Nuclear Chemistry
Cumulative Examination

Wednesday, 21 October 2oo9

Write your answers to the following questions *in the order listed*. Make sure that the answers are well-organized and self-explanatory. The total number of points on this exam is 50.

1. (2 point each) Give concise and accurate answers to the following questions:
   (a) What is the key feature of two nuclides that are said to be "isotones?"
   (b) What is the key feature of two nuclides that are said to be "isobars?"
   (c) What is the relationship between the mean life and half life of a radionuclide?
   (d) Write a COMPLETELY balanced equation for the β^- decay of the nuclide ^{239}Np (Z=93, the first transuranic nuclide to be identified later shown to have a half life of 2.35 days).
   (e) The *baryon number* is conserved in nuclear decay. What is a baryon in this context?

2. (5 points each) The ^{137}Cs nuclide is something of a nuisance because it is strongly produced in the fission of uranium, it has a moderate half life of 30 years and emits penetrating gamma radiation. The ground state intrinsic spin and parity of ^{137}Cs is 7/2+ and it decays to the stable nucleus ^{1}37Ba that has an intrinsic spin/parity of 3/2+with a Q-value of 1175.6 keV.
   (a) This beta decay is an example of an allowed Gammow-Teller transition between states. What are the intrinsic spins and their relative alignment of the particles that are emitted in an allowed Gammow-Teller β^- decay?
   (b) Would you expect this beta decay to go directly from the ground state of the parent to the ground state of the daughter nucleus? Explain why or why not.
   (c) Suppose that some of the β^- decay goes to an excited state. What is the most likely decay mode of this state and how will the lifetime of this state compare to the β^- decay lifetime?
   (d) A article in the October 15, 2009 edition of the New York Times stated that area surveys of the Hanford nuclear reactor site were being performed to determine the extend of contamination of rabbits (yes rabbits) with ^{137}Cs. Cesium is a group 1 element and is easily absorbed by biological systems. The surveys were carried out with some detector carried in a helicopter. Describe a plausible radiation detector that could be used to carry out this survey.
   (e) Make an estimate of the geometrical efficiency for observing a ^{137}Cs source on the ground with a 15-inch diameter detector carried in the helicopter at an altitude of 500 feet.

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3. (5 points each) Large samples of ^{238}Pu have been used in some spacecraft as heat sources for radioisotope thermoelectric generators colloquially called "nuclear batteries". The heat created by the decay is converted into electrical power with thermocouples. This isotope decays by alpha emission with a half life of 87.74 years and has a Q-value of 5.593 MeV.

   (a) Give a concise reason why the plutonium isotope is much more preferable in this application to ^{60}Co even though this cobalt isotope is available in much higher quantities, has a shorter 5.27 year half life (higher decay rate), emits two gamma rays, and only a slightly lower total decay Q-value of 2.824 MeV.

   (b) What is the thermal power in Watts emitted by a 1.0 gram sample of ^{238}Pu?

   (c) The ^{238}Pu is prepared by chemical separation of used reactor fuel and is contaminated by its famous neighboring isotope ^{239}Pu that is produced at a higher rate. The ^{239}Pu builds up over time as a byproduct in nuclear (fission) reactors. Write the sequence of three nuclear reactions that take place to produce the problematic ^{239}Pu isotope. Hint: the production involves the most abundant heavy isotope in the nuclear fuel.