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Exercise #_____: Nuclear Reactions

Nuclear chemistry differs from traditional chemistry because elements are changed from one type into another. To describe the details of this process, isotopic notation is used. In isotopic notation the mass number (*A*) is written as a superscript and the atomic number (Z) is written as a subscript before the element symbol (*E*).

Writing nuclear reactions requires that the atomic number, *Z*, and the mass number, *A*, add up to the same value on each side. In earlier chapters, *Z* stood for the number of protons. In nuclear chemistry it is more general and stands for the charge. (*Note:* Since protons have a +1 charge, this generally does not change anything.) The mass number, *A*, is the sum of protons and neutrons. It is used more generally here as the approximate mass in atomic mass units. The mass of a proton or a neutron is about 1 amu. Each particle of an atom can be written in isotopic notation as follows:

Examples of Particles

beta particle (electron)	${}^{0}_{-1}e$
positron	${}^{0}_{+1}e$
alpha particle	${}^{4}_{2}He$
proton	${}^{1}_{1}H$
neutron	${}^{1}_{0}n$
gamma ray	${}^{0}_{0}\gamma$

Knowing these symbols and their meanings is helpful in understanding nuclear reactions.

Balancing Nuclear Reactions

Two conditions must be met to balance nuclear reactions:

1. The sum of the masses of the reactants must equal the sum of the masses of the products.
   (i.e., the values of A must balance on both sides of the equation.)

2. The sum of the protons for the reactants must equal the sum of the protons for the products.
   (i.e., the values of Z must balance on both sides of the equation.)

There are 4 basic modes of radioactive decay:

- Alpha decay
- Beta decay
- Electron capture
- Positron emission

A 5th mode of radioactive decay, gamma emission, can occur in conjunction with the other four.

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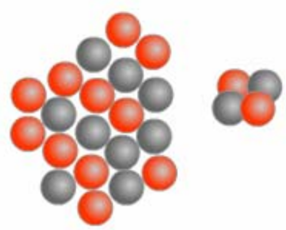
Alpha Decay

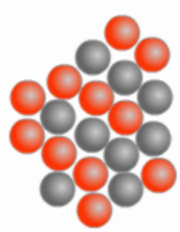
In α-**decay**, an α-particle is ejected from the unstable nucleus of a radioactive element. An α-**particle** consists of two protons and two neutrons, and is identical to the nucleus of a ${}^{4}_{2}\mathbf{He}$ atom. Note that the loss of protons from the radioactive atom results in the formation of a different element.

${}^{24}_{13}\mathrm{Al}$



α-particle decay converts the **Al** nucleus to a **Na** nucleus.

${}^{20}_{11}\mathrm{Na}$



α

α-decay of a nucleus with *n* protons results in a nucleus with an atomic number of (*n*-2).

$${}^{24}_{13}\mathrm{AL} \rightarrow {}^{20}_{11}\mathrm{Na} + {}^{4}_{2}\mathrm{He}$$

Sample Problems could be stated in a variety of ways:

1. Uranium – 238 decays by alpha radiation to produce what other element? **OR**

$${}^{238}_{92}\mathrm{U} \rightarrow {}^{4}_{2}\mathrm{He} + \underline{\qquad\quad}$$

2. What element did we start out with if the result of alpha decay is Lead – 214? **OR**

$$\underline{\qquad\quad} \rightarrow {}^{214}_{82}\mathrm{Pb} + {}^{4}_{2}\mathrm{He}$$

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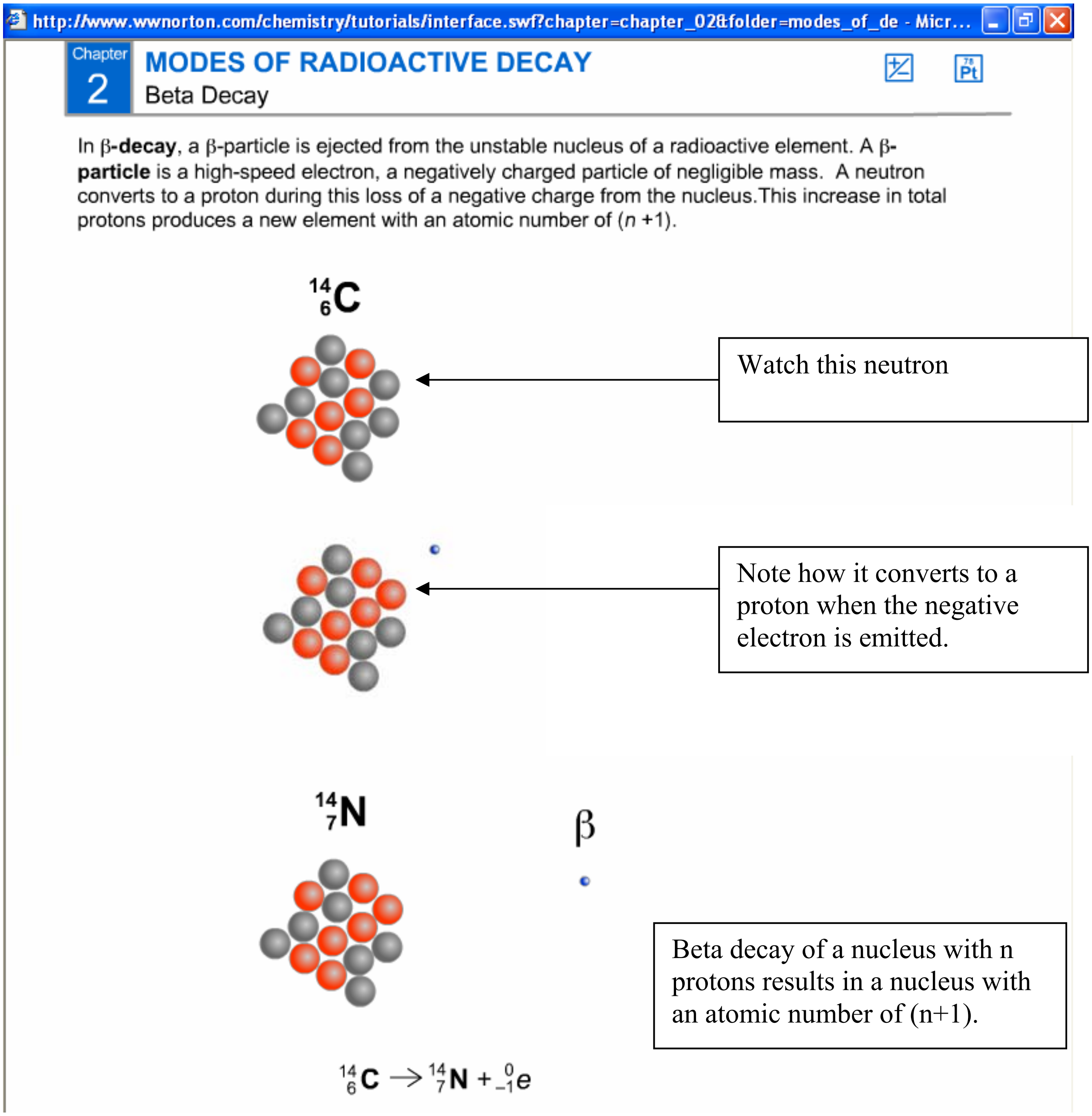

Sample Problems:

1. Thorium – 234 decays by beta radiation to what other element? **OR**

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

2. What element did we start out with if the result of beta decay is bismuth – 214? **OR**

$$\_\_\_\_\_ \rightarrow {}^{0}_{-1}e + {}^{214}_{83}Bi$$

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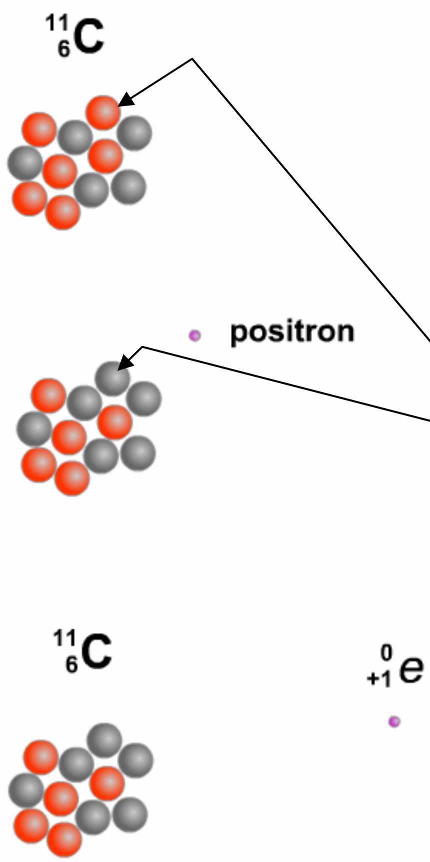
Positron Emission

In **positron emission**, a positron is ejected from the unstable nucleus of a radioactive element. A **positron** is a positively charged particle of negligible mass. A proton converts to a neutron as the positive charge is lost from the nucleus. This decrease in total protons produces a new element with an atomic mass of (*n*-1).



Think of a proton as the sum of a neutrally charged neutron and a positively charged positron.

Note how the top right nucleon, a proton, converts to a neutron when the positron is emitted.

Positron emission in a nucleus with n protons results in a nucleus with an atomic number of (n-1).

$$^{11}_{6}C \rightarrow {}^{11}_{5}B + {}^{0}_{+1}e$$

Sample Problems:

1. Determine how many positrons are emitted during the following decay process:

$$4\,^{1}_{1}H \rightarrow {}^{4}_{2}He + \underline{\qquad\quad}$$

2. What element is produced when nitrogen – 14 is bombarded with an alpha particle and a positron is emitted? OR

$$^{14}_{7}N + {}^{4}_{2}He \rightarrow {}^{0}_{+1}e + \underline{\qquad} .$$

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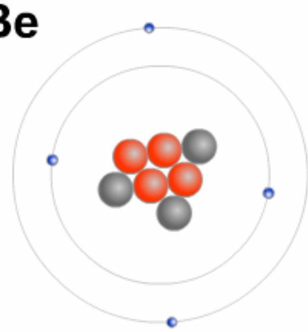
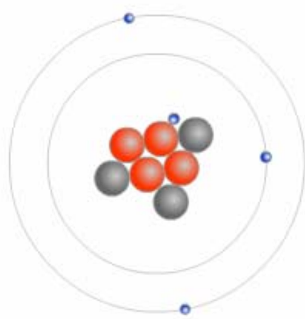
Electron Capture

In **electron capture**, an orbital electron is captured by the unstable nucleus of a radioactive element. The gain of a negative charge from the nucleus means that one proton converts to a neutron. This decrease in total protons produces a new element with an atomic mass of (*n* –1). Note: this reaction emits an uncharged, almost massless, particle called a neutrino.

$^{7}_{4}$Be



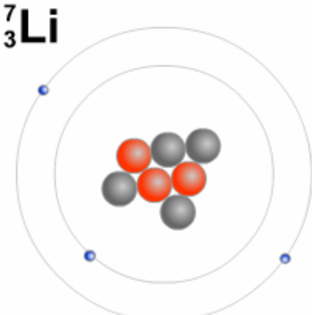
An unstable $^{7}_{4}$**Be** nucleus will undergo electron capture.



Think of the positive charge of the proton being neutralized by the negative charge of the electron, resulting in a neutrally charged neutron.

An electron from the lower orbital can fall into the positively charged nucleus.

$^{7}_{3}$Li



Electron capture of a nucleus with *n* protons results in a nucleus with an atomic number of (*n* –1).

$$^{7}_{4}\mathrm{Be} + ^{0}_{-1}e \rightarrow ^{7}_{3}\mathrm{Li}$$

Sample Problem:

1. What element is produced when mercury – 201 captures an inner shell electron with the production of a gamma ray to release excess energy? **OR**

$$^{201}_{80}\mathrm{Hg} + ^{0}_{-1}\mathrm{e} \rightarrow \_\_\_\_\_ + ^{0}_{0}\gamma$$

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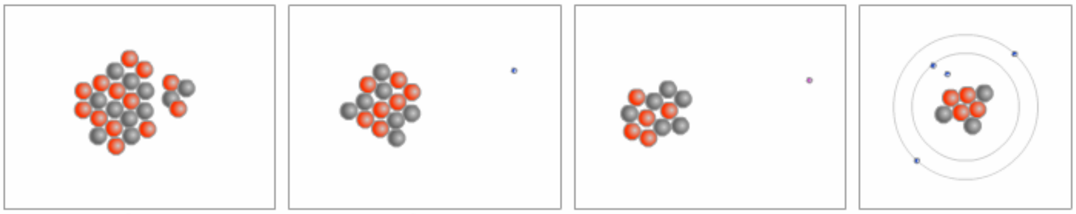
Summary



α-decay | β-decay | positron emission | electron capture

In **α-decay**, an α-particle (identical to a helium nucleus of two protons and two neutrons) is ejected from an unstable nucleus, creating a new element with two fewer protons.

In **β-decay**, a negatively charged electron is ejected from the unstable nucleus, converting a neutron to a proton and creating a new element with one more proton.

In **positron emission**, a positron (like an electron, but with a positive charge) is ejected from the unstable nucleus, converting a proton to a neutron and creating a new element with an atomic number of *n* –1.

In **electron capture**, the orbit of an electron from the lowest orbital decays sufficiently for the electron to be captured by the nucleus. A proton is converted to a neutron, and a new element with an atomic number of *n* –1 is created.

Not all nuclear arrangements of protons and neutrons are stable. Atoms that are formed (inside stars, or in nuclear reactors here on Earth) with unstable proton/neutron ratios will undergo radioactive decay. Four kinds of radioactive decay are **α-decay**, **β-decay**, **positron emission**, and **electron capture**. Some radioactive nuclei are extremely unstable and exist for only a fraction of a second. Others are relatively stable and have half-lives of many years.

Complete the following equations. State the type of decay process at work.

Process

1. ${}^{195}_{79}\mathrm{Au} + {}^{0}_{-1}\mathrm{e} \rightarrow$ ____   ____________________

2. ${}^{135}_{53}\mathrm{I} \rightarrow {}^{135}_{54}\mathrm{Xe} +$ ____   ____________________

3. ${}^{59}_{27}\mathrm{Co} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{56}_{25}\mathrm{Mn} +$ ____   ____________________

4. ${}^{38}_{19}\mathrm{K} \rightarrow$ ____ $+ {}^{0}_{1}\mathrm{e}$ ____________________

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