CHM152LL: Nuclear Chemistry Summer Worksheet

- **This worksheet is a summary of Nuclear Chemistry concepts and questions – you will not turn it in for a grade.**
- **An answer key will be available in PS149 – please check your answers before the final exam.**

I. Radioactive Isotopes and Nuclear Equations

Atoms are composed of three main 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 number. 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 (or **Nuclear Symbol):** Shorthand for keeping track of protons and neutrons in the nucleus

mass number = A
atomic number = Z E = Element symbol

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

mass number: whole number sum of protons (p^+) and neutrons (n) in an atom's nucleus.
Different isotopes of an element will have different mass numbers.

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

Exercise 1: Complete the following table (for practice):

Isotope	Mass Number	# of Protons	# of Neutrons	# of Electrons
Strontium - 90				
${}^{222}Rn$				

Modes of Decay

There are five different ways in which naturally occurring radioactive nuclei decay. Note that in emission reactions, often called decay reactions, the particle is a product. In the capture reaction, the particle is a reactant.

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

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

positron (${}^{0}_{1}e$) emission (or decay): a positron, ${}^{0}_{1}e$, is emitted when a proton inside an atom decays to produce a neutron and a positron. In this type of radioactive decay, the parent and daughter are different elements but have the same mass.

$$ {}^{22}_{11}Na \longrightarrow {}^{0}_{1}e + {}^{22}_{10}Ne $$

electron capture: an electron in the 1s orbital "falls" into the nucleus, which fuses with a proton to form a neutron.

$$ {}^{82}_{37}Rb + {}^{0}_{-1}e \longrightarrow {}^{82}_{36}Kr $$

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:

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

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

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:

$$ \underset{\text{parent nuclide}}{{}^{222}_{86}Rn} \longrightarrow \underset{\text{daughter nuclide}}{{}^{218}_{84}Po} + {}^{4}_{2}\alpha $$

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

Exercise 1: **Identify the missing element** in each to complete the following nuclear equations:

a. Argon-40 is bombarded with a proton.

$$ {}^{40}_{18}Ar + {}^{1}_{1}H \longrightarrow {}^{1}_{0}n + \underline{\qquad} $$

b. Uranium-238 has a half-life of about 4.5 billion years and is used to date very old rocks.

$$ {}^{238}_{92}U \longrightarrow 6\,{}^{0}_{-1}e + 8\,{}^{4}_{2}\alpha + \underline{\qquad} $$

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

a. Uranium-234 is **produced** when a radioactive isotope undergoes alpha decay.

b. Cobalt-60 is **produced** when a radioactive isotope undergoes beta decay.

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**.

II. Half-Life and the Amount of Sample Left

Radioactive decay is a first order rate process and all radioactive substances have a characteristic half-life. From first order kinetics the half life, $t_{1/2}$, is related to the rate constant, k, by the following equation:

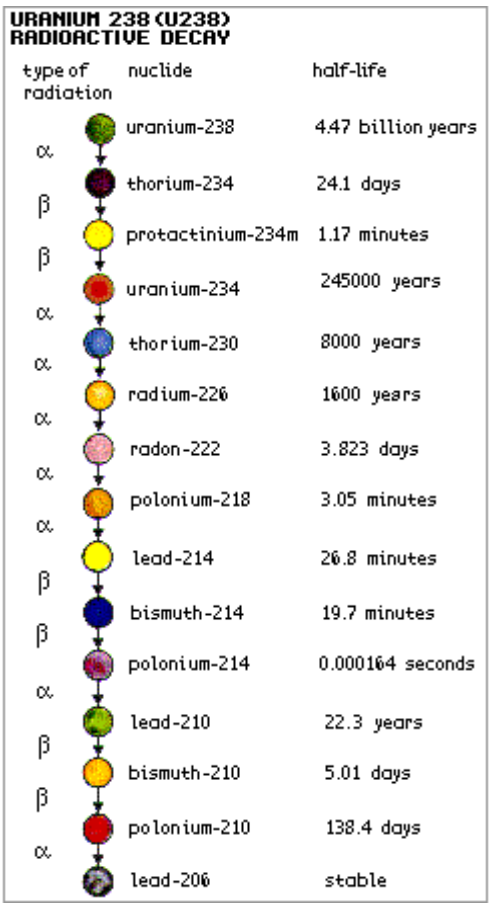
$$k \cdot t_{1/2} = 0.693 \qquad \ln\left(\frac{A_t}{A_0}\right) = -kt;$$

The amount of sample remaining after a given time can be calculated from the following first order rate law

where A_0 = initial activity or amount of substance; A_t = activity or amount of substance after a certain time; k = rate constant; and t = time.

Half-life ($t_{1/2}$) is *the time required for half the amount of a radioactive sample to decay*, so we can also 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 decay series for Uranium-238. Use the information provided in the figure and the first order equations provided above to answer the following questions:



Exercise 1: a. What is the half-life for Thorium-230? _____

b. How many half-lives have passed for Thorium-230 after 32,000 years? _____ half-lives (HL)

c. How much of an 95.6-mg sample of Thorium-230 would remain after 32,000 years?

d. What is the value of the rate constant, k, for Th-230?

e. How much of a 35.8-mg sample of Thorium-230 would remain after 18500 years?

f. How much time will it take for a 280 mg sample of Thorium-230 to decay to 11.0 mg?