Nuclear Chemistry

(What is radiation?)

Model: Nuclide symbols for three isotopes of carbon

$^{12}_{6}C$	$^{13}_{6}C$	$^{14}_{6}C$
carbon-12	carbon-13	carbon-14

Critical Thinking Questions:

1. How many protons are in carbon-12? ____ How many neutrons are in carbon-12? ____

2. How many protons are in carbon-13? ____ How many neutrons are in carbon-13? ____

3. How many protons are in carbon-14? ____ How many neutrons are in carbon-14? ____

4. Make a list of what is the same and what is different among isotopes.

5. What does the subscripted 6 represent in all three nuclide symbols in the Model?

Information: Nuclear reactions and ionizing radiation

A **nuclear reaction** is a change in the composition of the nucleus of an atom. This is not normally considered a chemical reaction, and does not depend on what molecule the atom might be in.

There are three types of nuclear reactions: fusion, fission, and radioactivity. Fusion (combining of nuclei into larger nuclei, such as in stars and the sun) and fission ("splitting the atom," such as in a nuclear reactor) do not concern us much in chemistry.

Some isotopes are radioactive, meaning that their nuclei break down ("decay") and give off particles, "rays," or both. There is no simple way to predict which isotopes are radioactive.

Table 1: Some types of ionizing radiation produced in nuclear reactions

Type of Radiation	Symbol	Mass Number	Charge	Relative penetrating ability	Shielding required	Biological hazard
Alpha particle	α, $^{4}_{2}He$	4	2+	very low	clothing	none unless inhaled
Beta particle	β, $^{0}_{-1}e$	0	1–	low	heavy cloth, plastic	mainly to eyes, skin
Gamma ray	γ, $^{0}_{0}\gamma$	0	0	very high	lead or concrete	whole body
Neutron	$^{1}_{0}n$	1	0	very high	water, lead	whole body
Positron	β^{+}, $^{0}_{1}e$	0	1+	low	heavy cloth, plastic	mainly to eyes, skin

Critical Thinking Questions:

6. What does the subscript indicate in the **symbols** in Table 1?

7. Explain how your answer to CTQ 6 is consistent with your answer to CTQ 5.

8. Consider the following nuclear reaction: $^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$

   a. What type of radiation is produced?

   b. How does the number of protons in the reactant compare with the total number of protons in the products?

   c. How does the number of neutrons in the reactant compare with the total number of neutrons in the products?

   d. How does the mass number of the reactant compare with the total of the mass numbers of the products?

   e. Show how each side of the reaction equation would change if a gamma ray were also released in the process.

9. Balance the mass numbers and "atomic numbers" to complete the equation.

   a. $^{131}_{53}I \rightarrow {}^{0}_{-1}e +$ ☐

   b. What type of radiation is given off in this reaction?

Table 2: Half-lives of some radioisotopes

Radioisotope	Radiation type	Half-life	Use
barium-131	γ	11.6 days	detection of bone tumors
carbon-14	β	5730 yr	carbon dating
chromium-51	γ, X-rays	27.8 days	measuring blood volume
cobalt-60	β, γ	5.3 yr	food irradiation, cancer therapy
iodine-131	β	8.1 days	hyperthyroid treatment
uranium-238	α, β, γ	4.47×10^9 yr	dating igneous rocks

The time required for half of a sample of a radioactive isotopes to decay is called the half-life ($t_{½}$).

Critical Thinking Questions:

10. Consider a 100-gram sample of radioactive cobalt-60.

    a. How much time will it take before half the sample has decayed?

    b. Approximately how many grams of radioactive cobalt-60 will remain after 11 years?

11. Consider a sample of iodine-131.

    a. How many half-lives would it take for the sample to decay until less than 1% of the original isotope remained?

    b. How many days would this be?

12. Considering only the half lives of uranium-238 and iodine-131, which would be more appropriate for internal usage (ingestion) for medical tests? Explain.

Exercises:

1. After an organism dies, it stops taking in radioactive carbon-14 from the environment. If the carbon-14:carbon-12 ratio ($^{14}_{6}\mathrm{C}\,/\,^{12}_{6}\mathrm{C}$) in a piece of petrified wood is one sixteenth of the ratio in living matter, how old is the rock? (Hint: How many half lives have elapsed?)

2. Would chromium-51 be useful for dating rocks containing chromium? Why or why not?

3. Suppose that 0.50 grams of barium-131 are administered orally to a patient. Approximately how many <u>milligrams</u> of the barium would still be radioactive two months later?

4. Complete the equations.

   a. $^{30}_{15}\mathrm{P} \longrightarrow {}^{0}_{1}e +$ (What type of radiation is this? _____)

   b. $^{113}_{47}\mathrm{Ag} \xrightarrow{\textit{beta decay}}$

   c. $\xrightarrow{\alpha \textit{ and } \gamma \textit{ emission}} {}^{222}_{86}\mathrm{Rn} + \quad + {}^{0}_{0}\gamma$

5. Read the assigned pages in your textbook and work the assigned problems.