Study Guide for Nuclear Chemistry

- Chemical vs. nuclear reactions
- Isotopes and nuclides
- Nuclear stability
- Nuclear binding energy; energy changes in nuclear reactions ($E = mc^2$)
- Types of radiation
  - alpha emission
  - beta emission
  - gamma emission (energy; not a particle)
  - positron emission
  - electron capture
- Balancing nuclear equations
- Nuclear decay kinetics and half-life; application to radiocarbon dating
  - decay rate = $k(A)$
  - $\ln (A_0 / A_t) = kt$
  - half life: $t_{1/2} = 0.693 / k$
- Nuclear fission vs. fusion

Instructions: You may use your text, notes, tutors, and classmates to help you complete this assignment. Record your answers on the answer sheet attached to this packet. Your answer sheet will be collected at the same time you pick up your in-class exam. Late homework will be accepted for a 15% deduction up until 11:59 PM on the assignment's due date (if you intend to submit an assignment late, email me for instructions). You may keep homework questions for future study. This assignment is worth 25 points.

1. Radiocarbon dating of archaeological artifacts depends on the slow and constant production of radioactive carbon-14 in the upper atmosphere by neutron bombardment of nitrogen-14 atoms. The neutrons come from the bombardment of other atoms by cosmic rays. Write the balanced nuclear reaction for the process that converts N-14 to C-14.

   Carbon-14 atoms produced in the upper atmosphere combine with oxygen to yield $^{14}CO_2$*, which slowly diffuses into the lower atmosphere, where it mixes with ordinary* $^{12}CO_2$ *and is taken-up by plants during photosynthesis. When these plants are eaten, carbon-14 enters the food chain and is ultimately distributed evenly throughout all* ***living*** *organisms. An equilibrium is established between the amount of C-14 consumed by the organism and the amount that is lost through exhalation of* CO_2 *and excretion. In other words, the amount of C-14 in a living organism remains constant over time. When the organism dies, it ceases to take-up carbon-14, which very slowly decays back to nitrogen-14 through slow nuclear (beta) decay. Therefore, the older a dead thing is, the less C-14 it has.*

2. Write a balanced nuclear equation for the radioactive decay of C-14 to N-14.

3. What is the name of the process by which ^{14}C is converted to ^{14}N in the previous problem?

4. Radiocarbon measurements (radiocarbon dating) made in 1988 on a sample of the Shroud of Turin, a religious artifact thought by some to be the burial shroud of Christ, showed a ^{14}C decay rate of 14.2 disintegration per min per gram of carbon. Calculate the decay rate constant, *k*, for this process (in yr^{-1}), given that the half-life of carbon-14 is 5,715 years.

5. Based solely on the radiocarbon dating data in Question #4, what is the age of the shroud if currently living organisms show a ^{14}C decay rate of 15.3 disintegration per min per gram of carbon? Assume currently living organisms have the same amount of C-14 as organisms living in ancient times.

6. Let's pretend that you were once royalty in an ancient kingdom. The bad news is that you are long dead and mummified in a tomb. A modern-day archaeologist finds the remains of your magnificently preserved body. The scientist finds that 63.2% of the carbon-14 in your remains has *decayed*. How many years ago did you die?

7. Potassium-40 has a very long half-life of 1.26 x 10^9 years. It can decay through **two** different and exclusive mechanisms to yield argon-40. Write balanced equations for **both** of these nuclear processes that result in the same product (Ar-40).

8. Unlike nuclear fission utilized in current nuclear power plants, the main appeal of nuclear **fusion** as a power source is that the hydrogen isotopes used as fuel are cheap and plentiful and that the fusion products are non-radioactive and non-polluting. The technical problems that must be overcome before achieving a practical and controllable fusion method are staggering, however. One such problem is that a temperature of about 40 million Kelvins is required to initiate the fusion process. Calculate the amount of energy released (in **kJ/mol**) for the fusion reaction of ^1H and ^2H atoms to yield a ^3He atom given the information below.

particle	**mass**
^1H	1.67358 x 10^{-27} kg
^2H	3.34457 x 10^{-27} kg
^3He	5.00835 x 10^{-27} kg

9. It has been estimated that 3.9 x 10^{23} kJ/s is radiated into space by the sun. What is the rate of the sun's mass loss in **kg/s**?

10. Which nuclear process will **not** affect the number of neutrons or protons in the nucleus?

    a) α emission
    b) β emission
    c) γ emission
    d) positron emission
    e) electron capture

11. What is the product when polonium-204 (^{204}Po, element #84) undergoes **electron capture**?

12. What is the product when ruthenium-106 (^{106}Ru, element #44) undergoes **β emission**?

13. Which of the following elements has an isotope with the **most** stable nucleus?

    a) C
    b) Pb
    c) Cu
    d) Au
    e) Fe

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