Objective 15 Practice Problems:

1. a. What is the difference between nuclear radiation and electromagnetic radiation? What is the source of each type of radiation? Which radiation type involves more energy?

b. Name each type of nuclear radiation and its nuclide symbol. (A nuclide symbol shows the mass number (superscript), atomic number (subscript), symbol, and charge if needed.)

c. (i) Describe how to protect yourself from each type of radiation.

(ii) Alpha particles have the highest relative biological effectiveness (RBE = 20) but is blocked by skin. Why are alpha particles so dangerous?

(iii) X rays and gamma radiation have the lowest relative biological effectiveness (RBE = 1) but is blocked by a lead shield or thick concrete. How is the wavelength of electromagnetic radiation related to the thickness of the shielding?

d. How can you tell whether a substance is radioactive? (Hint: see atomic number, number of neutrons and protons.)

2. Nuclear reactions.

a. Carbon-14 (^{14}C) is the radioactive isotope of carbon and is used to determine the age of fossils (carbon dating). When ^{14}C undergoes radioactive decay. It emits a beta particle. Below is a partial radioactive decay nuclear equation:

$$^{14}C \text{ ---> } ^{0}e + {}^{14}X$$

The superscripts represent ____.

The subscripts represent atomic number. Write in the atomic number in each reactant and product.

What element is X? How many protons and neutrons are in this isotope?

b. Potassium-40 is radioactive and is a beta emitter. Write a balanced nuclear equation that represents the radioactive decay of K-40. How many protons and neutrons are in K-40?

c. Americium-241 is used in smoke detectors and is an alpha emitter. Write a balanced nuclear equation that represents the radioactive decay of Am-241. How many protons and neutrons are in Am-241?

d. Uranium-235 undergoes induced nuclear fission by capturing (reacting with) a neutron to produce barium-141, krytpton-92, neutrons, gamma radiation, and a lot (200 MeV) of energy. Write a balanced nuclear equation that represents the induced fission of U-235. How many neutrons are produced? How many protons and neutrons are in U-235?

e. Boron neutron capture therapy is a cancer therapy. Boron-10 captures a neutron to form lithium-7, gamma radiation, 2.4 MeV of energy, and a type of particle radiation. Write a balanced nuclear equation that represents the boron neutron capture reaction. What type of particle radiation is produced?

3. Of these two isotopes of gallium, $^{71}_{31}Ga$ and $^{76}_{31}Ga$, one is stable and the other is radioactive.

a. Determine the number of protons, neutrons, and electrons in each isotope.

b. Predict which one is radioactive. Give reasons. (Hint: elements with an atomic number > 83 are radioactive. Isotopes with an odd number of protons and odd number of neutrons are almost always radioactive.)

c. For the radioactive isotope, predict whether it is an alpha emitter or beta emitter. Write a balanced nuclear equation that shows its decay. (Hint: In general, heavy elements are alpha emitters and light elements are beta emitters.)

4. We studied reaction rates earlier in Chem 1B.

The rate (speed) of a radioactive decay reaction is first order in the radioactive isotope. E.g., ^{14}C decay is 1st order:

$$^{14}C \text{ ---> } ^{0}e + {}^{14}N \qquad \text{rate} = k\,N^{1}$$

where N = number of ^{14}C nuclei in sample, k = rate constant

The half-life of a first order reaction is $t_{1/2} = 0.693/k$.

For ^{14}C, $t_{1/2}$ = 5,730 years. This means half of the original sample has undergone radioactive decay after 5,730 years. After another 5,730 years, half of the remaining sample (or ½ x ½ = ¼ of original sample) has decayed.

a. Draw a graph of N vs. time for the radioactive decay of ^{14}C.

b. If the original amount of ^{14}C is 2 g, how many g are left after 4 half-lives? How many years have elapsed?

c. Your analysis of a fossil sample shows 0.1 g of ^{14}C. How many g of ^{14}C was in the sample about 17,000 years ago?

d. The Earth is believed to be about 5 billion years old. The half life of U-238 is 4.5 billion years. How much U-238 remains from the birth of the Earth?

e. (i) The rate of radioactive decay of a radioactive isotope is _____. (Hint: See order.)

(ii) Would you rather be exposed to a radioisotope with a long half-life or short half-life? Give reasons. (Hint: how is half-life related to rate?)

5. In a 70 kg human, there is 1.6×10^{4} g of carbon. A very small amount of this carbon is radioactive carbon-14. The relative abundance of radioactive carbon-14 is 1 carbon-14 in 10^{12} C. Carbon-14 is a beta emitter with a half-life of 5730 years. The mass destroyed per disintegration is 7.85×10^{-32} kg.

a. Write a balanced nuclear equation that shows the radioactive decay of carbon-14. What is the order of this reaction and any radioactive decay reaction?

b. Calculate the number of carbon-14 nuclei in a 70 kg human.

c. Calculate the radiation exposure in mrem/year from carbon-14.

d. How is carbon-14 used to date fossils? (Hint: compare the ratio of carbon-12 to carbon-14 in a living organism vs. a dead one.)

6. Radon is a source of concern for homeowners.
a. Where does radon come from? See Nuclear Radiation Lecture Slide 24 on the U-238 decay series. Write the nuclear equations that show how radon is produced.
b. See Nuclear Radiation Lecture Slide 24 on the U-238 decay series.
(i) Which isotope has the largest k? Give reasons.
(ii) After one month, which isotope is present is the highest amount? Give reasons.
(iii) Which isotope limits the amount of other isotopes produced?
c. In the U-238 decay series, radon is the only isotope that is a gas. Why does radon being a gas make radon so dangerous?
d. Is radon more or less dangerous than carbon-14? Give reasons. Consider state of matter, radioactive decay type, half-life and other.
e. Radon gas was detected in the chemistry stockroom. Since a very small amount of radon was detected, you calculate the approximate time required for 90% of the radon to decay. How much lab time will you miss? (Hint: see half-life and number of half-lives for 90% of a sample to decay.)

7. Uranium-235 undergoes induced fission and is used in nuclear power plants or weapons. In induced fission, a U-235 nucleus captures a neutron to form U-236. The unstable U-236 decays to form Ba-144, Kr-89, neutrons, gamma rays, and energy. The neutrons initiate a chain reaction.
a. How many neutrons are formed in the U-235 induced fission reaction? Write a balanced nuclear reaction to support your answer.
b. How is the chain reaction different in a nuclear power plant and in a nuclear bomb?
c. Describe how a light water nuclear power plant works. Include the substance(s) used in the fuel rods, control rods, moderator, and coolant.
d. How does the plant work to produce electricity?
e. What type(s) of radiation would you encounter if you worked in a nuclear power plant? Identify the specific source of each type of radiation. For one radiation type, write a nuclear equation that shows the source of radiation.
f. What is one advantage of nuclear power? What is one disadvantage of nuclear power?
g. The scientific community believes the earth's climate is changing due to global warming. Global warming is caused by the burning of fossil fuels. Which fuel, fossil fuels or nuclear fuel, is cleaner? Give reasons. (See The World's Foremost Environmentalist Weighs In On Nuclear Power, SOURCE: http://www.washingtonpost.com/wp-dyn/content/article/2006/04/14/AR2006041401209.html)
h. Would you want a nuclear power plant in your backyard? Give reasons.