_1}{m_1 + m_2} Q$$

4. Calculate the binding energies of $^3\mathrm{H}$ and $^3\mathrm{He}$. Why is one bigger than the other?

5. The following figure shows the rotational energy levels relative to the ground state (in MeV) vs spin angular momentum quantum number (S = 0, 2, 6, etc.) of the U-238 nucleus



(a) Show, by taking ratios of the first few energy levels, how closely the rotational energies approximately follow the expected pattern of energies for quantized angular momentum states $E_S = \hbar^2 S(S+1)/2I$, where S = spin quantum number and I is the moment of inertia.
(b) Using the moment of inertia formula for a uniform spherical mass, calculate the approximate U-238 radius from the first few energies. How does this compare to the expected radius for U-238?

6. A rock sample is analyzed and found to have approximately 2.5 mg of and 25 mg of U-238. How old is the rock, assuming all the lead comes from the U-238 decay chain?

7. Complete the following decays

$$^{27}\mathrm{Si} \rightarrow {}^{27}\mathrm{Al} +$$
$$^{74}\mathrm{As} \rightarrow {}^{74}\mathrm{Se} +$$
$$^{230}\mathrm{Th} \rightarrow {}^{226}\mathrm{Ra} +$$
$$^{83}\mathrm{Rb} + e^- \rightarrow {}^{83}\mathrm{Kr} +$$
$$^{23}\mathrm{Mg} \rightarrow {}^{23}\mathrm{Na} +$$

8. Show that in a nuclear beta decay, the calculated Q value using the *atomic* mass difference doesn't need to account for the electron mass separately, but the decay to a positron must include an additional subtraction of 2 electron masses.