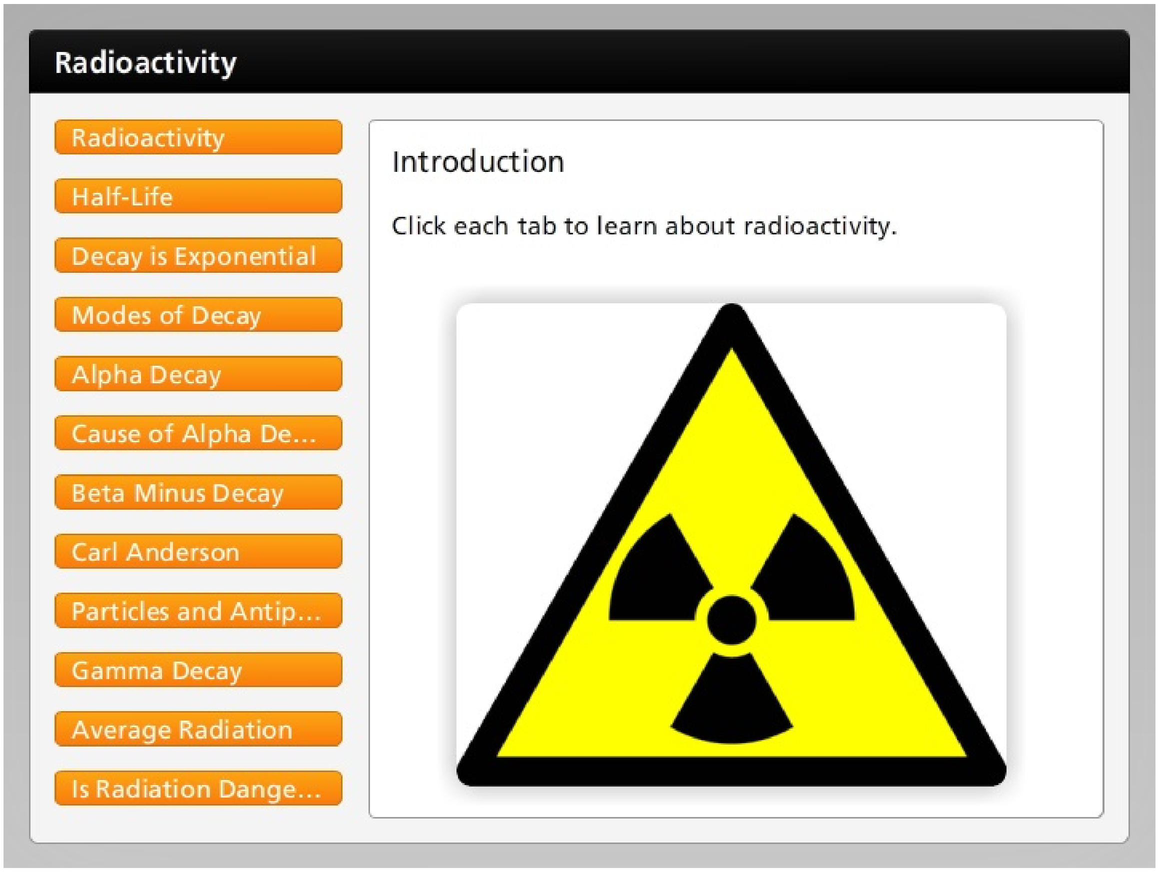
Module 8: 20th Century Physics
Topic 4 Content: Radioactivity

Introduction



Click each tab to learn about radioactivity.

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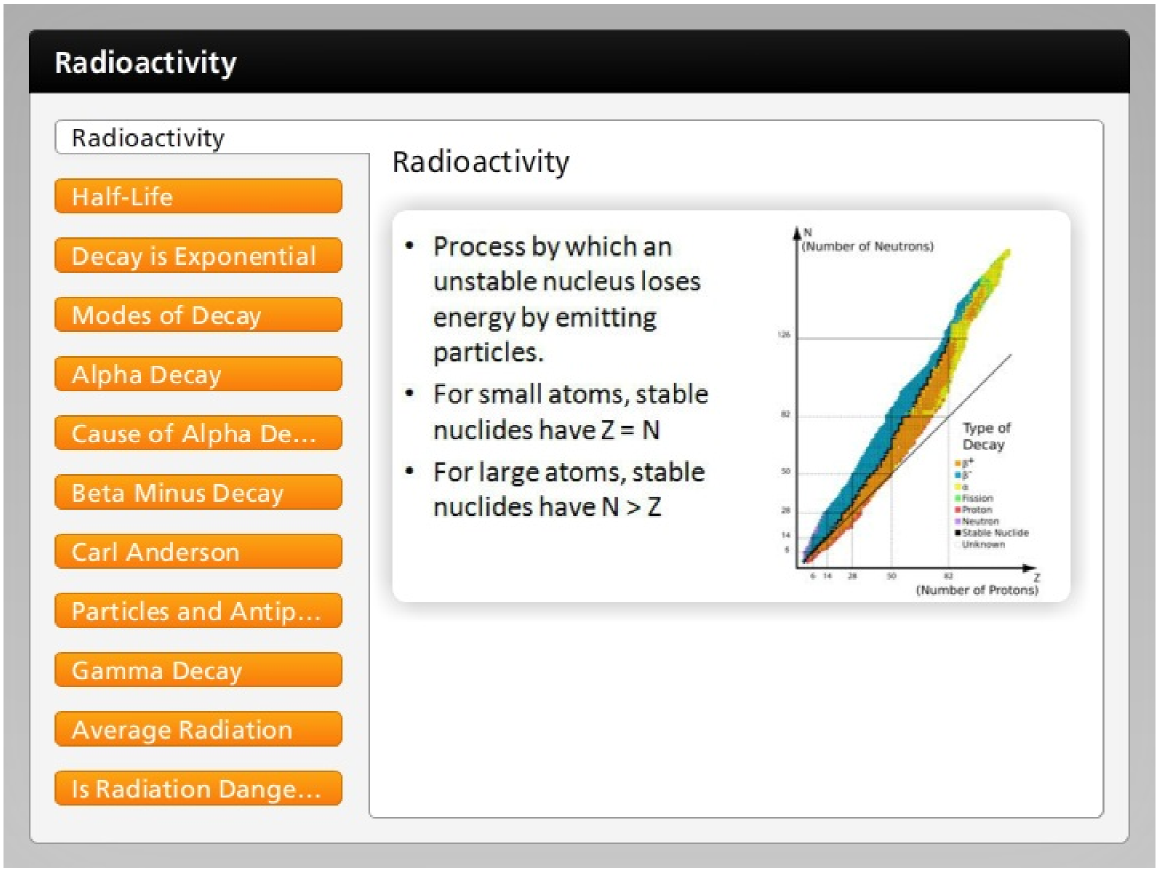
Radioactivity

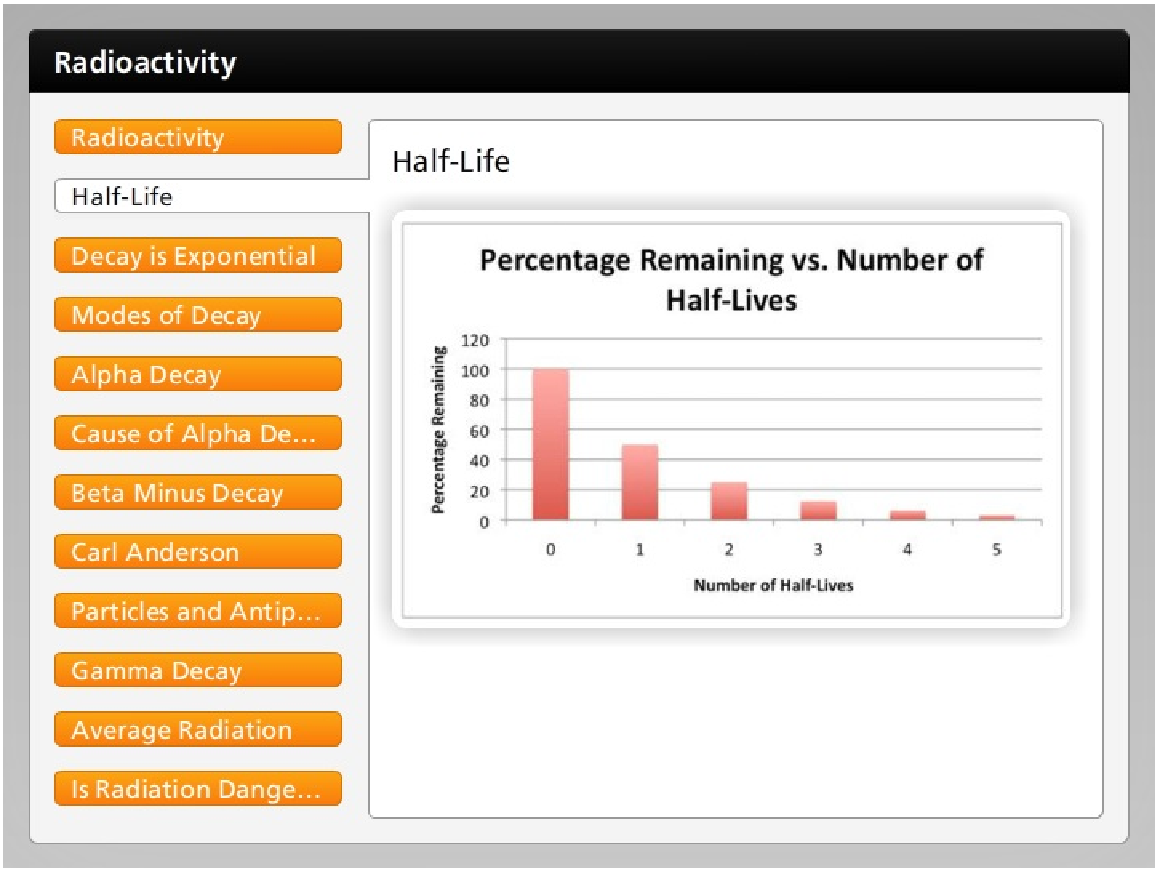


Radioactivity is the process by which an unstable nucleus loses energy by emitting particles. These particles are called radiation. The process occurs randomly and spontaneously, you cannot tell exactly when it will happen. Scientists have measured radioactive decay over time to calculate decay constants that help us predict how long it will take for an unstable nuclide to decay.

The graphic shows which nuclides are likely to undergo radioactive decay. Smaller atoms are stable when there are equal numbers of protons and neutrons. Larger atoms are stable when there are more neutrons than protons. The black region in the center of the colored area represents the stable nuclides. Sometimes this is referred to as the “valley of stability”.

There are three basic types of radiation called alpha, beta and gamma. These names are just the first three letters of the Greek alphabet. An alpha particle is a Helium nucleus, a beta particle is an electron, and a gamma particle is a high energy photon. Nuclides that have more neutrons tend to undergo beta minus decay. Nuclides that have fewer neutrons tend to undergo beta plus decay. When we get above eighty two protons there are no more stable nuclides.

Half-Life



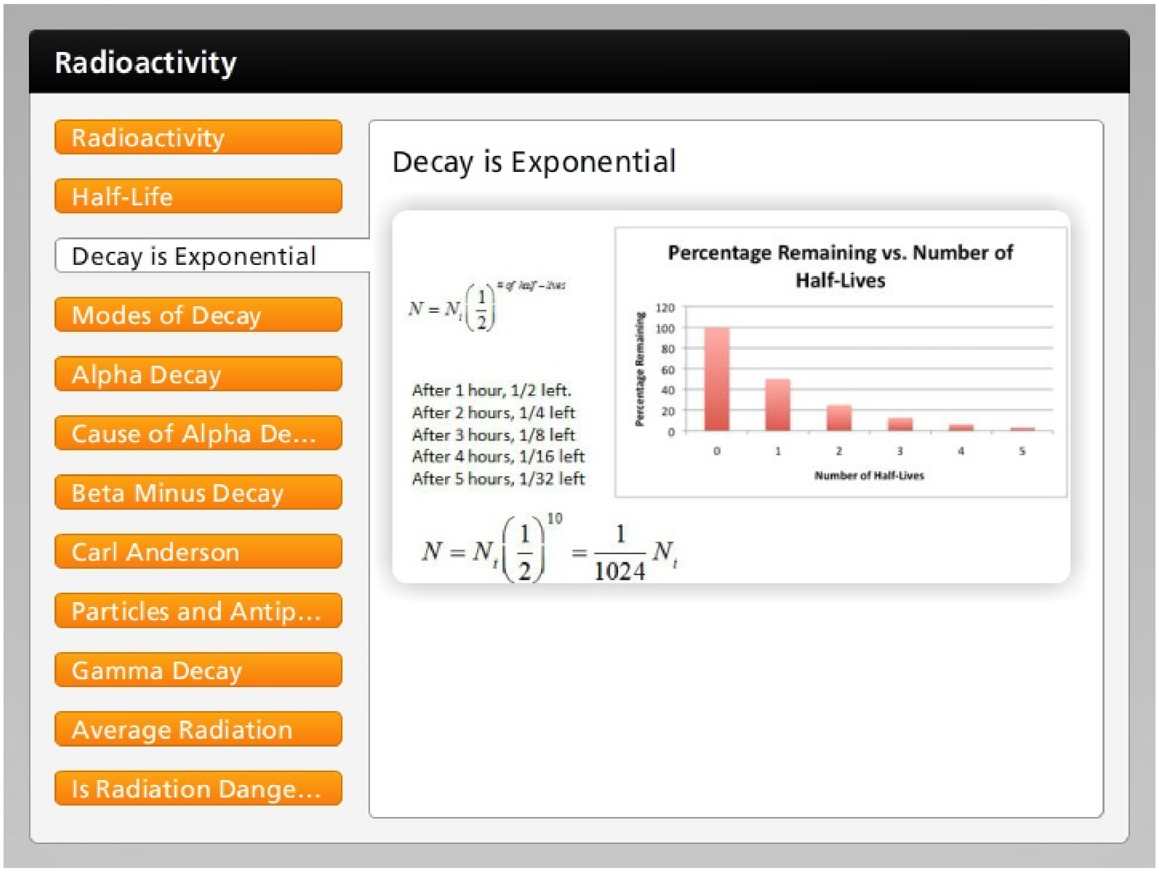
A term used to describe how fast a substance decays is half-life. The half-life is the amount of time it takes for half of the original sample of a radioactive substance to decay.

Depending on the nuclide, half lives can range from one thousandth of a second to ten to the twenty-fourth years. Every time one half life passes, half of the original amount of the substance will have decayed.

The graph shows how the amount decreases with the number of half-lives. After one half-life, there is fifty percent left. After two half-lives, there is twenty five percent left. With each additional half-life, half of the remaining amount decays.

You might recognize this as an exponential function.

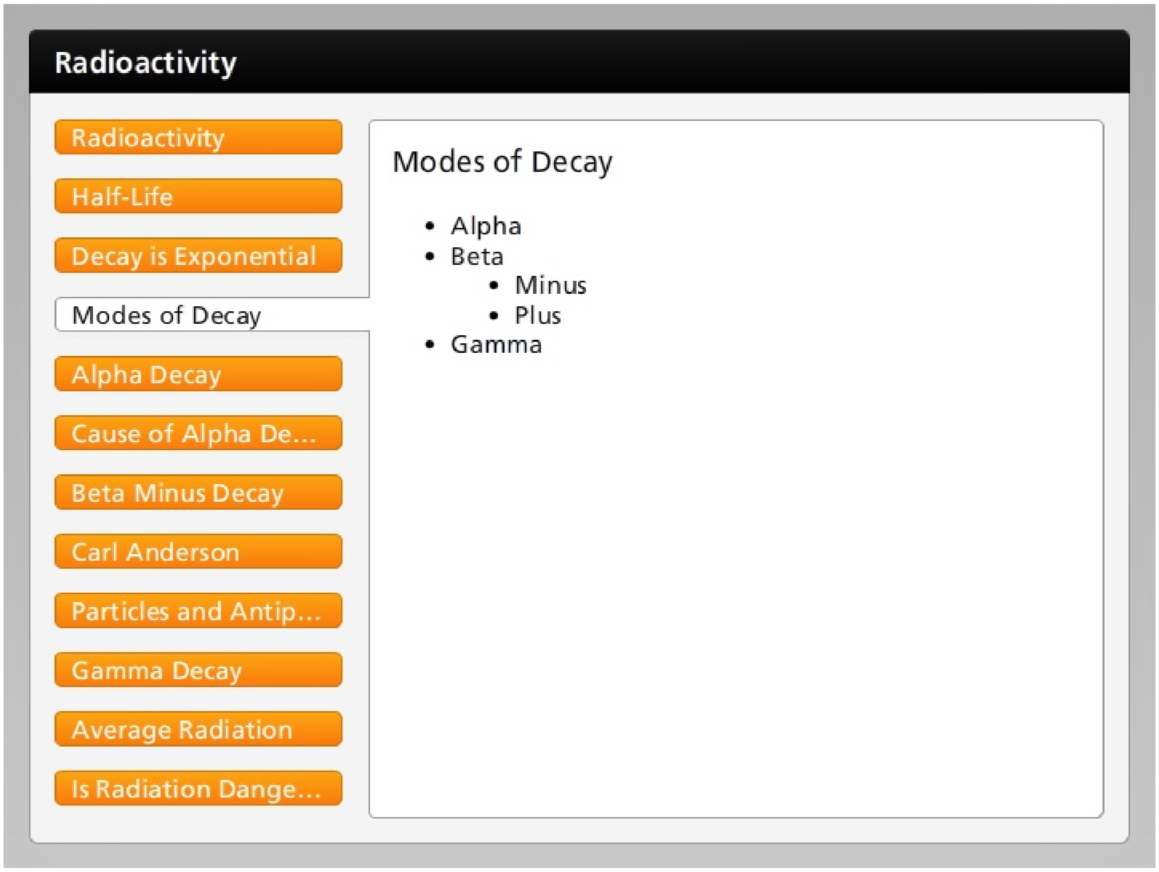
Decay is Exponential



For example, the half life of Nobelium two fifty nine is about one hour. So after one hour, fifty percent is gone. We could keep dividing the amount in half each hour to see how much is left, or we could use this equation. The number of atoms left, N, equals the initial number of atoms, N I, times one-half to the number of half-lives that have passed.

Let's say you wanted to know how much Nobelium two fifty nine is left after ten hours. Ten is ten half-lives. One-half to the tenth power is one over one thousand twenty four. As a percentage, that is zero point zero nine eight percent.

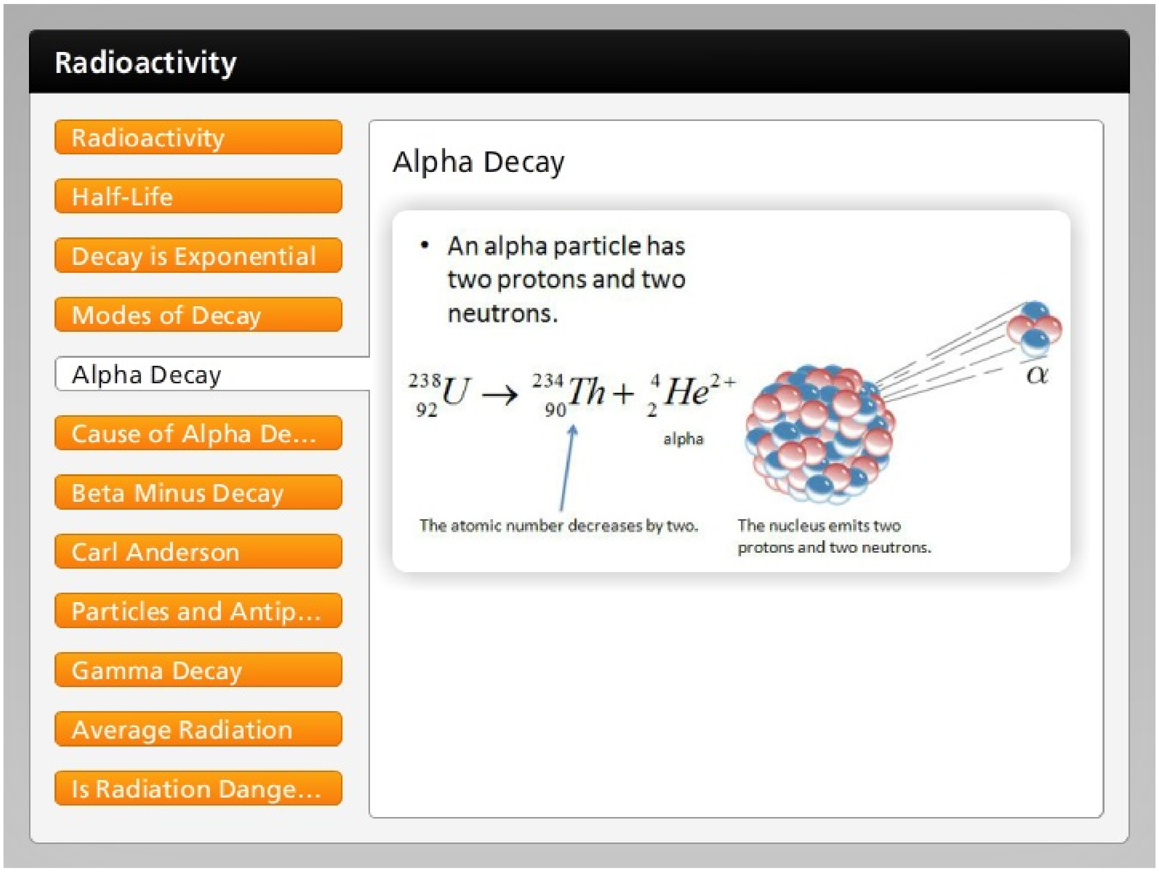
Modes of Decay



- Alpha
- Beta
    - Minus
    - Plus
- Gamma

Let's look at each of the modes of decay individually. There are three basic modes - alpha, beta and gamma decay. Beta has two types that are called minus and plus.

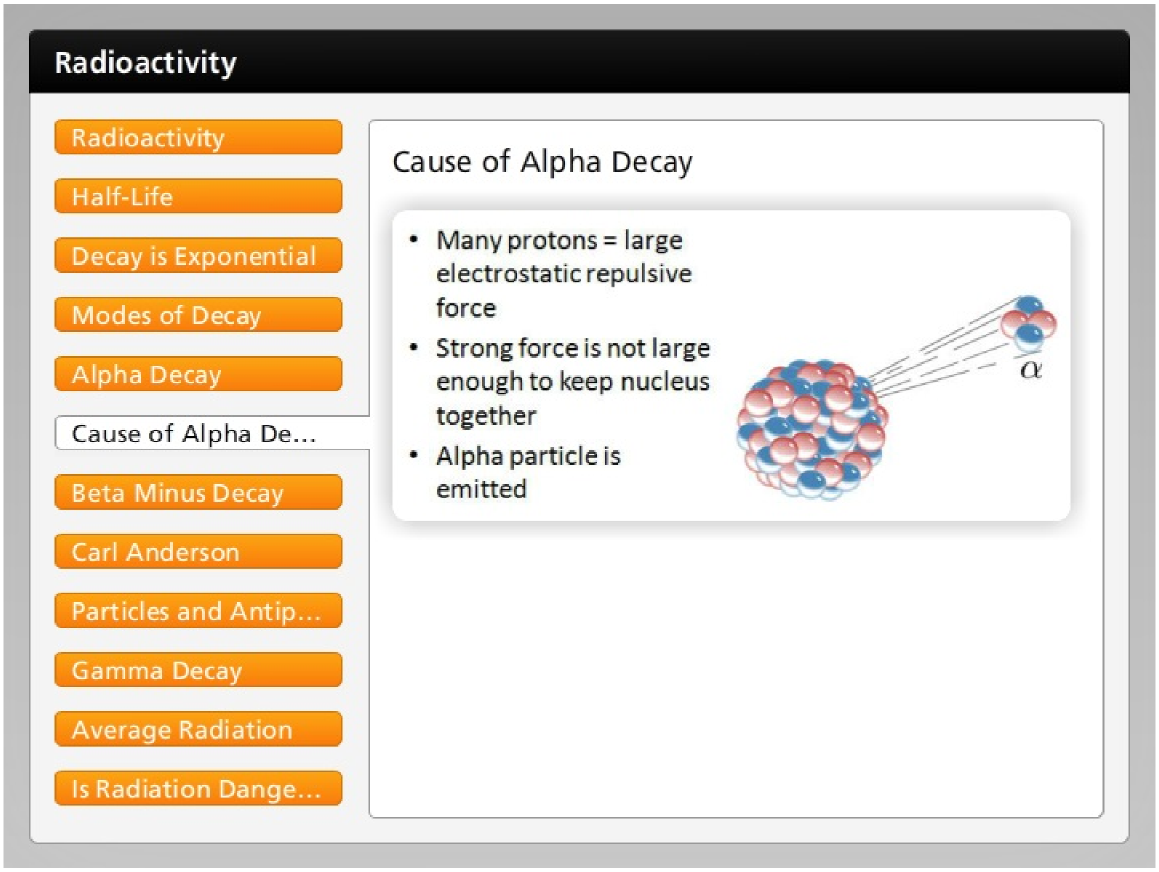
Alpha Decay



An alpha particle is a Helium nucleus. It has two protons and two neutrons. It has a charge of plus two e, where e represents the value of the charge of the electron.

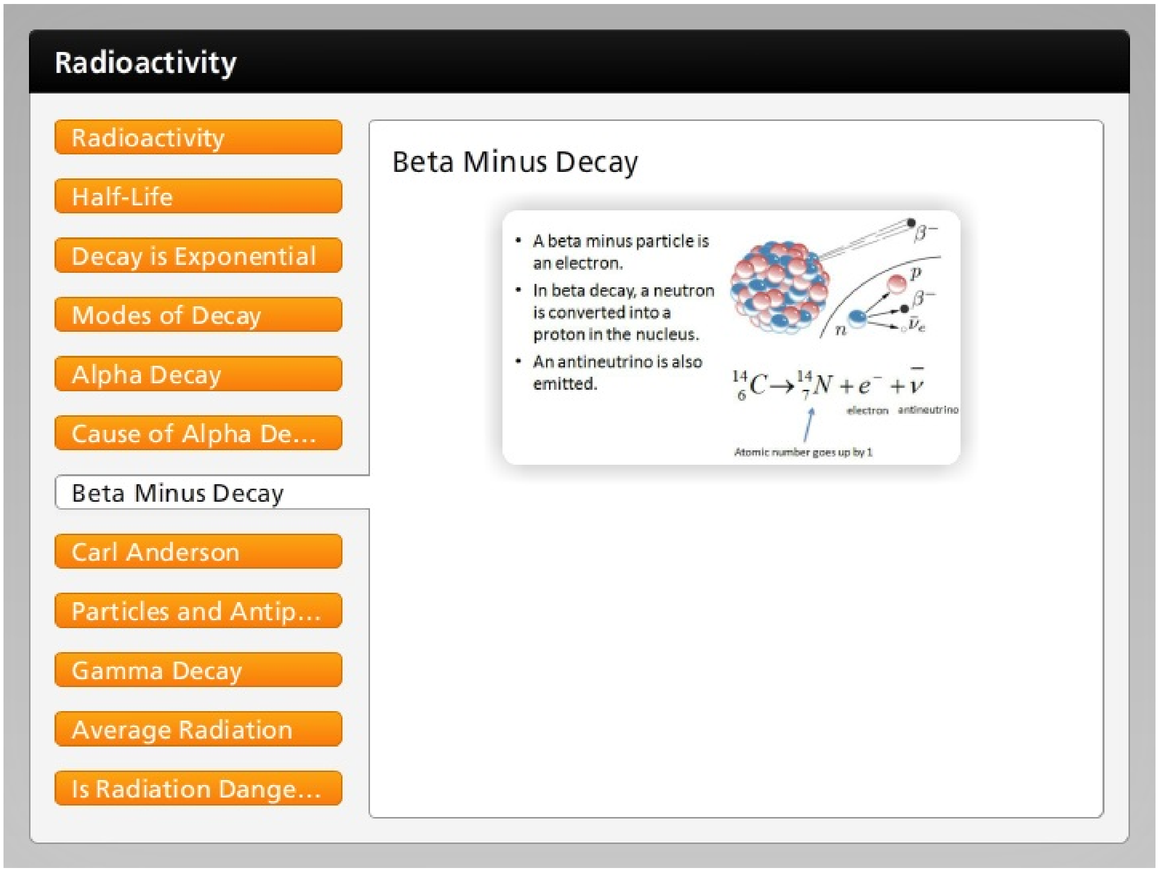
If an atom undergoes alpha decay, it loses two protons. This means its atomic number decreases by two, and it changes into a different element. In a typical reaction, Uranium two thirty eight decays to Thorium ninety and an alpha particle. Notice that the number of nucleons is conserved. Uranium has two hundred and thirty eight nucleons - the total of the neutrons and protons - and this stays the same before and after the decay. If we add the atomic masses of the Thorium and the Helium, two hundred and thirty four plus four, we get two hundred and thirty eight. The +2 with the Helium is to indicate that it is just the nucleus, without any electrons so that we can see charge is conserved.

Cause of Alpha Decay



When a nucleus gets large, the repulsive forces between the protons cannot be overcome by the strong nuclear force that holds the nucleus together. An alpha particle is emitted, which leaves two fewer protons in the nucleus.

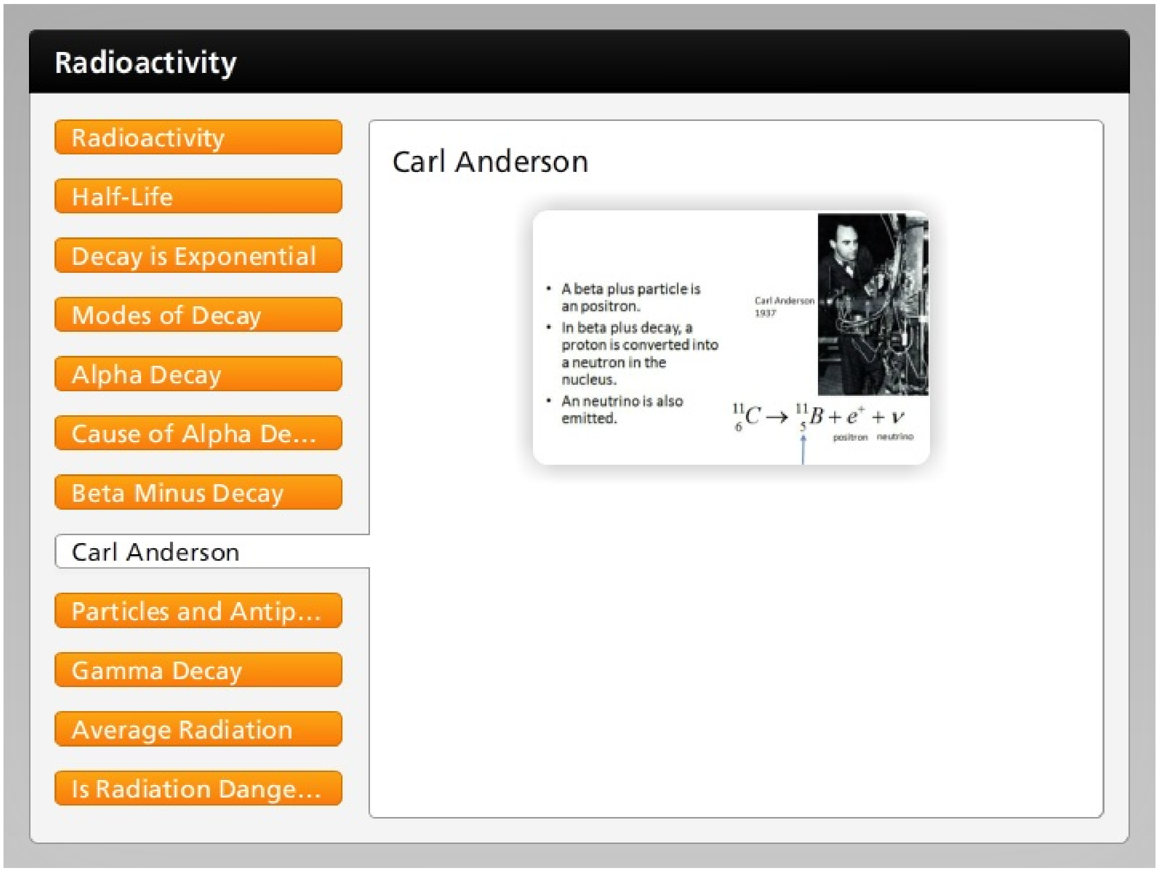
Beta Minus Decay



A beta minus particle is an electron. In beta minus decay a neutron is converted into a proton in the nucleus. An antineutrino is also emitted. Beta decay is related to the nuclear weak force. We will discuss antineutrinos in more detail later in this topic.

In a typical reaction, Carbon fourteen decays to Nitrogen fourteen plus an electron and an antineutrino. Notice that the atomic number changes from six to seven because a neutron changed into a proton. Charge is conserved in this reaction because the number of positive and negative charges both increased by one, so the total charge did not change.

Carl Anderson



A beta particle is a positron. A positron is the antiparticle pair to the electron. It has opposite sign charge and the same mass as the electron. The positron was predicted by Paul Dirac in 1928 and was discovered in 1932 by Carl Anderson. Anderson was awarded the Nobel Prize for this discovery in 1936.

In beta plus decay, a proton is converted into a neutron in the nucleus. A neutrino is also emitted. Beta decay is related to the nuclear weak force. A neutrino is a particle that travels close to the speed of light and passes through most matter. The neutrino has a small, non-zero mass and no charge.

In a typical reaction, Carbon eleven decays to Boron eleven plus an positron and a neutrino. Notice that the atomic number changes from six to five because a proton changed into a neutron. Charge is conserved in this reaction.

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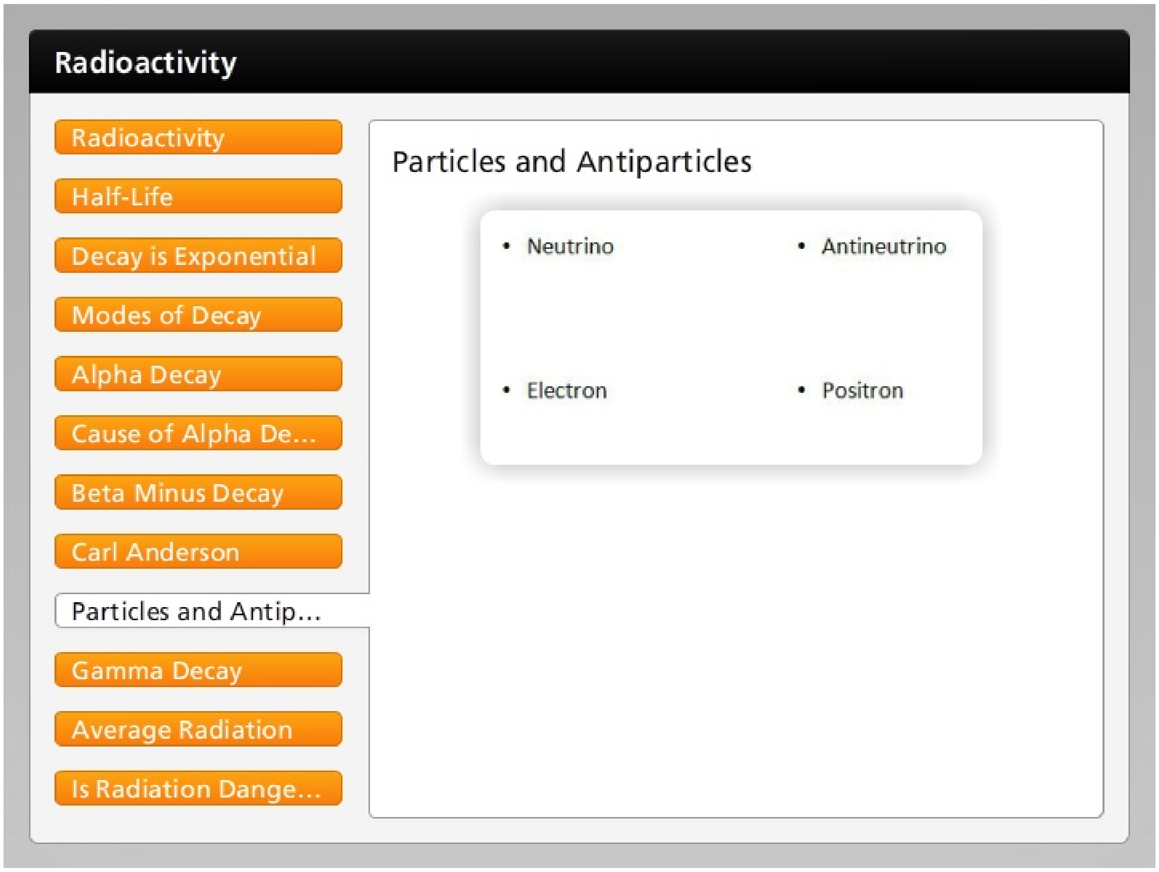
Particles and Antiparticles

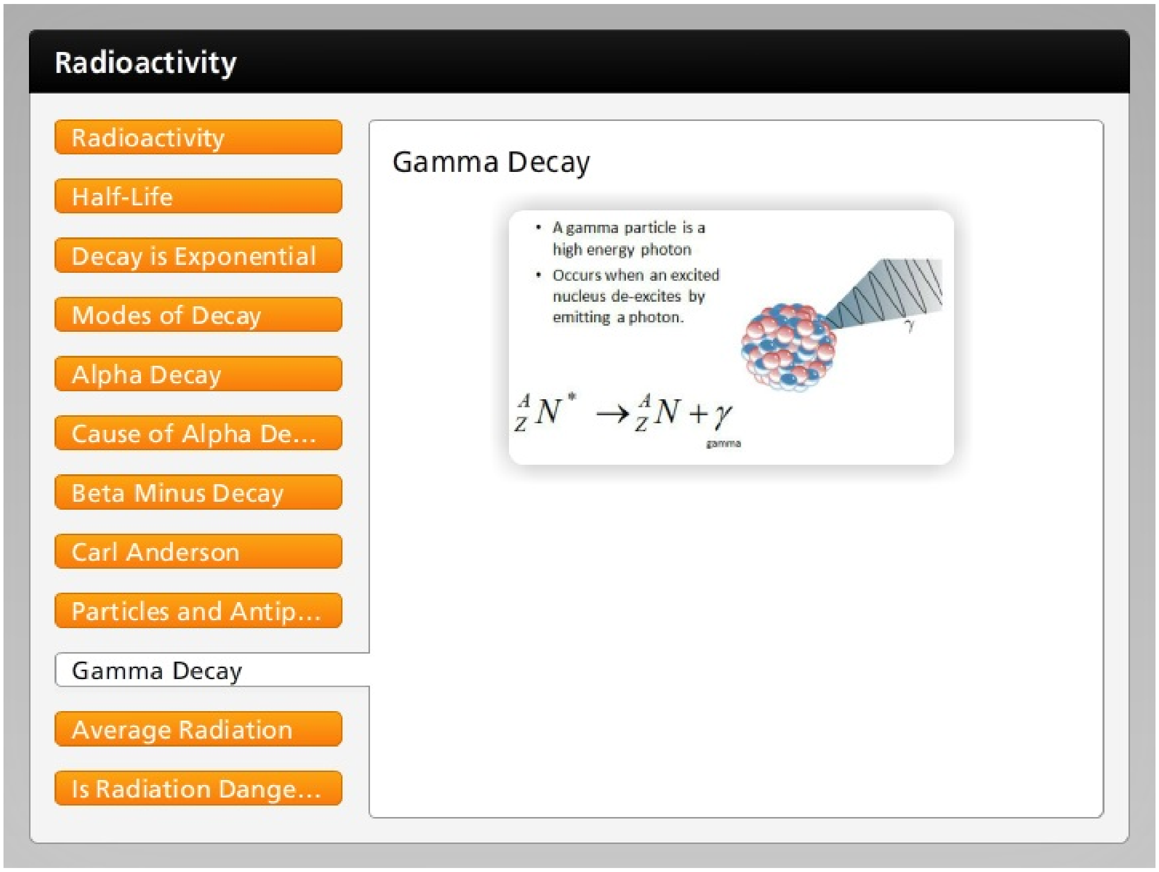


Every particle has an antiparticle partner. The antiparticle partner has the same mass and opposite charge as the particle. When an antiparticle collides with its particle partner, the two particles annihilate each other and their mass is converted into energy by E equals m c squared.

The antiparticle partner to the neutrino is the antineutrino. Antineutrinos also have a very small, but non-zero mass and no charge. The positron is the antiparticle partner to the electron. The positron has the same mass as the electron, but the opposite charge.

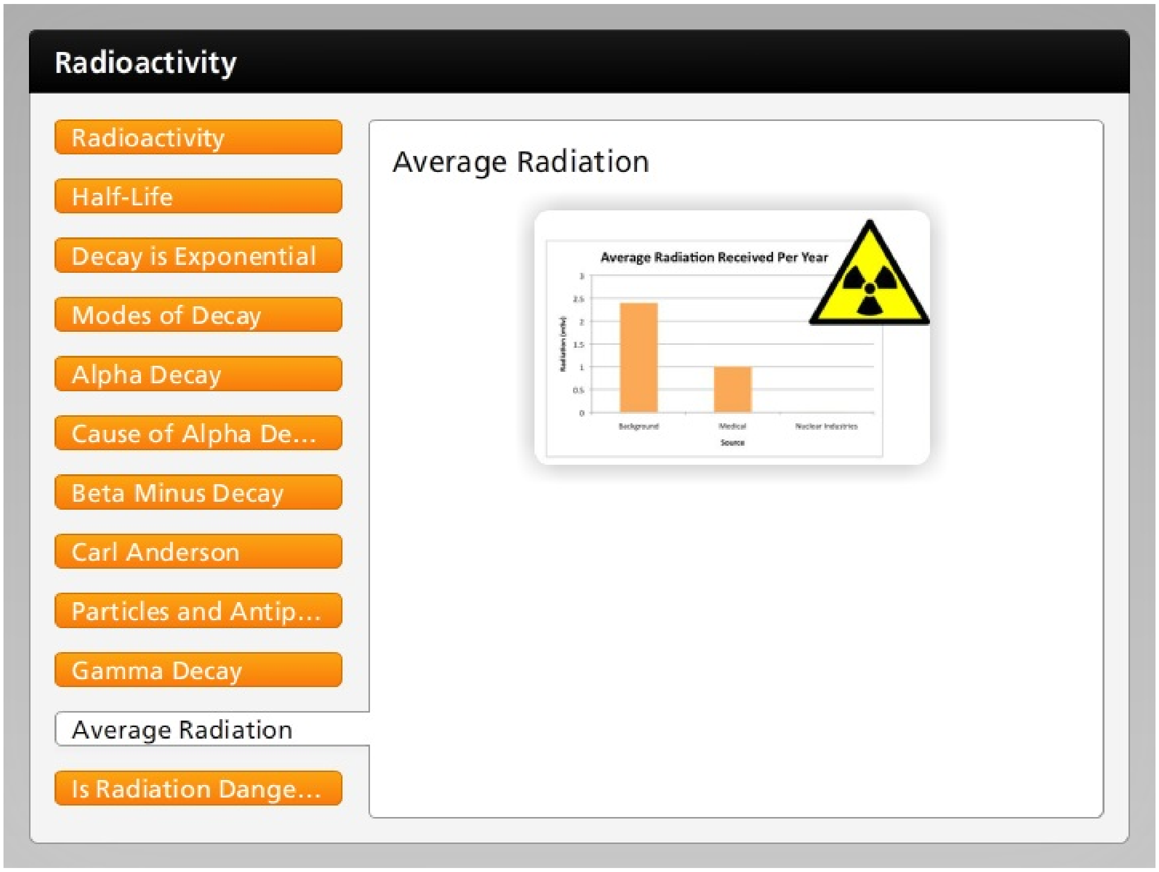
The existence of the neutrino was first proposed by Wolfgang Pauli in 1930, and in 1934 Enrico Fermi picked the name neutrino or little neutral one for the particle. Physicists had observed that the beta decay reaction appeared to violate conservation of energy and momentum. Because they knew this could not be true, the neutrino was invented to fix the problem. The neutrino was very difficult to detect because it had very little mass and no charge, so it did not interact, it just passed through most matter. Neutrinos were not detected until 1956. Frederick Reines and Clyde Cowan received the Nobel Prize for this discovery in 1995.

Gamma Decay



A gamma particle is a high energy photon. Gamma decay occurs when an excited nucleus de-excites by emitting a photon. There is no change to the numbers of protons or neutrons in the nucleus, so there is no change to the atomic number. A typical reaction shows the asterisk to indicate an excited state and then a decay to a non-excited state.

Average Radiation

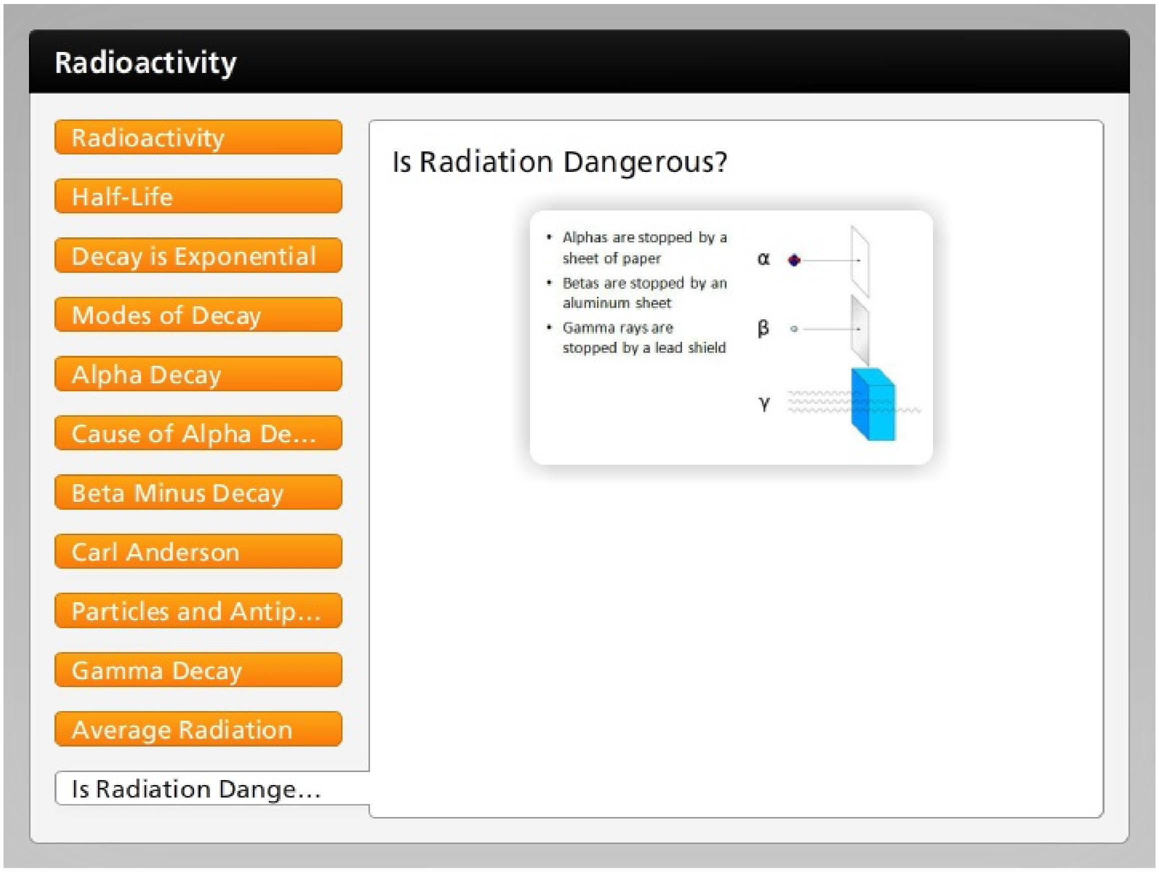


Natural sources of radioactivity include radiation caused by the interaction of cosmic rays with atoms in the atmosphere and naturally occurring radioactive elements such as potassium, carbon, uranium and thorium as well as radon.

The amount of natural background radiation that we receive each year is much larger than the amount of radiation we receive from other sources. The graph illustrates the worldwide averages for annual radiation received in millisieverts. Naturally occurring background radiation is about 500 times as great as the manmade kind that results from the nuclear power and weapon industries. Medical tests can contribute from four to one hundred times as much radiation as nuclear power and weapons sources, depending on how many medical tests you have in a year. Radiation exposure can increase your risk of cancer.

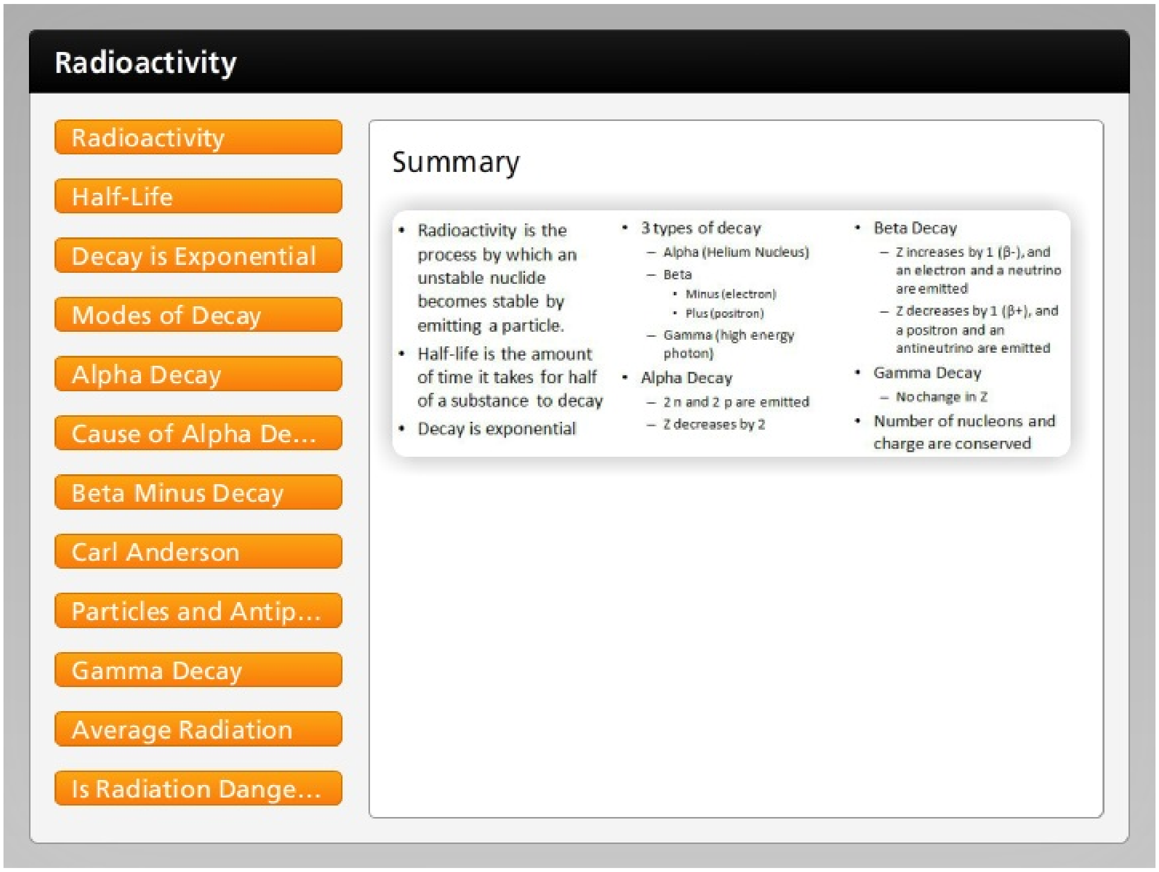
An interesting fact is that bananas are radioactive because of the potassium forty they contain. If you eat one banana a day for three hundred and sixty five days, you would have an annual radiation dose of zero point zero three six millisieverts. One medical x-ray is equivalent to the amount of background radiation you would receive in about ten days. A CT scan gives the equivalent of two to three years of background radiation dose. To minimize your risk of cancer, unnecessary tests should be avoided.

Is Radiation Dangerous?



You might be wondering if radiation is dangerous to people. Radiation can damage human cells by ionizing them, but shielding can protect you. Let's consider each type individually. An alpha particle can be stopped by a piece of paper. The only way it can harm you is by entering through an opening in your skin or if you eat it. Beta particles are more penetrating, but they can be stopped by a few millimeters of aluminum. Gamma rays are the most penetrating because they have the most energy, lead shielding is needed to protect people from gamma radiation. X-ray radiation is less energetic than gamma, but can still be harmful.

Summary



Radioactivity is the process by which an unstable nuclide becomes stable by emitting a particle. Half-life is the amount of time it takes for half of a substance to decay. The amount of the remaining substance decreases exponentially.

There are three types of radioactive decay that are named alpha, beta and gamma.

An alpha particle is a helium nucleus, a beta plus particle is a positron, a beta minus particle is an electron and a gamma is a high energy photon.

For each type of decay, the number of nucleons (neutrons and protons) and the charge are conserved. Next, you will practice writing nuclear decay reactions.