10.1 RADIOACTIVE DECAY
When Henri Becquerel placed uranium salts on a photographic plate and then developed the plate, he found a foggy image. The image was caused by rays that had not been observed before. For his discovery of radioactivity, Becquerel shared the 1903 Nobel Prize for Physics with Marie and Pierre Curie.
Radioactivity is the process in which an unstable atomic nucleus emits charged particles and energy.

Any atom containing an unstable nucleus is called a radioactive isotope, or radioisotope for short.

Radioisotopes of uranium—primarily uranium-238—were the source of radioactivity in Becquerel’s experiment.
About 26,000 years ago, more than 100 mammoths died at a sinkhole in Hot Springs, South Dakota. Scientists found the age of the remains by measuring amounts of the radioisotope carbon-14 in the mammoth bones.
Unlike stable isotopes such as carbon-12 or oxygen-16, radioisotopes spontaneously change into other isotopes over time.

Nuclear decay occurs when the composition of a radioisotope changes.

Uranium-238 decays into thorium-234, which is also a radioisotope.
Types of Nuclear Radiation

Scientists can detect a radioactive substance by measuring the nuclear radiation it gives off.

**Nuclear radiation** is charged particles and energy that are emitted from the nuclei of radioisotopes.
### Types of Nuclear Radiation

<table>
<thead>
<tr>
<th>Radiation Type</th>
<th>Symbol</th>
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<th>Mass (amu)</th>
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<tr>
<td>Alpha particle</td>
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<td>$\gamma$</td>
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Types of Nuclear Radiation

Alpha Decay

An alpha particle is a positively charged particle made up of two protons and two neutrons—the same as a helium nucleus. When a uranium-238 sample decays, it emits alpha particles.

• An alpha particle has a 2+ charge.
• An alpha particle has a mass of 4 amu.
• The symbol for an alpha particle, $^4\text{He}$, shows its mass and charge.
Types of Nuclear Radiation

The nuclear equation for the alpha decay of uranium-238 is shown below.

\[
\begin{align*}
\text{238}_{92}^{} \text{U} & \rightarrow \text{234}_{90}^{} \text{Th} + \text{4}_2^{} \text{He} \\
\end{align*}
\]

- The mass number on the left (238) equals the sum of the mass numbers on the right (234 + 4).
- The atomic number on the left (92) equals the sum of the atomic numbers on the right (90 + 2).
- The equation is balanced.
Beta Decay

When thorium-234 decays, it releases negatively charged radiation called beta particles.

A beta particle is an electron emitted by an unstable nucleus. The symbol for a beta particle is $^0_e$.
In beta decay, the product isotope has one proton more and one neutron fewer than the reactant isotope.

The mass numbers of the isotopes are equal because the emitted beta particle has essentially no mass.

The balanced equation for beta decay of thorium-234 is shown below.

\[
\begin{align*}
\text{Th} & \rightarrow \text{Pa} + e \\
\text{Th}^{234} & \rightarrow \text{Pa}^{234} + e^0
\end{align*}
\]
Types of Nuclear Radiation

Gamma Decay

A **gamma ray** is a penetrating ray of energy emitted by an unstable nucleus.

Gamma radiation has no mass and no charge.

Like X-rays and visible light, gamma rays are energy waves that travel through space at the speed of light.
Types of Nuclear Radiation

During gamma decay, the atomic number and mass number of the atom remain the same. The energy of the nucleus decreases. Gamma decay often accompanies alpha or beta decay.

Thorium-234 emits both beta particles and gamma rays (abbreviated as $\gamma$) as it decays.

\[
\begin{align*}
\text{^{234}_{90}Th} & \rightarrow \text{^{234}_{91}Pa} + \text{^0_{-1}e} + \gamma 
\end{align*}
\]
Types of Nuclear Radiation

The penetrating power of nuclear radiation varies with the type.

- **Alpha particles** ($\alpha$)
- **Beta particles** ($\beta$)
- **Gamma rays** ($\gamma$)
Effects of Nuclear Radiation

**Background radiation** is nuclear radiation that occurs naturally in the environment.

- Radioisotopes in air, water, rocks, plants, and animals all contribute to background radiation.
- Cosmic rays are streams of charged particles (mainly protons and alpha particles) from outer space.
- Background radiation levels are generally low enough to be safe.
Effects of Nuclear Radiation

Most rocks contain at least trace amounts of radioactive elements. The mineral autunite is an important source of uranium.
**Effects of Nuclear Radiation**

When nuclear radiation exceeds background levels, it can damage the cells and tissues of your body.

- Alpha particles can cause skin damage similar to a burn.
- Beta particles can damage tissues in the body more than alpha particles.
- Gamma rays can penetrate deeply into the human body, potentially exposing all organs to ionization damage.
Effects of Nuclear Radiation

Ionizing radiation can break chemical bonds in proteins and DNA molecules.

Alpha particles are not a serious health hazard unless an alpha-emitting substance is inhaled or eaten.

Radon gas is a potentially dangerous natural source of alpha particles because it can be inhaled. Prolonged exposure to radon-222 can lead to lung cancer.
Effects of Nuclear Radiation

Radon gas is produced underground as the uranium in rocks and soil decays.

Insulation, modern windows, and modern building materials keep radon from escaping.

Radon naturally diffuses up through the ground.

Radon enters through pinholes and cracks in the foundation.

Radon gas dissolved in water is released through agitation.

Radon is produced by the nuclear decay of uranium found in rocks and soil.
Detecting Nuclear Radiation

A Geiger counter uses a gas-filled tube to measure ionizing radiation.

• When nuclear radiation enters the tube, it ionizes the atoms of the gas.

• The ions produce an electric current, which can be measured.

• The greater the amount of nuclear radiation, the greater the electric current produced in the tube is.
Detecting Nuclear Radiation

Wearing protective clothing, a firefighter uses a Geiger counter to test the ground for radioactivity.
Detecting Nuclear Radiation

Many people who work with or near radioactive materials wear film badges to monitor their exposure to nuclear radiation.

• The badge contains a piece of photographic film. The film is developed and replaced periodically.
• The exposure on the film indicates the amount of radiation exposure for the person wearing the badge.
Assessment Questions

1. What happens when an atomic nucleus decays?
   a. The atom loses an electron and gains energy.
   b. Some of the protons in the nucleus are converted to neutrons.
   c. A nucleus breaks into two parts of approximately equal mass.
   d. An unstable nucleus emits charged particles and energy.
Assessment Questions

1. What happens when an atomic nucleus decays?
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   ANS: D
2. During alpha decay, the nucleus emits an alpha particle, or
   a. proton.
   b. neutron.
   c. deuterium nucleus.
   d. helium nucleus.
Assessment Questions

2. During alpha decay, the nucleus emits an alpha particle, or
   a. proton.
   b. neutron.
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   ANS: D
Assessment Questions

4. Nuclear radiation can damage cells in the body by
   a. ionizing atoms in molecules in the cell.
   b. making holes in the cell wall.
   c. making isotopes in the cell radioactive.
   d. causing water to vaporize and rupture the cell.
Assessment Questions

4. Nuclear radiation can damage cells in the body by
   a. ionizing atoms in molecules in the cell.
   b. making holes in the cell wall.
   c. making isotopes in the cell radioactive.
   d. causing water to vaporize and rupture the cell.

   ANS: A
Assessment Questions

1. A Geiger counter measures radiation by detecting ions formed when charged particles pass through a tube filled with gas.

   True
   False
Assessment Questions

1. A Geiger counter measures radiation by detecting ions formed when charged particles pass through a tube filled with gas.

   True
   False

   ANS:  T