22.01 Fall 2016, Problem Set 3

September 19, 2016

Complete all the assigned problems, and do make sure to show your intermediate work.

Part I
Skill-Building Problems (50 points)

1 Activity and Half Lives

1. Given the half lives and modern-day abundances of the three natural isotopes of uranium, calculate the isotopic fractions of uranium when the Earth first formed 4.5 billion years ago.

2. Explain the principle behind radioisotope carbon dating. Look up the Shroud of Turin, the supposed burial cloth of Jesus of Nazareth. What would be the isotopic fraction of ^{14}C expected if the Shroud of Turin was real? What was the actual isotopic fraction of ^{14}C, and how old does that make it?

2 RTG Operation

In these problems, consider the decay of ^{239}Pu, the isotope used in radioisotope thermoelectric generators (RTGs).

1. Write the two possible types of decay reactions for ^{239}Pu, and state which decay processes (and competing processes) may be possible for each general type of reaction. You don't have to address every single energy level, there are dozens! Just group them into categories.

2. Now consider only the *three* most likely alpha decay energies of ^{239}Pu. Draw a complete energy level diagram showing alpha decay to these energy levels, and any possible, successive decays to the ground state.

3. It is clear that ^{239}Pu produces a few types of radiation at many different energies. Do you expect the alpha particles, the gamma rays, the spontaneous fissions, or the x-rays to be responsible for producing the most heat generation in an RTG, and why?

3 Medical Isotope Physics

In these problems, consider the decay of ^{99}Mo, a crucial medical isotope widely used in imaging and diagnosis procedures.

1. Calculate the Q-value for the decay of ^{99}Mo to $^{99\mathrm{m}}$Tc using the binding energies of the initial and final nuclei, and any other information that you need.

2. You may have noticed that ^{99}Mo is an unstable isotope. Which nuclear reactions could create ^{99}Mo? Write the nuclear reactions for these processes, and calculate their Q-values to justify your answer.

4 Allowable Nuclear Reactions

For these problems, determine whether the following reactions would be allowed, and answer the additional questions.

1. Which of the following decay methods are energetically allowable from the ground state of ^{216}At? Back up your reasoning with an energetic argument.

   (a) Alpha decay
   (b) Beta decay
   (c) Positron decay
   (d) Electron capture
   (e) Isomeric transition
   (f) Spontaneous fission
      i. Can you find an instance where this particular one is energetically allowable?
      ii. Why do you think it's never observed?

2. For the reactions which are allowed, write the full nuclear reaction in each case, and draw a graph of the energy spectrum you would expect to see from each released form of radiation, including secondary ejections of particles or photons.

Part II
Take-Home Lab - Measuring Half-Lives (50 points)

Using your spinthariscope, devise a way to experimentally measure the half life of ^{241}Am (pretend you don't already know what it is). An intermediate step is to measure the total activity in your spinthariscope. Assume the following:

1. The americium in your spinthariscope is entirely depleted (^{241}Am)
2. You have a known mass of 3μg of ^{241}Am.

You must state any other assumptions and calculations that you make. Compare your answer to that on the KAERI Table of Nuclides.

Example approaches may include counting decays by hand (highly not recommended), or figuring out some way to ... digitize them, with some sort of ... digital device ...

22.01 Introduction to Nuclear Engineering and Ionizing Radiation

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