Name: ________________________

CHM 130LL: Nuclear Chemistry

Radioactive Decay, Nuclear Equations, and Half-Lives

I. View the "Nuclear Energy" video

II. Radioactive Isotopes and Nuclear Equations

Atoms are composed of three subatomic particles: protons, neutrons and electrons. Protons and neutrons are found in the nucleus of an atom. The total number of protons and neutrons determines an atom's mass. The number of protons defines the element.

Some nuclei are unstable, so they decompose (or "decay") over time, spontaneously emitting particles and/or energy. Such emissions are called **radioactivity** (or radioactive decay) and such unstable atoms are referred to as **radioactive isotopes**. Different isotopes are commonly identified by their element name or chemical symbol and their mass. For example, uranium-235 (U-235) and uranium-238 (U-238) are two different isotopes of the element uranium, and carbon-12 (C-12) and carbon-14 (C-14) are isotopes of the element carbon.

Some isotopes can also be induced to decay as a result of bombardment by high-energy particles (e.g. neutrons, electrons, and other nuclei). These kinds of nuclear changes are called **nuclear transmutation**.

Both radioactive decay and nuclear transmutation are examples of **nuclear reactions**.

Atomic Notation (also called **Nuclear Symbol):**

- Shorthand for keeping track of protons and neutrons in the nucleus

$$\text{mass number} = A,\ \text{atomic number} = Z \quad {}^{A}_{Z}E \text{ = Element symbol}$$

atomic number: whole number of protons (p^+) = whole number of electrons (e^-) in neutral atom
- given the atom, this can be obtained from the Periodic Table

mass number: whole number sum of protons (p^+) and neutrons (n) in an atom's nucleus
- this is generally provided

Some common particles have the following atomic notation: **proton=**$^{1}_{1}H$ **neutron=**$^{1}_{0}n$ **electron=** $^{0}_{-1}e$

Exercise 1: The carbon-14 isotope is used to estimate the age of something that was once alive.

Write the atomic notation for carbon-14: [ ]

How many neutrons are in each neutral carbon-14 atom? __________

Exercise 2: The potassium-40 isotope is used to estimate the age of rocks.

Write the atomic notation for potassium-40. [ ]

How many neutrons are in each neutral potassium-40 atom? __________

Exercise 3: Complete the following table:

Isotope	Mass Number	# of Protons	# of Neutrons	# of Electrons
Argon-37				
^{238}U				
Lead-206				

Different Types of Radioactive Decay

There are five different ways in which naturally occurring radioactive nuclei decay. They differ in their emissions:

alpha (α) emission: a helium nucleus, $^{4}_{2}\alpha$ or $^{4}_{2}He$, is emitted. In this case, the parent and daughter are atoms of different elements and also have different masses.

$$^{238}_{92}U \longrightarrow \; ^{4}_{2}\alpha + \; ^{234}_{90}Th$$

beta (β) emission: an electron, $^{0}_{-1}\beta$ or $^{0}_{-1}e$, is emitted when a neutron inside an atom decays to produce a proton and an electron. In this case, the parent and daughter are of different elements but the mass remains the same.

$$^{234}_{90}Th \longrightarrow \; ^{0}_{-1}\beta + \; ^{234}_{91}Pa$$

gamma (γ) emission: high energy photons or gamma rays, $^{0}_{0}\gamma$, are emitted. This generally accompanies the emission of a particle.

$$^{99m}_{43}Tc \longrightarrow \; ^{99}_{43}Tc + \; ^{0}_{0}\gamma$$

A nuclear reaction can also be forced to occur by bombarding a radioactive isotope with another particle. This process of causing radioactivity is called ***nuclear transmutation***. Nuclear transmutations can result in α, β, and γ emissions as well as the production of protons, neutrons, and other isotopes:

$$^{14}_{7}N + \; ^{4}_{2}\alpha \longrightarrow \; ^{17}_{8}O + \; ^{1}_{1}H$$

$$^{235}_{92}U + \; ^{1}_{0}n \longrightarrow \; ^{141}_{56}Ba + \; ^{92}_{36}Kr + 3\; ^{1}_{0}n$$

Balancing Nuclear Equations

- This differs from balancing general chemical equations because instead of balancing elements (or atoms) present, **mass numbers** (protons + neutrons) **and atomic numbers are balanced**.

For example: $^{222}_{86}\text{Rn} \longrightarrow {}^{218}_{84}\text{Po} + {}^{4}_{2}\alpha$

parent nuclide — daughter nuclide

where the mass numbers are equal to 222, and the atomic numbers are equal to 86.

Exercise 1: Identify the unknown isotope or particle in each to complete the following nuclear equations:

a. The carbon-14 isotope forms when atmospheric nitrogen is bombarded by cosmic rays.

$$^{14}_{7}\text{N} + {}^{1}_{0}\text{n} \longrightarrow {}^{14}_{6}\text{C} + \underline{\hspace{3em}}$$

b. Identify the radioactive isotope that decays to produce a neutron and phosphorus-30 when bombarded with an alpha particle.

$$\underline{\hspace{3em}} + {}^{4}_{2}\alpha \longrightarrow {}^{1}_{0}\text{n} + {}^{30}_{15}\text{P}$$

Exercise 2: Write balanced nuclear equations for the following processes:

a. The carbon-14 isotope undergoes beta decay.

b. Zinc-64 is produced when a radioactive isotope undergoes beta decay.

c. Uranium-235 (U-235) decays by alpha emission.

d. A radioactive isotope undergoes beta decay to produce sulfur-32.

Exercise 3: The inhalation of radon-222 and its decay to form other isotopes poses a health hazard. Write balanced nuclear equations for the decay of radon-222 to lead-206 in eight steps.

a. Step 1: Radon-222 decays by alpha emission. (Radon has the element symbol Rn.)

b. Step 2: The daughter product in part a decays by alpha emission.

c. Step 3: The daughter product in part b decays by beta and gamma emissions.

d. Step 4: The daughter product in part c decays by beta and gamma emissions.

e. Step 5: The daughter product in part d decays by beta emission.

f. Step 6: The daughter product in part e decays by alpha emission.

g. Step 7: The daughter product in part f decays by beta and gamma emissions.

h. Step 8: The daughter product in part g decays by alpha and gamma emissions.

The final stable isotope is **lead-206**.

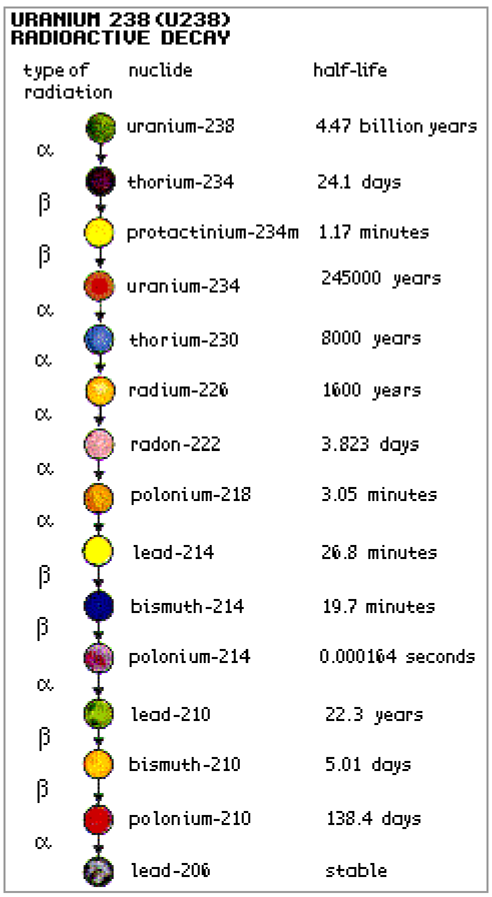
III. Radioactive Decay and the Concept of "Half-Life"

Radioisotopes are unstable forms of an element that go through a process called "radioactive decay." In **radioactive decay**, the nucleus of the unstable atom "decays" by releasing particles and/or energy. During this process, a "**daughter**" element is produced that has a different nuclear structure than the original "**parent**" element. In the following exercise we are going to explore this process of decay and the rate at which it occurs.

Half-Life and the Amount of Sample Left

Because **half-life** ($t_{1/2}$) is *the time required for half the amount of a radioactive sample to decay*, we can estimate how much of a radioactive sample remains after a given amount of time if we know the half-life.

Figure 1 below indicates the parent and daughter nuclei as well as the half-lives for all the radioactive isotopes in the Uranium-238 decay series. Use the figure to answer the following questions:



Exercise 1: a. What is the half-life for Polonium-218? _______

b. How many half-lives have passed for Polonium-218 after 9.15 minutes? _____ half-lives (HL)

c. How much of an 89.6-mg sample Polonium-218 would remain after 9.15 minutes? (Circle your answer.)

Exercise 2: a. What is the half-life for Bi-210? _________

b. How many half-lives have passed for Bi-210 after 10.02 days? _____ half-lives (HL)

c. How much of a 64.0-mg sample Bi-210 would remain after 10.02 days? (Circle your answer.)

Exercise 3: a. What is the half-life for Pb-210? _________

b. How many half-lives have passed for Pb-210 after 89.2 years? _____ half-lives (HL)

c. How much of a 50.4-mg sample Pb-210 would remain after 89.2 years? (Circle your answer.)

IV. Radiation and Biological Hazards (Independent Study)

Go to the SyRIS home page (http://glory.gc.maricopa.edu/~mvillarb/SyRIS/) and click on any of the links to learn more about radioactivity, its uses, and its effects on our lives.