

Name: _____

CHM 130LL: Nuclear Chemistry

Radioactive Decay, Nuclear Equations, and Half-Lives

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

$$\begin{array}{l} \text{mass number} = A \\ \text{atomic number} = Z \end{array} \text{E} = \text{Element symbol}$$

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: $\text{proton} = {}^1_1\text{H}$ $\text{neutron} = {}^1_0\text{n}$ $\text{electron} = {}^0_{-1}\text{e}$

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

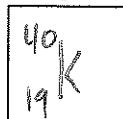
Write the atomic notation for carbon-14:



How many neutrons are in each neutral carbon-14 atom? 8

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? 21

Exercise 3: Complete the following table:

Isotope	Mass Number	# of Protons	# of Neutrons	# of Electrons
Argon-37	37	18	19	18
^{238}U	238	92	146	92
Lead-206	206	82	124	82

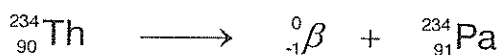
Different Types of Radioactive Decay

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

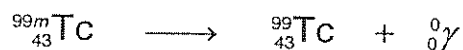
alpha (α) emission: a helium nucleus, $^4_2\alpha$ or ^4_2He , is emitted. In this case, the parent and daughter are atoms of different elements and also have different masses.



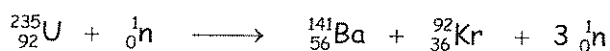
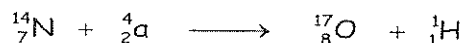
beta (β) emission: an electron, $^0_{-1}\beta$ or $^0_{-1}\text{e}$, is emitted when a neutron inside an atom decays to produce a proton and an electron. In this case, the parent and daughter are of different elements but the mass remains the same.



gamma (γ) emission: high energy photons or gamma rays, $^0_0\gamma$, are emitted. This generally accompanies the emission of a particle.

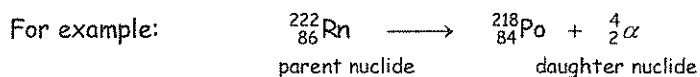


A nuclear reaction can also be forced to occur by bombarding a radioactive isotope with another particle. This process of causing radioactivity is called *nuclear transmutation*. Nuclear transmutations can result in α , β , and γ emissions as well as the production of protons, neutrons, and other isotopes:



Balancing Nuclear Equations

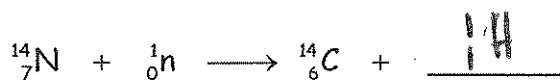
- This differs from balancing general chemical equations because instead of balancing elements (or atoms) present, mass numbers (protons + neutrons) and atomic numbers are balanced.



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.

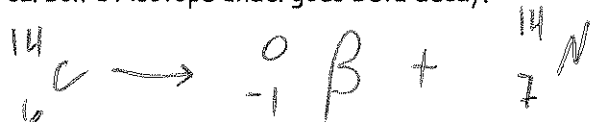


- b. Identify the radioactive isotope that decays to produce a neutron and phosphorus-30 when bombarded with an alpha particle.

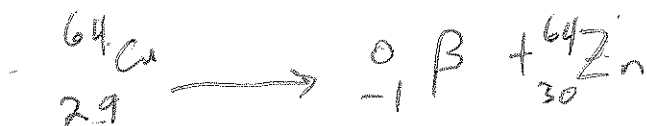


Exercise 2: Write balanced nuclear equations for the following processes:

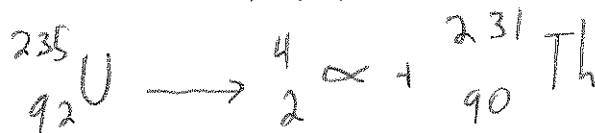
- a. The carbon-14 isotope undergoes beta decay.



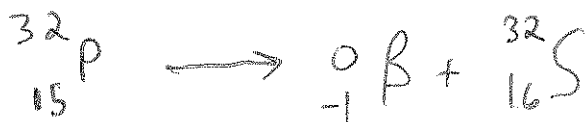
- b. Zinc-64 is produced when a radioactive isotope undergoes beta decay.



- 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.

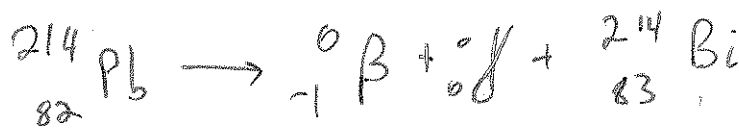
- a. Step 1: Radon-222 decays by alpha emission. (Radon has the element symbol Rn.)



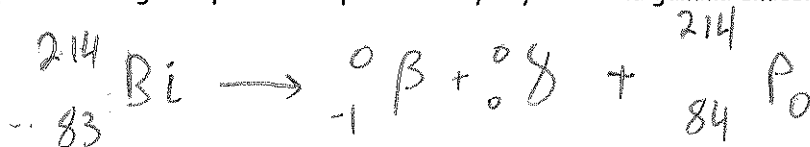
- b. Step 2: The daughter product in part a decays by alpha emission.



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



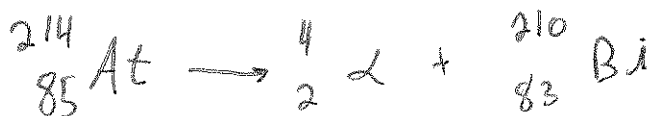
- d. Step 4: The daughter product in part c decays by beta and gamma emissions.



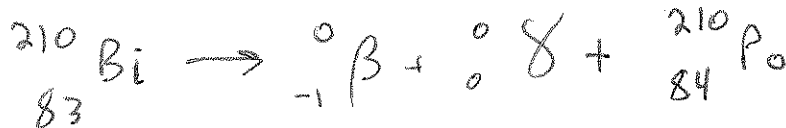
- e. Step 5: The daughter product in part d decays by beta emission.



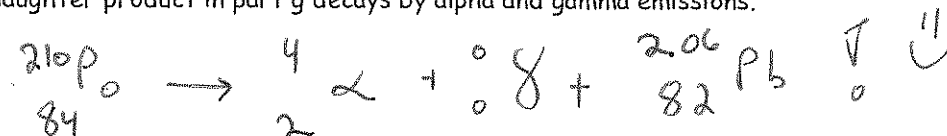
- f. Step 6: The daughter product in part e decays by alpha emission.



- 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.