POGIL Activity: Types of Radiation

Summary

Atoms can form ions by either gaining or losing electrons. When an atom gains one or more electrons it has a negative charge and is called an anion. When an atom loses one or more electrons it has a postive charge and is called a cation. Ionization is when an atom is struck with enough energy to knock an electron off of it, causing it to have a +1 charge. If an atom absorbs a photon with enough energy then ionization will occur.

Radiation is any form of energy or particles that starts in a center and moves outwards. Examples include all forms of light (also called electro-magnetic radiation) and alpha particles and beta particles. Some forms of radiation are non-ionizing: they cannot cause any atoms or molecules to lose an electron. These include radio waves, microwaves, infrared light and visible light. All of these forms of radiation are made of photons traveling at the speed of light. You should not look directly at the Sun because the light from the Sun is so bright it can burn your eyes and blind you. This is not because it is ionizing but because it is so intense.

Another category for radiation is called ionizing radiation. This is radiation that is energetic enough to knock electrons loose from atoms it hits. Some forms of electromagetic radiation are ionizing: ultraviolet, x-rays, and gamma rays. These forms of light have such short wavelengths, and such large energies, that they can ionize atoms. Another form of radiation is made of massive particles (photons do not have any mass). There are two kinds: alpha-particles and beta-particles. Alpha-particles are high-speed helium-4 nuclei with a mass of 4 amu and a charge of +2. Once an alpha-particle loses its very high speed and gains two electrons it becomes an ordinary atom of helium, which has two protons and two neutrons in its nucleus. Beta-particles are high-speed electrons with a mass of 5.49×10^{-4} amu and a charge of –1. All forms of ionizing radiation are capable of damaging DNA and causing mutations. Ultraviolet light from the Sun causes sun burns because it ionizes atoms in the skin, causing damage. Only gamma-rays, alpha-particles, and beta-particles are considered nuclear radiation because they are the only forms that come out of atomic nuclei. Nuclear radiation is dangerous but so are x-rays and ultraviolet light because they, too, can cause ionization.

POGIL Activity: Types of Radioactive Decay Summary

Some important words in this activity need to be defined. First, **emit**, which means to give off or send out. **Absorb** means to take in and become one thing. The **parent nucleus** is the unstable atomic nucleus before it decays. The **daughter nucleus** is the same atomic nucleus after it has decayed. Usually the daughter nucleus is a different element from the parent nucleus.

Some kinds of ionizing radiation are electro-magnetic waves. Specifically, ultraviolet light, x-rays and gamma rays. Another kind of ionizing radiation has a mass and a charge. This kind of radiation is made of particles and they are emitted from an unstable atomic nucleus.

One type of nuclear decay releases something called an alpha-particle. An alpha-particle (or α-particle) is the nucleus of a helium-4 atom. It has a mass number of 4 and an atomic number of 2. Its atomic sybmol is either ${}^{4}_{2}\alpha$ or ${}^{4}_{2}He$. When it is first emitted it has a +2 electric charge. When a nucleus decays by alpha decay it releases an alpha-particle and its mass decreases by 4 and its atomic number decreases by 2. The number of protons in the original nucleus is reduced by 2 and the number of neutrons is also reduced by 2.

Another type of nuclear decay releases something called a beta-particle. A beta-particle (or β-particle) is an electron and its mass is 5.49×10^{-4} amu and it has an electric charge of –1. The atomic symbol for a beta-particle is either ${}^{0}_{-1}\beta$ or ${}^{0}_{-1}e^{-}$. It has a mass number of zero because it has a mass much smaller than 1 amu. The mass number counts up protons and neutrons and an electron is neither of these. It has an atomic number of –1 because it has a charge of –1. Atomic number is really the number of positive charges in an atomic nucleus and although an electron is not a nucleus it does have a charge. During beta decay a nucleus does not change its mass number. The atomic number increases by 1. The number of neutrons is decreased by 1 and the number of protons is increased by 1. According to the picture in the activity a neutron is changed into a proton.

A third type of nuclear decay releases a gamma ray. A gamma ray (or γ-ray) is a photon with a very small wavelength and a very large energy. When a nucleus emits a gamma ray photon the number of protons and neutrons remains the same. The photon is simply an amount of energy that matches the difference between two energy levels within an atomic nucleus.

A fourth type of nuclear decay releases a positron from an unstable atomic nucleus. A positron is a particle of anti-matter and it is the anti-matter partner of an electron. It has the same mass as an electron but a +1 electric charge. The atomic symbol for a positron is either ${}^{0}_{+1}\beta^{+}$ or ${}^{0}_{+1}e^{+}$. It is also called a beta-plus-particle. Its mass number is zero because, like an electron, its mass is very small compared to even a single proton or neutron. Its atomic number is +1 because it has a positive charge, just like a proton. During positron decay a nucleus does not change its mass number. The atomic number decreases by 1. The number of protons is decreased by 1 and the number of neutrons is increased by 1. According to the picture in the activity a proton is changed into a neutron.

The fifth and final type of radioactive decay in the activity is called electron capture. In electron capture a proton in an unstable atomic nucleus absorbs an electron and becomes a neutron. When using symbols to describe electron capture the symbol ${}^{0}_{-1}e^{-}$ is used for the electron.During electron capture decay the mass number of the nucleus does not change. The atomic number decreases by 1. The number of protons decreases by 1 and the number of neutrons increases by 1. Electron capture is similar to positron decay in its effects but happens by another path. Electron capture is different from the other decay modes because it involves the nucleus absorbing something instead of emitting something. For the actual event in which a nucleus captures an electron nothing observable happens so without chemical analysis to identify the elements in a sample it would not be detected.

Based on this activity it is possible to conclude that sometimes protons in unstable nuclei can become neutrons. Also, sometimes neutrons can become protons. In beta decay a neutron becomes a proton. In both positron decay and electron capture decay a proton becomes a neutron.

POGIL Activity: Alpha and Beta Decay

Summary

When a nucleus of the unstable isotope polonium-211 decays it does so by alpha decay. After some random amount of time it emits an alpha-particle and becomes lead-207. The alpha-particle is a helium-4 nucleus, with 2 protons and 2 neutrons. Its atomic symbol is $^{4}_{2}He$. The polonium-211 nucleus is different after it decays because it now has 2 fewer protons and 2 fewer neutrons. The result has to be lead-207 because lead has 2 fewer protons than polonium and with a mass number of 207 it must have 2 fewer neutrons, too. If the nucleus of a ^{40}K atom were to undergo alpha decay it would become ^{36}Cl.

The amount of time it takes for a single atom to decay is random. Unstable nuclei do not all decay at once but do so at random times. On average, though, a group of atoms will have half of their number decay before a certain amount of time has passed. This amount of time is called the half-life. After one half-life, half of the nuclei will be left. After a stretch of time equal to two half-lives, one quarter of the nuclei will remain. At that time, three quarters will have decayed.

Radioactive materials do not stay radioactive forever. Once a nucleus decays to become a stable nucleus it no longer changes.

If you have a larger group of unstable nuclei you will see more decay events per second than in a smaller group. Each atom decays at a random time but in a bigger group there are more atoms so for a short period of time there is a higher probability that a nucleus will decay. A larger sample of a radioactive material shows more radioactivity than a smaller sample.

When a nucleus of the unstable isotope hydrogen-3 decays it does so by beta decay. After some random amount of time it emits a beta-particle and becomes helium-3. The beta-particle is an electron and its atomic symbol is $^{0}_{-1}e^{-}$. The hydrogen-3 nucleus is different after it decays because one of the neutrons in that nucleus has been transformed into a proton. Because the number of particles in the nucleus is the same the mass number remains 3 but the atomic number increases by 1 and the nucleus become helium, which has two protons. If a nucleus of ^{14}C were to decay by beta-decay it would become ^{14}N.

The half-life of hydrogen-3 (also called tritium) is about 12 years.

POGIL Activity: Nuclear Equations

Summary

In this activity we reviewed some facts about istopes and radioactive decay modes. Isotopes are different versions of atoms of the same element. The isotopes of an element have the same number of protons but different numbers of neutrons. Some isotopes are stable and do not decay. Some isotopes are unstable and their nuclei undergo nuclear decay to become a different isotope of a different element. To talk about isotopes it's useful to use a symbol. In this symbol ($^{A}_{Z}X$) the X stands for the atomic symbol, the A stands for the mass number (which is the sum of protons and neutrons in the nucleus) and Z stands for the atomic number (which is just the number of protons). Mass number can be calculated using a simple mathematical formula: $A = Z + n^0$, where n^0 stands for the number of neutrons. Isotopes each have their own, individual names. Since isotopes have different numbers of neutrons they have different mass numbers. The name of an isotope is the name of the element followed by the mass number, like this: calcium-40 or calcium-42. Calcium-40 has 20 protons (as all calcium atoms do) and 20 neutrons. This is because $A – Z = n^0$. Similarly, calcium-42 has 20 protons and 22 neutrons.

Alpha decay is when an unstable atomic nucleus ejects an alpha particle. An alpha particle is an extremely high-speed helium-4 nucleus with 2 protons, 2 neutrons, and no electrons. When an atom decays by alpha decay its atomic number decreases by 2. The mass number decreases by 4. The atomic symbol for a alpha-particle is $^{4}_{2}He$.

Beta decay is when an unstable atomic nucleus ejects a beta particle. A beta particle is an extremely high-speed electron. Inside the nucleus a neutron, which is the origin of the electron, becomes a proton. As a result a nucleus that decays by beta decay keeps the same mass number but the atomic number increases by 1. The atomic symbol for a beta-particle is $^{0}_{-1}\beta^{-}$.

Positron decay is when an unstable atomic nucleus ejects a positron. A positron is an extremely high-speed anti-electron. Inside the nucleus a proton, which is the origin of the positron, becomes a neutron. As a result a nucleus that decays by positron decay keeps the same mass number but the atomic number decreases by 1. The atomic symbol for a positron is $^{0}_{+1}\beta^{+}$.

Electron capture decay is when an unstable atomic nucleus absorbs an electron. The orbitting electron that is absorbed joins up with a proton and together they become a neutron. As a result a nucleus that decays by electron capture keeps the same mass number but the atomic number decreases by 1. The atomic symbol for the electron that is absorbed is $^{0}_{-1}e^{-}$.

Nuclear equations are a way to represent a nuclear process using symbols. They follow two rules. First, the sum of the mass numbers for all particles on the left side of the arrow must equal the sum of the mass numbers on the other side. Second, the sum of the atomic numbers for all particles on the left side of the arrow must equal the sum of the atomic numbers on the other side. At right are some example radioactive decay equations.

1. $^{208}_{84}Po \rightarrow\ ^{4}_{2}He +\ ^{204}_{82}Pb$
2. $^{14}_{6}C \rightarrow\ ^{14}_{7}N +\ ^{0}_{-1}\beta^{-}$
3. $^{50}_{25}Mn \rightarrow\ ^{50}_{24}Cr +\ ^{0}_{+1}\beta^{+}$
4. $^{81}_{36}Kr +\ ^{0}_{-1}e^{-} \rightarrow\ ^{81}_{35}Br$

Nuclear equations can also be used to describe other things besides nuclear decay. First, they can be used to describe nuclear fission. Fission is when an atomic nucleus splits into two smaller atomic nuclei. Second, nuclear fusion, which is when two small atomic nuclei combine to make a single, larger nucleus. And third, artificial transmutation is when atomic nuclei are smashed together at high speeds, resulting in a nucleus becoming a different element. In this activity we learned how to write balanced nuclear equations for all of these things.

Here is an example equation for nuclear fusion: $^{2}_{1}H +\ ^{3}_{1}H \rightarrow\ ^{4}_{2}He +\ ^{1}_{0}n^{0}$. Here is an example equation for transmutation: $^{4}_{2}He +\ ^{14}_{7}N \rightarrow\ ^{17}_{8}O +\ ^{1}_{1}H$.

And here is an example equation for nuclear fission: $^{235}_{92}U +\ ^{1}_{0}n^{0} \rightarrow\ ^{141}_{56}Ba +\ ^{92}_{36}Kr + 3\ ^{1}_{0}n^{0}$.