Balancing Nuclear Reaction Equations

Why?

Nuclear reactions are going on all around us. Using correctly balanced equations is important when trying to understand nuclear reactions. All equations need to be balanced to conform to two conservation laws: the mass number is conserved, and the electrical charge is conserved.

Success Criteria

- Use the conservation laws to find an unknown in a nuclear reaction equation.
- Write a balanced nuclear equation for a natural transmutation.

Prerequisites

- atomic symbols including mass number, atomic number, and charge

Information

${}^{4}_{2}He$ = a helium nucleus, also known as an alpha particle

${}^{0}_{-1}e$ = an electron, also known as a beta particle when emitted by a nucleus

Model

The following are two nuclear reaction equations:

$${}^{220}_{87}Fr \longrightarrow {}^{4}_{2}He + {}^{216}_{85}At$$

$${}^{16}_{7}N \longrightarrow {}^{0}_{-1}e + {}^{16}_{8}O$$

Key Questions

1. What are the products of francium-220 decay? Write the names of the products.

alpha particle + astatine -216

2. What are the products of nitrogen-16 decay? Write the names of the products.

beta particle + oxygen - 16

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3. (a) Is the alpha particle gained or released by the Fr-220?

   released

   (b) Is the beta particle gained or released by the N-16?

   released

4. (a) What is the mass number of an alpha particle?

   4

   (b) What is the charge of an alpha particle?

   +2

5. (a) What is the mass number of a beta particle?

   0

   (b) What is the charge of a beta particle?

   -1

6. By examining the equations in the model, what is the mathematical relationship between the total mass number of the reactants and the total mass number of the products? Show your work.

   mass # reactants = mass # products

7. By examining the equations in the model, what is the mathematical relationship between the total charge in the nuclei of the reactants and the total charge of the nuclei in the products? Show your work. [Note: you are looking for the charge of the nuclei not the ionic charge on particles.]

   charge reactants = charge products

8. How do your answers to Key Questions 6 and 7 support the laws of conservation of mass number and charge?

   mass # and charge remain the same after the reaction

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Exercises

1. Look at the equations in the model and explain what happens to the nucleus of each of the starting elements during the reaction.

breaks into two nuclei

2. Given the equation: $^{27}_{13}Al + ^{4}_{2}He \rightarrow ^{30}_{15}P + ^{1}_{0}n$

(a) How is this equation similar to the equations in the model?

mass # and charge remain constant

(b) How is this equation different from the equations in the model?

equal # of reactants + products
alpha particle is on the reactant side

3. Use the laws of conservation of mass number and charge to determine the identity of X in equations below. Refer to a periodic table as needed.

$^{222}_{86}Rn \rightarrow ^{4}_{2}He + X$ $^{218}_{84}Po$

$^{14}_{6}C \rightarrow ^{0}_{-1}e + X$ $^{14}_{7}N$

$X \rightarrow ^{0}_{+1}e + ^{19}_{9}F$ $^{19}_{10}Ne$

4. Write the balanced equation for the beta decay of Sr-90.

$^{90}_{38}Sr \rightarrow ^{0}_{-1}e + ^{90}_{39}Y$

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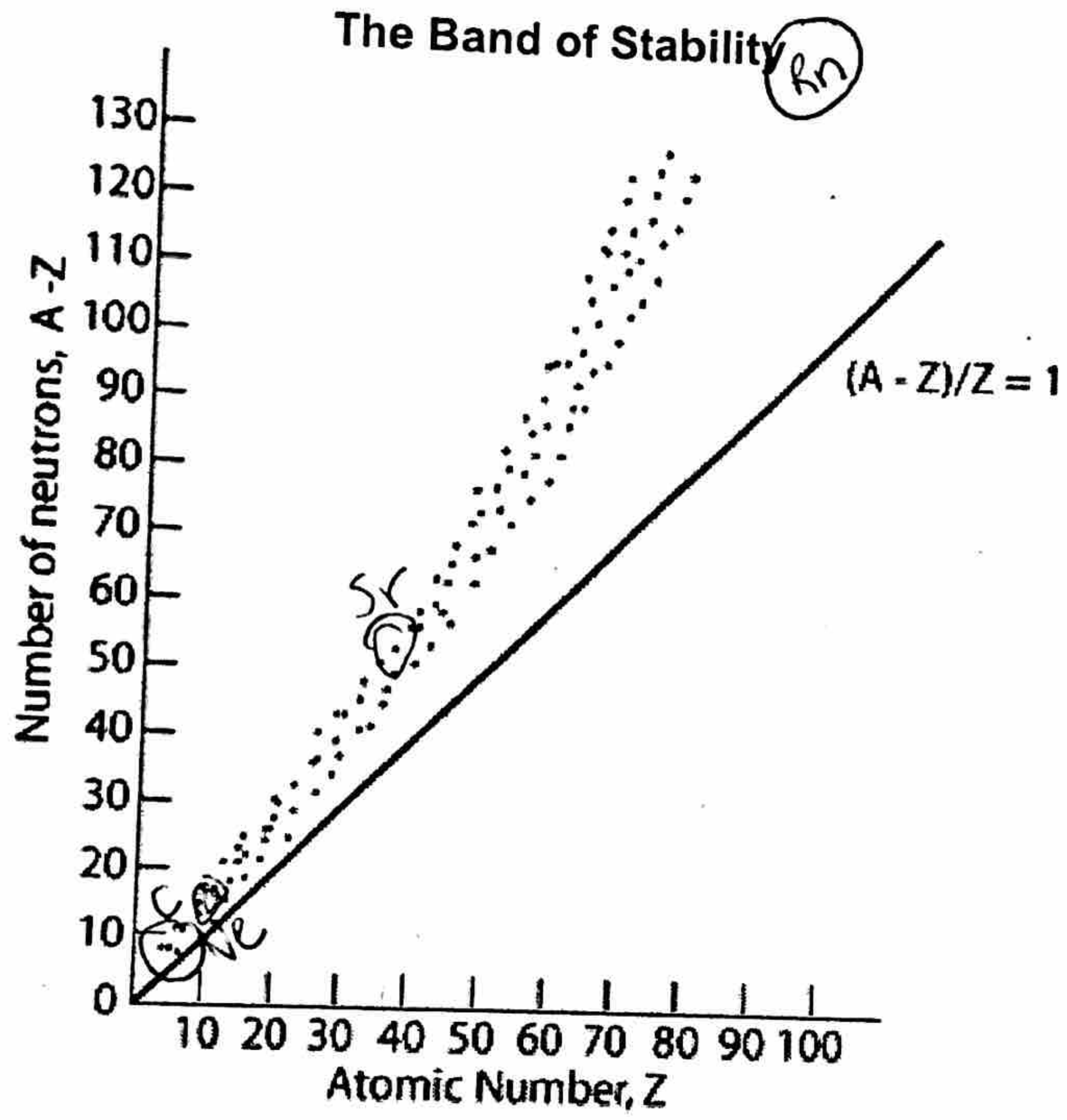
5. Below is a graph showing the number of neutrons versus the number of protons for all stable naturally occurring nuclei. (The solid line represents a neutron to proton ratio of 1:1.)



http://www.algebralab.org/practice/practice.aspx?file=Reading_TheBandOfStability.xml

(a) Find the reactants from Exercises 3 and 4 on the graph. Where are they located on the graph in relation to the belt of stability?

$^{222}_{86}Rn$ z = 86, 136

$^{19}_{10}Ne$ z = 10, 9

$^{14}_{6}C$ z = 6, 8

$^{90}_{38}Sr$ z = 38, 52

(b) Are these reactants stable or do they decay spontaneously? Explain your answer.

Rn decays spontaneously

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Research

1. The change of U-235 to Pb-206 is used in the dating of geologic formations.
(a) Why is U-235 unstable? Use the information in Exercise 5 to provide an answer.

$^{235}_{92}U$ A= 92
143 not on the chart

(b) Why is it possible to use this decay to date geologic formations?

It decays spontaneously so we know this is occuring in an even decay

2. If C-14 is constantly decaying, how is it that a living being has a constant amount of C-14 throughout its lifetime?

the half life is longer than the lifetime of a living being

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Nuclear Chemistry Worksheet

Nuclear reactions that involve bombardment of nuclei vary in their products. For example:

$^{9}_{4}Be + ^{4}_{2}He \rightarrow ^{12}_{6}C + ^{1}_{0}n$

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

$^{27}_{13}Al + ^{1}_{1}H \rightarrow ^{26}_{13}Al + ^{2}_{1}H$

$^{45}_{21}Sc + ^{1}_{0}n \rightarrow ^{42}_{19}K + ^{4}_{2}He$

In nuclear equations, the total number of positive charges (represented by the atomic numbers) of the reactants (substances on the left of the reaction arrow) equals the total number of positive charges of the products (substances on the right of the reaction arrow). The total mass of the reactants must also equal the total mass of the products.

For example:
A uranium-238 atom decays by emitting an alpha particle to form a thorium-234 atom.

$^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He$

Another example:
Potassium-40 decays to calcium-40 by beta emission.

$^{40}_{19}K \rightarrow ^{40}_{20}Ca + ^{0}_{-1}\beta$

In both examples, the total mass on the left equals the total mass on the right. The total number of positive charges on the left equal the total number of positive charges on the right.

Write out or complete the following nuclear reactions.

1) Technetium-99 ($^{99}_{43}Tc$) decays by beta emission to form ruthenium-99 ($^{99}_{44}Ru$). $^{99}_{43}Tc \rightarrow ^{0}_{-1}e + ^{99}_{44}Ru$

2) Phosphorus-32 decays by beta emission to form sulfur-32.
$^{32}_{15}P \rightarrow ^{0}_{-1}e + ^{32}_{16}S$

3) Francium-212 ($^{212}_{87}Fr$) decays by alpha emission.

$^{212}_{87}Fr \rightarrow ^{4}_{2}He + ^{208}_{85}At$

4) Fluorine-18 decays to oxygen-18 by positron emission.

$^{18}_{9}F \rightarrow ^{18}_{8}O + ^{0}_{1}e$

5) Sodium-24 decays by beta emission.

$^{24}_{11}Na \rightarrow ^{0}_{-1}e + ^{24}_{12}Mg$

6) Krypton-76 absorbs a beta particle to form bromine-76.

$^{76}_{36}Kr + ^{0}_{-1}e \rightarrow ^{76}_{35}Br$

7) Aluminum-27 absorbs an alpha particle to form phosphorus-30 and emits a neutron. $^{27}_{13}Al + ^{4}_{2}He \rightarrow ^{30}_{15}P + ^{1}_{0}n$

8) Nitrogen-14 absorbs an alpha particle to form oxygen-17 and emits a proton. $^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H$

9) When neptunium-239 decays, plutonium-239 is formed and a particle is emitted. (Be sure to include the correct particle in the equation.)

$^{239}_{93}Np \rightarrow ^{239}_{94}Pu + ^{0}_{-1}e$

10) A particular atom absorbs a neutron to form uranium-236. No particle is emitted. $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U$

Complete the following nuclear equations:

11) $\underline{^{14}_{6}C} \rightarrow ^{0}_{-1}e + ^{14}_{7}N$

12) $\underline{^{9}_{4}Be} + ^{4}_{2}He \rightarrow ^{12}_{6}C + ^{1}_{0}n$

13) $^{239}_{93}Np \rightarrow ^{239}_{94}Pu + \underline{^{0}_{-1}e}$

14) $^{4}_{2}He + \underline{^{238}_{92}U} \rightarrow ^{240}_{94}Pu + ^{1}_{0}n + ^{1}_{0}n$

15) $^{1}_{0}n + \underline{^{235}_{92}U} \rightarrow ^{236}_{92}U$

16) $^{13}_{7}N \rightarrow \underline{^{13}_{6}C} + ^{0}_{+1}e$

17) $^{15}_{7}N$ + $^{1}_{1}H$ → $^{12}_{6}C$ + $^{4}_{2}He$

18) $^{6}_{3}Li$ + $^{1}_{0}n$ → $^{3}_{1}H$ + $^{4}_{2}He$

19) $^{226}_{88}Ra$ → $^{4}_{2}He$ + $^{222}_{86}Rn$

20) $^{18}_{9}F$ → $^{18}_{10}Ne$ + $^{0}_{-1}e$

21) $^{49}_{24}Cr$ → $^{49}_{23}V$ + $^{0}_{+1}e$

22) $^{239}_{94}Pu$ + $^{4}_{2}He$ → $^{241}_{95}Am$ + $^{1}_{1}H$ + $^{1}_{0}n$

23) $^{7}_{3}Li$ + $^{7}_{3}Li$ → $^{4}_{2}He$ + $^{10}_{4}Be$

24) $^{3}_{1}H$ + $^{2}_{1}H$ → $^{4}_{2}He$ + $^{1}_{0}n$

25) $^{14}_{6}C$ → $^{14}_{7}N$ + $^{0}_{-1}e$

26) $^{9}_{4}Be$ + $^{4}_{2}He$ → $^{12}_{6}C$ + $^{1}_{0}n$

27) $^{14}_{7}N$ + $^{4}_{2}He$ → $^{18}_{8}O$ + $^{0}_{+1}e$

28) $^{26}_{12}Mg$ + $^{1}_{0}n$ → $^{27}_{11}Na$ + $^{0}_{+1}e$

29) $^{59}_{27}Co$ + $^{2}_{1}H$ → $^{61}_{27}Co$ + $^{0}_{+1}e$

30) $^{208}_{84}Po$ → $^{204}_{82}Pb$ + $^{4}_{2}He$

Nuclear Chemistry

(What is radiation?)

Model: Nuclide symbols for three isotopes of carbon

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

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

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

Critical Thinking Questions:

1. How many protons are in carbon-12? 6 How many neutrons are in carbon-12? 6
2. How many protons are in carbon-13? 6 How many neutrons are in carbon-13? 7
3. How many protons are in carbon-14? 6 How many neutrons are in carbon-14? 8
4. Make a list of what is the same and what is different among isotopes.

   same: element, # protons | different: mass #, # of neutrons

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

   # of protons (charge)

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?

Charge

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

it is the same

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

   a. What type of radiation is produced? alpha particle

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

   Same

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

   same

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

   same

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

   just a gamma ray, but has no charge and no mass so it would be the same

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

   a. $^{131}_{53}I \rightarrow \, ^{0}_{-1}e \quad + \quad$ $^{131}_{54}Xe$

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

   beta particle

CA08

General, Organic, and Biological Chemistry: A Guided Inquiry, Michael P. Garoutte, 2007, John Wiley & Sons

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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 ($t_{1/2}$).

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?

   5.3 yr

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

   $n = \frac{11}{5.3} = 2.08$ $A = \frac{100g}{2^{2.08}}$ 23.7g

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?

   $100 \times .0099 = .99g$ → $.99g = \frac{100g}{2^n}$ → $2^n \cdot .99 = 100$ ↳ .99%

   $\log 2^n = \log 101$

   $n \log 2 = 2.00$

   $n = 6.66$

   b. How many days would this be?

   6.66 × 8.1 day 54 days

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.

$^{238}U \rightarrow 4.47 \times 10^9$ yr

$^{131}I \rightarrow 8.1$ days

it decays much more quickly

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Exercises:

1. After an organism dies, it stops taking in radioactive carbon-14 from the environment. If the carbon-14:carbon-12 ratio ($^{14}_{6}C/^{12}_{6}C$) 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?)

$0.0625 = \frac{1}{2^n}$ $2^n \cdot 0.0625 = 1$

$\log 2^n = \log 16$ $n = 4$ half lives

$n \log 2 = \log 16$ $4 \times 5730 = 22920$ years

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

No b/c the half-life of chromium-51 is a very short period of time and there would be so little left that it would be difficult to detect

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

→ 60 days

$A = \frac{A_o}{2^n}$ $A = \frac{0.50 g}{2^{5.17}} = 0.0139 g \left| \frac{1000 mg}{1 g} \right.$ = 13.9mg

$n = \frac{60 \text{ days}}{11.6 \text{ days}} = 5.17$

4. Complete the equations.

a. $^{30}_{15}P \longrightarrow {}^{0}_{1}e + {}^{30}_{14}Si$ (What type of radiation is this? position)

b. $^{113}_{47}Ag \xrightarrow{\text{beta decay}} {}^{0}_{-1}e + {}^{113}_{48}Cd$

c. $^{226}_{88}Ra \xrightarrow{\alpha \text{ and } \gamma \text{ emission}} {}^{222}_{86}Rn + {}^{4}_{2}He + {}^{0}_{0}\gamma$

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

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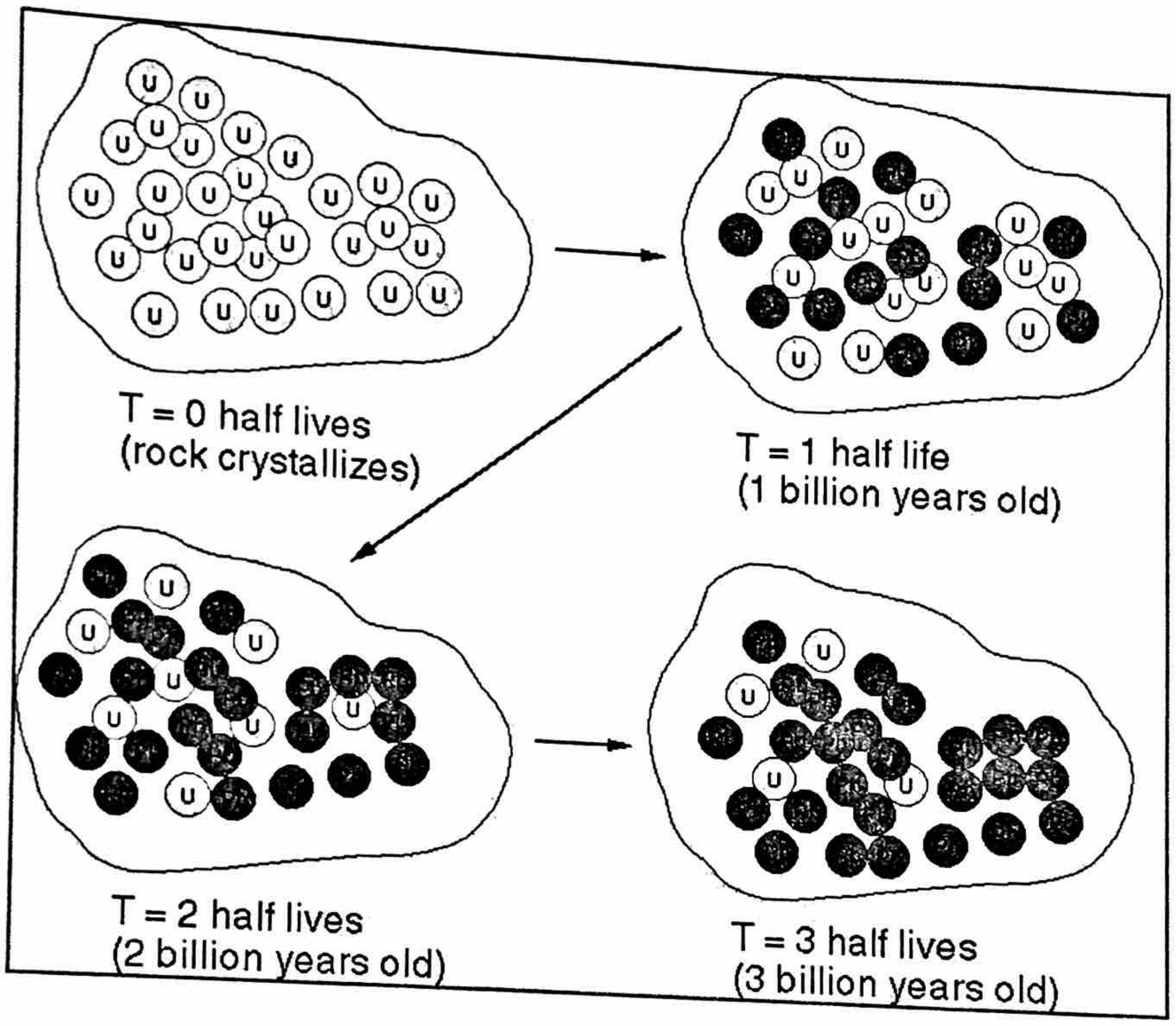
Name:
Date:
Block:

Radiometric Dating POGIL

Radiometric Dating Model:



Additional information:

Unstable isotopes decay at a regular rate over time. Different isotopes have varying rates of decay.

Key Questions:

1. How many uranium isotopes are present in the original (T=0) rock crystal?
   30
   a. Convert this number into a percentage
   100%
2. How many uranium isotopes are present after 1 billion (T=1) years?
   15
   a. Convert this number into a percentage
   50%
3. How many of the uranium isotopes decayed to form Lead (Pb) after 1 billion years?
   15
   a. Convert this number into a percentage
   50%
4. How many uranium isotopes are present after 2 billion years?
   8
   a. Convert this number into a percentage
   26%

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5. How many of the original uranium isotopes decayed to form Lead (Pb) after 2 billion years?

22

   a. Convert this number into a percentage

73%

6. How many uranium isotopes are present after 3 billion years?

4

   a. Convert this number into a percentage

13%

7. How many of the original uranium isotopes decayed to form Lead (Pb) after 3 billion years?

26

   a. Convert this number into a percentage

87%

Critical Analysis Questions:

8. How long is one half-life for the uranium isotope?

1 billion years

9. In your own words, define **half-life** in a complete sentence.

The amount of time it takes for half of a radioactive substance to decay into a non-radioactive substance

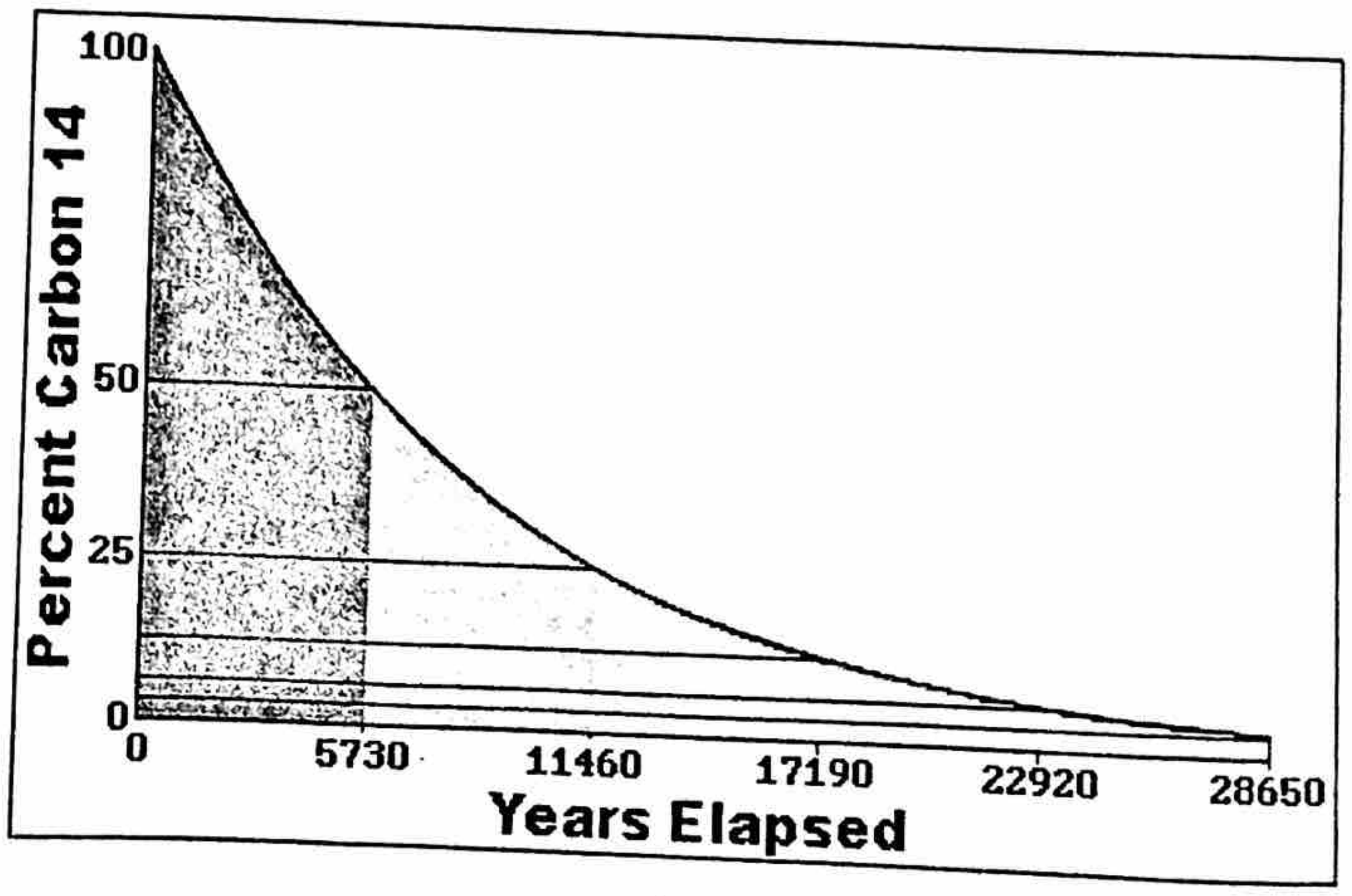
10. Describe how radioactive isotopes, like uranium can be used to estimate the age of rocks and fossils.

By looking at the composition of uranium compared to lead you can tell how much has already decayed, being able to say how old a material is.

Problems:

11. Carbon-14 is a radioactive isotope of carbon. Using the rate of decay graph, determine the half-life of carbon-14.

5730 year



12. What is the approximate age a fossil that had 1/8 th of its original C-14 left?

1 → 1/2 → 1/4 → 1/8

3 half-lives

3 x 5730 = 17190 years IS

$0.125 = \frac{1}{2^n}$

$0.125 \cdot 2^n = 1$

log $2^n = 8$ log

$n = 3$ x 5730

Honors Chemistry: Half-life. Solve the following problems.

1. The half-life of an isotope is 2.0 hours. How much of a 50.0 g sample is left after 6.0 hours? (6.25 g)

$n = \frac{6.0 \text{ hours}}{2.0 \text{ hours}} = 3$ $A = \frac{A_0}{2^n} = \frac{50.0g}{2^3}$ (6.25g)

2. The half-life of an isotope is 10.0 minutes. If 25.0 grams are left after 60.0 minutes, how many grams were in the original sample? (1600 g)

$n = \frac{60.0 \text{ minutes}}{10.0 \text{ minutes}} = 6$ $25.0g = \frac{x}{2^6}$

(x = 1600 g)

3. If 200.0 g of an isotope decays to 25.0 grams in 24.0 seconds, what is the half-life of this isotope? (8.0 s)

$25.0g = \frac{200.0g}{2^n}$ $\log 2^n = 8 \log$ n = 3 halflives

$\frac{2^n \cdot 25}{25} = \frac{200.0}{25}$ $\frac{n \log 2}{\log 2} = \frac{\log 8}{\log 2}$ $\frac{24.0 \text{ seconds}}{3}$ = (8 seconds)

4. The half-life of Carbon-14 is about 5730 years. If an artifact had 4.0 grams of C-14 originally, and it now has 1.0 grams of C-14, what is the approximate age of the artifact? (11,400 years)

$1.0g = \frac{4.0g}{2^n}$ $\frac{n \log 2}{\log 2} = \frac{\log 4}{\log 2}$ 5730 × 2 = (11460 y)

$1.0g \cdot 2^n = 4.0g$

$2^n = 4$ n = 2

5. The half-life of radon-222 is 3.8 days. How much of a 100.0 g sample is left after 15.2 days? (6.25 g)

$n = \frac{15.2 \text{ days}}{3.8 \text{ days}} = 4$ $A = \frac{100.0g}{2^4}$ = (6.25 g)

6. Carbon-14 has a half-life of 5,730 years. If a sample contains 70 mg originally, how much is left after 17,190 years? (8.75 g)

$n = \frac{17190}{5730} = 3$ $A = \frac{70}{2^3} = 8.75g$

7. How much of a 500.0 g sample of potassium-42 is left after 62 hours? The half-life of K-42 is 12.4 hours. (15.6 g)

$n = \frac{62}{12.4} = 5$ $A = \frac{500.0g}{2^5} = 15.6g$

8. The half-life of cobalt-60 is 5.26 years. If 50.0 g are left after 15.8 years, how many grams were in the original sample? (400 g)

$n = \frac{15.8}{5.26} = 3$ $50.0g = \frac{x}{2^3}$

$400g = x$

9. The half-life of I-131 is 8.07 days. If 25 g are left after 40.35 days, how many grams were in the original sample? (800 g)

$n = \frac{40.35}{8.07} = 5$ $25g = \frac{x}{2^5}$

$x = 800g$

10. If 100.0 g of Au-198 decays to 6.25 g in 10.8 days, what is the half-life of Au-198? (2.7 days)

$6.25 = \frac{100.0}{2^n}$ $\log 2^n = \log 16$ $\frac{n \log 2}{\log 2} = \frac{\log 16}{\log 2}$

$\frac{2^n \cdot 6.25}{6.25} = \frac{100}{6.25}$

$n = 4$ half-lifes

$\frac{10.8}{4} = 2.7$ days

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