ChemQuest 84

# Nuclear Equations

Name: ______________________

Date: ______________

Hour: _____

## Information: Notation

As you know, protons and neutrons reside in the nucleus. The mass number is the total number of protons and neutrons in an atom. We need a notation for describing the nucleus and different particles involved in nuclear reactions. The notation for a uranium-238 nucleus is as follows: $^{238}_{92}U$ .

In the uranium nucleus, there are 92 protons and therefore the charge of the nucleus is +92. There are also 146 neutrons and the mass number is then 238.

## Critical Thinking Questions

1. Given the following notation, how many protons and how many neutrons are in there in this nucleus? $^{99}_{43}Tc$ 43 protons 56 neutrons
2. Write the symbol for a thorium-234 nucleus. $^{234}_{90}Th$
3. A certain nucleus contains 84 protons and 125 neutrons. Write the symbol for this nucleus. $^{209}_{84}Po$

## Information: Alpha Decay

In chemical reactions, atoms rearrange to form new substances. The nuclei of the atoms involved in the reaction remain unchanged.

In a nuclear reaction, it is the nucleus of an atom that gets changed. As you know, there are protons and neutrons in the nucleus. Thus, nuclear changes will involve altering the protons and neutrons.

There are several types of radioactive decay, when the nucleus of an atom spontaneously disintegrates and gives off radiation. One type of radiation is the giving off of an alpha particle. Below, is the equation for uranium-238 decaying by alpha decay. After it decays, the uranium nucleus has turned into a thorium nucleus and an alpha particle is emitted.

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

## Critical Thinking Questions

4. Consider the equation in the information section.
   a) What is element #92 on the periodic table? U
   b) Write the notation for an alpha particle. $^{4}_{2}He$

5. Consider another alpha decay equation: $^{226}_{88}x \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$. What is the symbol that should be at the "x" at the beginning of the reaction? Ra

6. Consider yet another alpha decay equation: $^{99}_{x}Tc \rightarrow {}^{x}_{41}X + {}^{4}_{2}X$. Rewrite the equation without any x's. Fill in the proper numbers or letters to make the equation complete.
   $^{99}_{43}Tc \rightarrow {}^{95}_{41}Nb + {}^{4}_{2}He$

7. You should be able to make a generalized rule about the atomic numbers involved in radioactive decay. Compare the sum of the atomic numbers on the left and right side of the equation. Do the same for the mass numbers. What do you see?
   They are the same on both sides of the arrow

## Information: Other Particles

Nuclei may give off other particles besides alpha particles. Some of the particles have mass numbers and charges and other particles do not. A table listing some particles is given below:

| Name of Particle | Notation |
|---|---|
| Proton | $^{1}_{1}H$ or $^{1}_{1}p$ |
| Neutron | $^{1}_{0}n$ |
| Electron (or "Beta") | $^{0}_{-1}e$ or $^{0}_{-1}\beta$ |
| Positron | $^{0}_{1}e$ or $^{0}_{1}\beta$ |

## Critical Thinking Questions

8. Consider the following nuclear decay: $^{140}_{55}Cs \rightarrow {}^{140}_{56}Ba + {}^{0}_{-1}e$

   a) What kind of radioactive decay is this? Beta

   b) What do you notice about the sums of the atomic numbers on the left and right sides of the equation? They are the same

9. Write the equations for several different kinds of nuclear decay of: $^{223}_{87}Fr$

a) beta decay: $^{223}_{87}Fr \rightarrow ^{0}_{-1}e + ^{223}_{88}Ra$

b) positron decay: $^{223}_{87}Fr \rightarrow ^{0}_{1}e + ^{223}_{86}Rn$

c) alpha decay: $^{223}_{87}Fr \rightarrow ^{4}_{2}He + ^{219}_{85}At$

10. Consider an uranium-238 that goes through two consecutive decays. First, it emits an alpha particle. Then it emits a beta particle emission. Write the two equations and the symbol for the nucleus after the final decay. $^{238}_{92}U \rightarrow ^{4}_{2}He + ^{234}_{90}Th$

$^{234}_{90}Th \rightarrow ^{0}_{-1}e + ^{234}_{91}Pa$

## Information: Types of decay

There are five common types of decay: alpha (α), beta (β), positron ($\beta^+$), electron capture (EC) and gamma (γ) emission. The first three we have already looked at. Electron capture and gamma emission are a little different.

Electron capture (often abbreviated EC) is when an unstable nucleus picks up an electron from an inner orbital of an atom. According to nuclear equations, when the electron collides with a proton, a neutron is formed:

$$^{1}_{1}p + ^{0}_{-1}e \rightarrow ^{1}_{0}n$$

Notice once again that the sum of the atomic numbers on the left equals the sum on the right. The same is true of sum of the mass numbers. Here's an example equation of what happens to the nucleus when a proton is converted to a neutron during electron capture:

$$^{40}_{19}K + ^{0}_{-1}e \rightarrow ^{40}_{18}Ar$$

Gamma emission is a little different. In gamma decay, a gamma photon is released. Often gamma emission occurs very quickly after radioactive decay. The product nucleus is simply a lower-energy state of the original nucleus—there is no change in atomic number or mass number.

## Critical Thinking Questions

11. Write an electron capture equation for $^{42}_{20}Ca$

$^{42}_{20}Ca + ^{0}_{-1}e \rightarrow ^{42}_{19}K$

12. What is the final symbol for the nucleus formed by $^{209}_{84}Po$ after it undergoes alpha decay, then beta, then another alpha, followed by an electron capture?

$^{209}_{84}Po \rightarrow ^{4}_{2}He + ^{205}_{82}Pb$

$^{205}_{82}Pb \rightarrow ^{0}_{-1}e + ^{205}_{83}Bi$

$^{205}_{83}Bi \rightarrow ^{4}_{2}He + ^{201}_{81}Tl$

$^{201}_{81}Tl + ^{0}_{-1}e \rightarrow ^{201}_{80}Hg$

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# More Nuclear Stuff

Name: ______________________

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## Information: Predicting Types of Radioactive Decay

Atoms are stable when they have the right numbers of protons and neutrons. By looking at the average atomic mass for an atom on the periodic table, you can see how many protons and neutrons a stable nucleus has. For example, consider carbon. The average atomic mass is 12.01. Therefore, a carbon atom with 6 protons and 6 neutrons (carbon-12) is predicted to be stable since the mass number of 12 is close to the average atomic mass on the periodic table. However, carbon-14, which has 6 protons and 8 neutrons is not stable because 14 is too far from 12.

The following table is does not contain official rules, but guidelines.

| **Types of radioactive decay:** | **Alpha Emission** | **Beta Emission** | **Positron emission Or Electron Capture** |
|---|---|---|---|
| **When this type of decay occurs:** | When the atomic number is greater than 83. | When the atom appears to have too many neutrons. | When the atom appears to not have enough neutrons. |

Notice that you cannot predict perfectly. For example, an atom that does not have enough neutrons will decay by positron emission or electron capture but we won't know which one until we confirm it in the laboratory.

Again, consider carbon-14. It has an unstable nucleus. It won't decay by alpha emission because the atomic number isn't greater than 83. Will it decay by beta emission or positron/electron capture? Beta emission

## Critical Thinking Questions

1. Consider $^{47}_{20}Ca$ .
   a) Look at calcium on the periodic table, does the calcium-47 nucleus have too many or too few neutrons? too many neutrons
   b) Predict the type of decay and write the reaction. (Note: if you predict positron emission or electron capture, then you need to write BOTH reactions.)

   Beta emission

   $^{47}_{20}Ca \rightarrow ^{0}_{-1}e + ^{47}_{21}Sc$

2. Now consider aluminum-25. Predict the type of decay and write the reaction. (Again, if you predict positron emission or electron capture, then you need to write BOTH—do it that way for the rest of this worksheet.) too few neutrons → positron emission, electron capture

$^{25}_{13}Al + ^{0}_{-1}e \rightarrow ^{25}_{12}Mg$ or $^{25}_{13}Al \rightarrow ^{0}_{1}e + ^{25}_{12}Mg$

3. Predict the type of decay and write the reaction for each of the following nuclei:

a) sodium-26 beta emission $^{26}_{11}Na \rightarrow ^{0}_{-1}e + ^{26}_{12}Mg$

b) francium-223 alpha $^{223}_{87}Fr \rightarrow ^{4}_{2}He + ^{219}_{85}At$

c) niobium-140 alpha $^{140}_{41}Nb \rightarrow ^{4}_{2}He + ^{136}_{39}Y$

d) iron-60 beta emission $^{60}_{26}Fe \rightarrow ^{0}_{-1}e + ^{60}_{27}Co$

e) potassium-35 positron emission or electron capture $^{35}_{19}K \rightarrow ^{0}_{1}e + ^{35}_{18}Ar$ —or— $^{35}_{19}K + ^{0}_{-1}e \rightarrow ^{35}_{18}Ar$

## Information: Transmutation?

"Transmutation" is what the alchemists were trying to accomplish. They wanted to change lead into gold. They were trying all kinds of chemical reactions in an attempt to accomplish this feat. It is impossible to accomplish transmutation using with chemical reactions. Strangely enough, however, it is possible with nuclear reactions. Just about every nuclear reaction you have written so far ends up in a transmutation: a nucleus of one atom changing into a nucleus of a different atom.

Scientists can accomplish transmutation by using nuclear bombardment reactions. In the following reaction, nitrogen-14 is bombarded with alpha particles:

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

There's a special abbreviated notation for this reaction: $^{14}_{7}N\,(\alpha, p)\,^{17}_{8}O$. The notation tells us that an alpha particle ($\alpha$) is transformed to a proton (p) after it bombards the nitrogen nucleus, which is turned into an oxygen-17 nucleus.

Here's another reaction and abbreviated notation: $^{27}_{13}Al(\alpha, n)^{30}_{15}P$. Here, a neutron (n) is produced:

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

## Critical Thinking Questions

4. Given the following nuclear reactions, write the abbreviated notations:

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

b) $^{40}_{20}Ca + ^{4}_{2}He \rightarrow ^{43}_{21}Sc + ^{1}_{1}H$

$^{9}_{4}Be(\alpha, n)^{12}_{6}C$

$^{40}_{20}Ca(\alpha, p)^{43}_{21}Sc$

5. Given the following abbreviated notations, complete the abbreviated notations and then write the nuclear reactions:

a) $^{28}_{14}Si\ (\alpha, p)\ ^{?}_{?}X$

b) $^{?}_{?}X\ (\alpha, n)\ ^{197}_{79}Au$

$^{28}_{14}Si + ^{4}_{2}He \rightarrow ^{31}_{15}P + ^{1}_{1}H$

$^{194}_{77}Ir + ^{4}_{2}He \rightarrow ^{197}_{79}Au + ^{1}_{0}n$