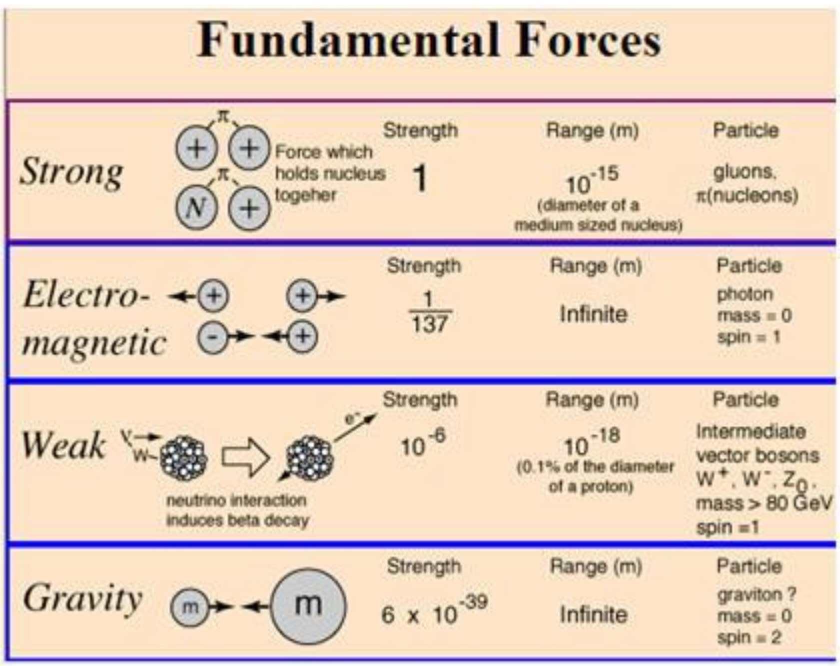
# Unit 8 Nuclear Radiation Parent Guide

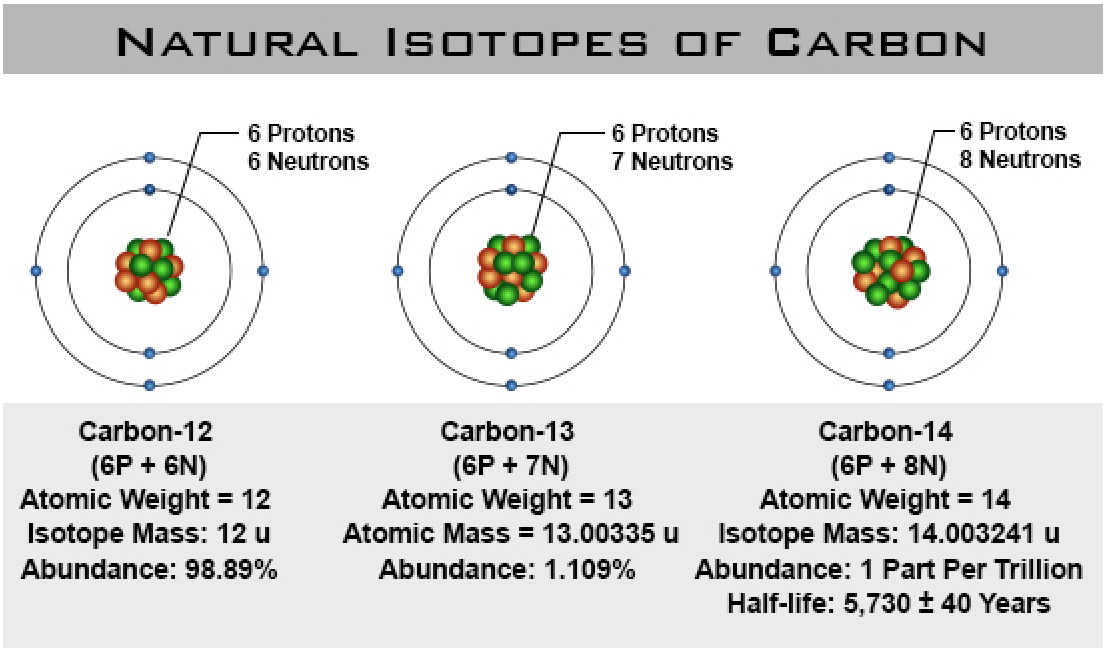
***What is radioactivity and why are things radioactive?***

The nucleus of an atom is comprised of subatomic particles called protons and neutrons. Protons have a positive charge and have a mass of 1 atomic mass unit (a.m.u.). Neutrons have no charge and also have a mass of 1 a.m.u. Because protons have a positive charge there exists an electrical repulsion among them. This repelling force must be overcome to keep the protons within close proximity (to keep them in the nucleus and keep the nucleus together). The force responsible for keeping the nucleus together is called the strong nuclear force. Without this force, protons could not be near each other. An atom's nucleus is unstable when there is not enough energy to overcome the repelling force of the protons; under this condition, the nucleus is unstable and therefore the atom is said to be radioactive. Radioactivity is the process by which an atom's nucleus decays and in doing so emits either particles and/or energy from the nucleus.




***What is a radioisotope?***

Not all atoms are radioactive. Radioisotopes are atoms of an element that possess an unstable nuclei. An isotope is an atom of an element that differs in its number of neutrons. For example, Carbon-12 has six neutrons and Carbon-14 has eight neutrons. Both atoms have the same number of protons and have similar chemical properties. Isotopes that are unstable, thus radioactive, are called radioisotopes.



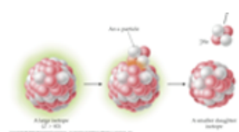

***What happens during decay?***

<u>Types of nuclear decay.</u> During radioactive decay, the nucleus of an atom emits particles and/or energy. The three main forms of nuclear decay are alpha particles, beta particles and/or gamma rays. During alpha decay, a particle that is the same size as the nucleus of a Helium atom is emitted from the nucleus of a radioisotope. In doing so, a new element is formed whose atomic number has decreased by 2 and atomic mass decreased by 4. Alpha particles possess an overall positive charge. During beta decay, a particle the same size as an electron is emitted from the nucleus. When a neutron in the nucleus of the atom undergoes a transformation and breaks down, it emits the beta particle and a proton remains in the nucleus. Thus the atomic number of the atom increases by 1, forming a new element. Because an electron has effectively no mass, the atomic mass of the new element is the same as the atom prior to decay. Since the beta particle is so small, it leaves the nucleus at high rates of speed. Gamma emission does not change the atom into a new element. Since a gamma ray is a form of energy rather than a particle, it does not change either the mass or the atomic number of the element. Gamma radiation is a very high-energy form of electromagnetic radiation. It is ionizing in that it has enough energy to remove electrons from otherwise stable atoms. In doing so, gamma rays create ions as they interact with other atoms. This gamma radiation is powerful enough to change the way DNA replicates and can cause cellular damage to biological systems. The ions that are created by gamma rays also have the ability to cause cellular damage. Typically gamma decay is associated with either alpha or beta decay.

| Type of Radiation | Symbol | Composition | Effect of Emission on | |
|---|---|---|---|---|
| | | | Atom No. | Atomic Wt. |
| Alpha Particle | ${}^{4}_{2}\alpha$ | 2 Protons<br>2 Neutrons | Decrease 2 | Decrease 4 |
| Beta Particle | ${}^{0}_{-1}e$<br>or<br>${}^{0}_{-1}\beta$ | High Speed Electron | Gain 1 | No Change |
| Gamma Ray | ${}^{0}_{0}\gamma$ | Form of Electro–magnetic Energy Similar to X-ray | No Change | No Change |

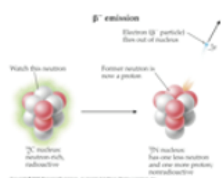
Nuclear decay reactions. When an unstable nucleus undergoes decay, new products can be formed. Below you can see a few examples of this nuclear process.

**Alpha emission**



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

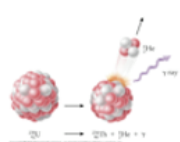
**Beta emission**



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

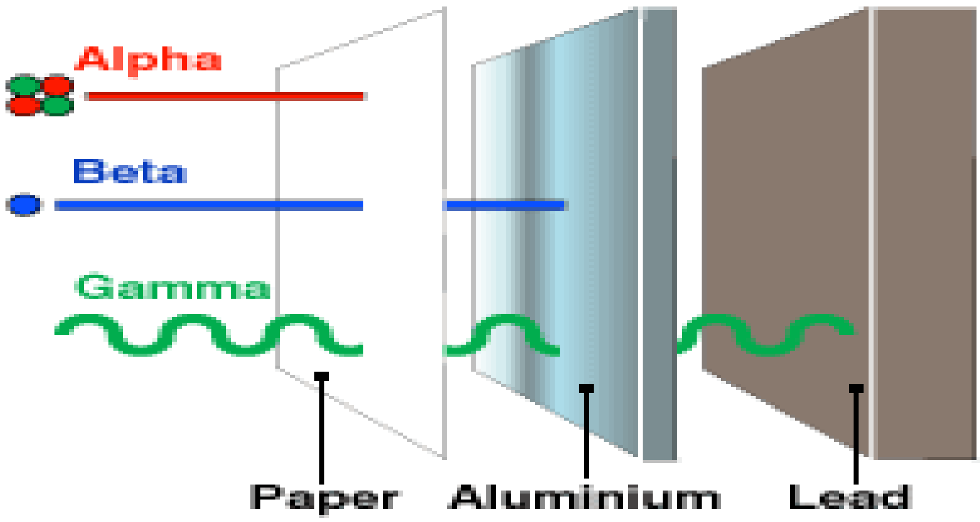
$${}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e$$

**Gamma emission**



$${}^{0}_{0}\gamma$$

Shielding nuclear decay. Another aspect of nuclear reactions is to exam the ability of the three main decay products to penetrate materials or be shielded. Because of an alpha particle's relatively large size and short range of motion, alpha particles are the most easily shielded type of nuclear decay. Wearing a mask to prevent inhaling an alpha particle can prevent alpha particles from readily entering the body. Beta particles are much smaller and travel a little farther. Their size makes them more difficult to shield but since they are a particle, material that is relatively dense (such as a sheet of aluminum) can stop a beta particle. Gamma radiation is very difficult to shield. Only very dense materials like lead or thick materials like several inches of concrete will stop a gamma ray. Gamma rays can easily penetrate through the human body and as they pass through, the more dense tissue (bones) will absorb some of the energy.

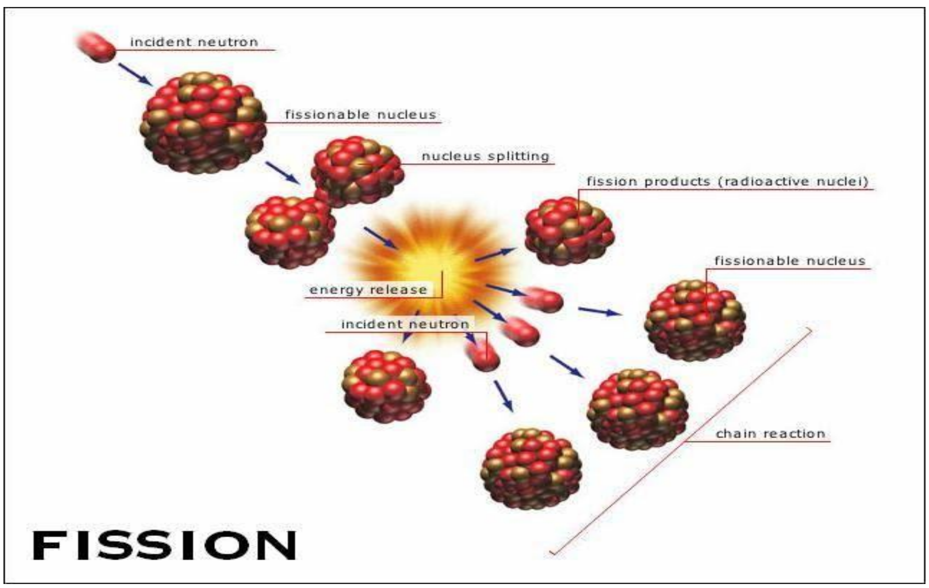



Biological effects. Alpha, beta and gamma decay are all ionizing which can cause harm to tissue. Generally speaking, radiation exposure does one of three things- nothing, cause mutations, or cause cellular death. There are many variables that influence the severity of cellular damage when exposure occurs. As seen in the chart below, there is no single factor that determines the extent of radiation damage.

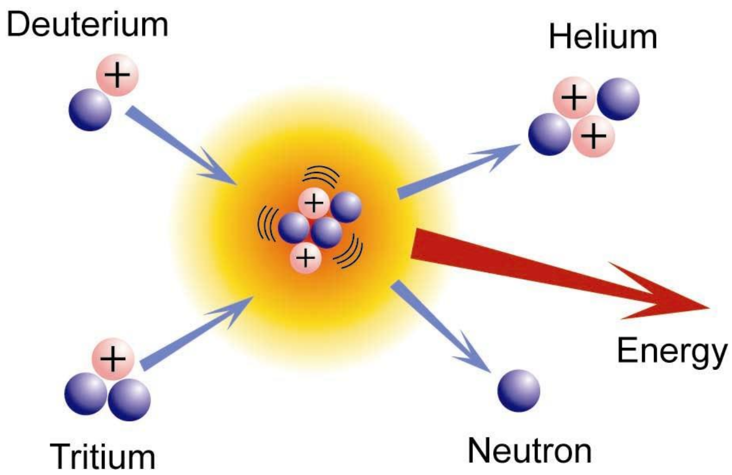
| |
|---|
| **Radiation Factors** |
| Dose |
| Dose rate |
| Volume of tissue irradiated |
| Type and quality of radiation |
| **Patient Factors** |
| Presence of other medical conditionsa (eg, homozygosity for ataxia telangiectasia mutation gene, autoimmune disease, diabetes [although some debate exists], previous history of diagnostic or therapeutic irradiation) |
| Individual susceptibility |
| Age |

***What is the difference between fission and fusion?***

The nucleus of an atom can be changed in one of two primary ways. During the process of fission, a large, unstable nucleus splits/decays into smaller daughter nuclei. The process is initiated with a neutron. Upon splitting, large amounts of energy are released as well as smaller nuclei that are radioactive. Because more neutrons are released as well, if there exists a critical mass of material capable of undergoing fission, a chain reaction can occur and thus continuous nuclear reactions (chain reaction) will occur (unless moderated or controlled). Fission is most commonly used in reactors to produce energy/electricity. Because such a small amount of fuel is needed to produce large quantities of energy, nuclear energy is an attractive way to produce electricity. Safety concerns and waste disposal issues are the primary reasons that prevent wide acceptance of the use of nuclear energy.




Fusion occurs when smaller nuclei are fused/combined into larger nuclei. This process occurs under very energetic conditions (very high temperatures and extreme pressures), therefore this process naturally occurs only in stars like our Sun. The process, like fission, yields large quantities of energy (actually 3-4 times more than fission) yet has fewer radioactive by-products.



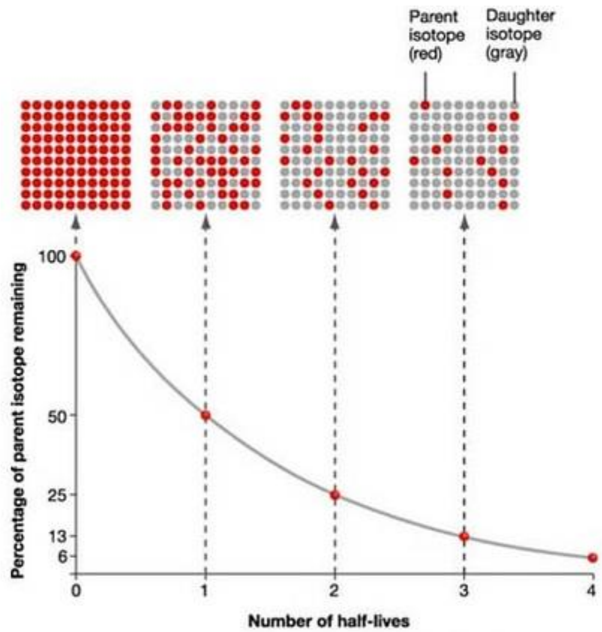

Using the mass-energy equivalence equation (Einstein's famous equation), $E = mc^2$, scientists have recognized that large quantities of energy can be obtained from the conversion of mass into energy. Not only that, relatively small amounts of mass (fuel) are needed.

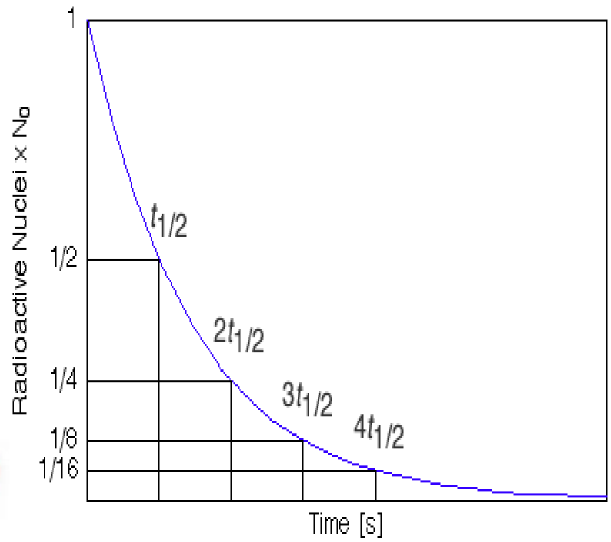
***How long is a radioisotope radioactive?***

Half-life. All radioisotopes are radioactive. But not all radioisotopes decay at the same rate. The rate of decay is called half-life. As the term implies, half-life is the time during which a radioisotope will become half as radioactive as it previously was. During this time period, half of the remaining nuclei will undergo decay. Half-life is specific for each radioisotope. For example C-14 has a half-life of 5,570 years whereas Rn-220 has a half-life of 52 seconds. Exposure to extreme temperatures or pressure or excessive electromagnetic radiation will not alter the half-life of a radioisotope. Since many radioisotopes are used for medical purposes, it is useful to know the half-life (and type of decay) to be able to determine how much exposure a patient will receive during the treatment process.

| Isotope | Half life | Decay constant ($s^{-1}$) |
|---|---|---|
| Uranium 238 | $4.5\times10^{9}$ years | $5.0\times10^{-18}$ |
| Plutonium 239 | $2.4\times10^{4}$ years | $9.2\times10^{-13}$ |
| Carbon 14 | 5570 years | $3.9\times10^{-12}$ |
| Radium 226 | 1622 years | $1.35\times10^{-11}$ |
| Free neutron 239 | 15 minutes | $1.1\times10^{-3}$ |
| Radon 220 | 52 seconds | $1.33\times10^{-2}$ |
| Lithium 8 | 0.84 seconds | 0.825 |
| Bismuth 214 | $1.6\times10^{-4}$ seconds | $4.33\times10^{3}$ |
| Lithium 8 | $6\times10^{-20}$ seconds | $1.2\times10^{19}$ |

Visualizing half-life. The graph below on the left can illustrate what percentage of a radioisotope remains after each half-life. So after 2 half-lives, 25% of the remaining nuclei are radioactive. The graph to the right illustrates the fractional amount of radioactive material remains per half-life. So after 2 half-lives, one-quarter of the nuclei are radioactive.




<u>Calculating using half-life.</u> There are several ways to use half-life to determine a quantity or to determine the half-life of a radioisotope based on the change in quantity over time. The most basic method is show each half-life as an individual step in which the original amount is divided in half for each half-life the sample undergoes. Students can take the original amount and continue to divide until their either reach a pre-determined final amount (I.e. 0.0977 grams), a set number of half-lives (I.e. 10 half-lives) or a set amount of time (I.e. 150 years).

**Let's mathematically examine the half-life of 100 grams of DDT.**

| End of Half life cycle | 1 15 yrs | 2 30 yrs | 3 45 yrs | 4 60 yrs | 5 75 yrs | 6 90 yrs | 7 105 yrs | 8 120 yrs | 9 135 yrs | 10 150 yrs |
|---|---|---|---|---|---|---|---|---|---|---|
| Grams of DDT remaining | 50 | 25 | 12.5 | 6.25 | 3.125 | 1.5625 | .78125 | .390625 | .1953125 | .09765625 |