Atoms consist of protons, neutrons, and electrons.

The isotope, carbon-12 ($^{12}_{6}C$), contains 6 protons and 6 neutrons.
Carbon-13 (^{13}C) contains 6 protons and 7 neutrons.
Carbon-14 (^{14}C) contains 6 protons and 8 neutrons.

Recall to add the number of protons (Z) and the number of neutrons to get the mass number (A). Except for the least massive element, hydrogen, the number of neutrons equals or exceeds the number of protons in stable nuclei to help reduce repulsive forces.

A *nuclide* refers to a nucleus with a specific number of protons and neutrons, while the term, *nucleons*, refers to protons and neutrons together. The nuclide symbol (Sy) is written as follows: $^{A}_{Z}Sy$. So, $^{12}_{6}C$ has Z=6 protons and the neutrons would be A-Z = 12-6= 6.

When writing a nuclear chemical equation, the mass numbers and atomic numbers must be the same on both sides of the equation.

The following are selected types of emissions from a radioactive nucleus (radioactive decay) that can be used to balance nuclear reactions.

Name	Atomic number	Mass number	Symbol	Charge
Alpha particle	2	4	$^{4}_{2}\alpha$	+2
Beta particle	-1	0	$^{0}_{-1}\beta$ or β^{-}	-1
Gamma ray	0	0	$^{0}_{0}\gamma$	0
Positron	1	0	$^{0}_{1}\beta$ or β^{+}	+1

The alpha particle is two protons and two neutrons that leave a nucleus with high energy. Skin, paper, and clothing are typically enough to stop alpha particles from radioactive decay. An alpha particle has the same composition as the nucleus of a helium-4 atom. After an alpha particle captures two electrons, it becomes a helium-4 atom. When those electrons are taken by the alpha particle, some other target loses those two electrons and becomes ionized (positively charged). If that target happens to be a living organism, chemical reactions continue to occur (the basis of mutation) until those two electrons are found somewhere else.

The beta particle is an electron that leaves the nucleus with high energy. If this high energy electron collides with living matter, it can be captured and/or eject electrons from molecules causing chemical reactions to occur (the basis of mutation). Beta particles can be stopped with a few millimeters of metal, such as aluminum (though this is not a preferred material), or with thicker amounts of wood, plastic, concrete or water. The penetrating distance of beta particles depends on the nuclide that generated it, but this penetrating distance can range from the skin surface to centimeters of flesh.

The gamma particle is high energy light with no rest mass and no charge. If a gamma particle collides with living matter, it can impart enough energy for matter to lose electrons possibly causing unwanted chemical reactions to occur (the basis of mutation). Thick shielding of lead, soil, or concrete is needed to reduce gamma rays. Because of the high penetrating power of gamma rays, damage can occur anywhere in the body.

Nuclear reactions may also occur by electron capture, where the nucleus captures an electron from one of the innermost shells. Because the electron that is captured is a reactant in the nuclear reaction electron capture is discussed separately from the others.

Name	Atomic number	Mass number	Symbol	Charge
Electron capture	-1	0	${}^{0}_{-1}e$ or e^-	-1

Electron capture, like the other decay modes, can result in x-ray radiation being released. Like gamma rays, x-rays have no mass or charge, but they do have enough energy to penetrate and ionize matter. If this happens in living tissue, it can cause unwanted chemical reactions.

This section gives example nuclear reactions. Note that other emissions may occur with these nuclear reactions, but you can ignore these other emissions at this level of study. If you are given the extra particles and/or emissions in the future, use the masses and atomic numbers of these emissions to build upon the simplified analysis provided below.

Alpha decay, Alpha emission (${}^{4}_{2}\alpha$).

Q. Radium-226 decays by what type of emission to produce radon-222?

A. Write the nuclear chemical equation to answer the question, an alpha particle. You must remember that an alpha particle has Z=2 and A=4 to write the equation. Use the periodic table to look up Z for radium and radon.

For Z, 88= 2 + 86. For A, 226= 4 + 222

$${}^{226}_{88}Ra \rightarrow {}^{4}_{2}\alpha + {}^{222}_{86}Rn$$

Q. Uranium-238 decays by alpha emission to produce what other product?

A. Write the nuclear chemical equation to answer the question, thorium-234.

For Z, 92= 2 + 90. For A, 238= 4 + 234. Look up Z=90 to see that it is thorium.

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

Q. Americium-241 decays by alpha emission to produce what product?

A. Write the nuclear chemical equation to answer the question, neptunium-237.

For Z, 95= 2 + 93. For A, 241= 4 + 237, so Z=93 and A=237.

$${}^{241}_{95}\text{Am} \rightarrow {}^{4}_{2}\alpha + {}^{237}_{93}\text{Np}$$

Beta decay, Beta emission (${}^{0}_{-1}\beta$).

Q. What isotope decays by beta emission to produce nitrogen-14?

A. Write the nuclear chemical equation to answer the question, carbon-14.

For Z, 6= -1 + 7. For A, 14 = 0 + 14, so Z=6 and A=14.

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

Q. What is the other product when potassium-40 decays to produce calcium-40?

A. Write the nuclear chemical equation to answer the question, a beta particle.

For Z, 19= -1 + 20. For A, 40 = 0 + 40. The particle has Z=-1 and A=0, a beta particle.

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

What happens is that a neutron (n) in potassium-40 loses an electron to become a proton (p) in calcium-40. The mass number remains unchanged, but the number of protons goes up by one.

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

Gamma decay, Gamma ray emission (${}^{0}_{0}\gamma$).

Gamma ray (or x-ray) emission may accompany other nuclear reactions. The emission of a gamma ray allows the nucleus to release energy. An example of gamma-ray emission with no other particles is an isomeric transition. With an isomeric transition, the starting isotope is often indicated with a * or m (metastable) to indicate that there is excess energy.

Q. Technetium-99m decays by gamma ray emission to produce what other product?

A. Write the nuclear chemical equation to answer the question, technetium-99.

For Z, 43= 0 + 43. For A, 99 = 0 + 99. The product has the same mass number and atomic number as the starting material.

$${}^{99}_{43}\text{Tc}^{*} \rightarrow {}^{0}_{0}\gamma + {}^{99}_{43}\text{Tc}$$

Electron capture (${}^{0}_{-1}$e or e^{-}).

Q. What is the other product when beryllium-7 decays by electron capture?

A. Write the nuclear chemical equation to answer the question, lithium-7.

For Z, 4= -1 + 3. For A, 7 = 0 + 7. The product has Z=3 and A=7. Look up Z=3 on the periodic table.

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

What happens is that a proton (p) in beryllium-7 captures an electron to become a neutron (n) in lithium-7. The mass number remains unchanged, but the number of protons goes down by one.

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

Positron emission (${}^{0}_{1}\beta$).

Q. What is the other product when carbon-11 decays by positron emission?

A. Write the nuclear chemical equation to answer the question, boron-11.

For Z, 6= 1 + 5. For A, 11 = 0 + 11. The product has Z=5 and A=11.

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

What happens is that a proton (p) in carbon-11 loses an positron to become a neutron (n) in boron-5. The mass number remains unchanged, but the number of protons goes down by one.

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

Q. What is the other product when carbon-11 decays by positron emission to produce a neutrino (${}^{0}_{0}v$)?

A. Write the nuclear chemical equation to answer the question, boron-11.

For Z, 6= 1 + 5 + 0. For A, 11 = 0 + 11 + 0. The product has Z=5 and A=11.

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

Half life

The half life is the time it takes for half of the initial sample to disappear. Half life is useful for radioactive decay because it also describes the time for the radioactivity of a sample to drop by half. Each half life that passes drops the radioactive emissions by half, so after 2 half lives have passed, the radiation would be 1/4 of its initial value.

Q. How long would it take 8mg of beryllium-7 to decay to 2mg by electron capture if the half life was 53 days.

A. After 1 half life, 4mg remain. After 2 half lives 2mg remain. 2 half lives is 106 days.

Q. How many half lives would it take 32mg of beryllium-7 to decay to 2mg by electron capture if the half life was 53 days.

A. Make a table to determine that it is after 4 half lives.

half lives	mass remaining
0	32mg
1	16mg

2	8mg
3	4mg
4	2 mg