Radioactivity is the consequence of an unstable atomic nucleus.

Radiation involves the release of:
1. High energy particles
2. High energy electromagnetic waves

Radioactivity is indicated by the international symbol.

Most elements exist as more than one isotope:
- The number of protons is the same in all atoms of a given element.
- Isotopes differ in the number of neutrons.
- Radioisotopes are unstable due to an imbalance in the number of protons and neutrons in their atomic nuclei.
- They undergo radioactive decay to become more stable isotopes.
Radiation from radioactive decay comes in two different categories:

1. High energy electromagnetic waves:
   - X-rays
   - gamma rays

2. High energy particles:
   - α-particles
   - β-particles
   - positrons

### Table 16.2: Types of Radioactive Decay

<table>
<thead>
<tr>
<th>Radiation Type</th>
<th>Nuclear Symbol</th>
<th>Energy Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>α particle</td>
<td>α</td>
<td>High energy particle</td>
</tr>
<tr>
<td>β particle</td>
<td>β</td>
<td>High energy particle</td>
</tr>
<tr>
<td>Protons</td>
<td>n</td>
<td>High energy particle</td>
</tr>
<tr>
<td>X-rays</td>
<td></td>
<td>Electromagnetic radiation</td>
</tr>
<tr>
<td>Gamma rays</td>
<td>γ</td>
<td>Electromagnetic radiation</td>
</tr>
</tbody>
</table>

If a nucleus has too many neutrons compared with protons, it may undergo α- or β-decay:

1. **α-decay**: loss of high-energy particle containing 2 protons + 2 neutrons:
   - The nuclear symbol is: \( ^4_2 \alpha \)
   - α-particles are identical to an ionized helium atom

2. **β-decay**: a neutron is converted into a proton plus a high energy electron:
   - The nuclear symbol is: \( ^0_{-1} \beta \)
   - This electron is ejected at ~90% the speed of light!!

Examples of radioactive decay:

- **Thorium-232** (\(^{232}\text{Th}\)) undergoes **α-decay** to become **Radium-228**:

- **Phosphorus-32** (\(^{32}\text{P}\)) undergoes **β-decay** to become **Sulfur-32**:
If a nucleus has too many protons compared with neutrons, positron decay occurs:
- The nuclear symbol is: \( {}^{+1}_0 \beta \)
- Positrons are similar to \( \beta^- \) particles in mass and energy, except they have a positive charge.
- Nitrogen-13 (\(^{13}\text{N}\)) undergoes positron decay to produce Carbon-13:

\[
{}^{13}_7 \text{N} \rightarrow {}^{13}_6 \text{C} + {}^{0}_1 \beta
\]

The type of decay that occurs depends on:
1. Atomic size
2. Neutron/proton ratio

General patterns:
- \( \alpha \)-decay tends to occur at very large elements
- \( \beta^- \)-decay occurs when neutron/proton ratio is too high
- Positron decay occurs when neutron/proton ratio is too low

Electromagnetic radiation is a type of energy that travels as a wave at the speed of light:
- The wavelength of electromagnetic radiation is the distance from crest to crest of the wave.
- The amount of energy in electromagnetic radiation is \textit{inversely} proportional to its wavelength
- The shorter the wavelength, the \textit{higher} the energy
Electromagnetic radiation exists in a wide variety of wavelengths, called the **electromagnetic spectrum**. Radioactive decay occurs in the high energy (short wavelength) part of the spectrum.

**X-rays** and **gamma radiation** ($\gamma$-rays) are high-energy forms of electromagnetic radiation:
- Useful in medical diagnostics (*in small doses!*)
- Potentially very damaging to living tissue

**Ionizing radiation** describes energy emitted from a nuclear reaction that dislodges electrons from an atom, thus forming an ion:
- Loss of an electron produces a cation (+ charged ion)

**WHAT DETERMINES EFFECTS OF RADIATION?**
- Two characteristics of ionizing radiation determine its biological effects:
  1. The **energy** of the radiation
  2. The **penetrating power** of the radiation
- Non-penetrating radiation can be **shielded** by external materials such as clothing or dense materials:
**BIOLOGICAL EFFECTS OF IONIZING RADIATION**

- **Ionizing radiation** changes molecules so they become highly reactive:
  - Changes the structure—and therefore function—of important biomolecules (especially proteins & DNA)
  - **Example:** Ionizing radiation breaks the phosphodiester bonds in the DNA backbone

- Gamma irradiation is often used to sterilize food of harmful microorganisms:
  - Kills bacteria & destroys viruses by damaging their DNA
  - Food does NOT become radioactive

**CHAPTER 16: Nuclear Chemistry and Medicine**

**RADIATION SICKNESS**

- Excessive radiation exposure can produce a serious illness called **radiation sickness**
- Radiation exposure may be:
  - **Acute:** a short, intense dose (think nuclear bomb)
  - **Chronic:** a prolonged, smaller dose (think ingestion of a radioactive metal)

- Symptoms can appear soon after the exposure, or show up later in time:
  - Acute affects appear like severe flu symptoms
  - Chronic effects can include cancer or blood disorders (due to bone marrow damage)

**SYMPTOMS OF RADIATION SICKNESS**

<table>
<thead>
<tr>
<th>Mild exposure (1-2 Gy)</th>
<th>Moderate exposure (2-5 Gy)</th>
<th>Severe exposure (5-4 Gy)</th>
<th>Very severe exposure (10 Gy or higher)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nausea and vomiting</td>
<td>Within 2 hours</td>
<td>Within 3 hours</td>
<td>Within 1 hour</td>
</tr>
<tr>
<td>Diarrhea</td>
<td>Within 3 hours</td>
<td>Within 3 hours</td>
<td>Within 1 hour</td>
</tr>
<tr>
<td>Headache</td>
<td>Within 24 hours</td>
<td>Within 4 hours</td>
<td>Within 2 hours</td>
</tr>
<tr>
<td>Fever</td>
<td>Within 3 hours</td>
<td>Within 1 hour</td>
<td>Within 1 hour</td>
</tr>
<tr>
<td>Dizziness and disorientation</td>
<td>Within 1 week</td>
<td>Immediate</td>
<td></td>
</tr>
<tr>
<td>Weakness, fatigue</td>
<td>Within 6 weeks</td>
<td>Within 1 week</td>
<td>Immediate</td>
</tr>
<tr>
<td>Hair loss, bloody vomit and stools, infections, poor wound healing, low blood pressure</td>
<td>Within 1 week</td>
<td>Immediate</td>
<td></td>
</tr>
</tbody>
</table>
Nuclear medicine is a branch of medical imaging that uses small amounts of radioactive material to diagnose and determine the severity of or treat a variety of diseases.

There are two different branches of nuclear medicine:

1. Diagnostic nuclear medicine
   - Non-imaging
   - Imaging
2. Radiotherapy

Radiation of various types may be used to form images of body parts for diagnostics:

- The use of radiation requires a source (derived from a radioactive sample) and a detector.
- The pictures below show a hand visualized through radiation of different energies.

Several common imaging techniques are performed with external electromagnetic sources:

- X-rays (2D image)
- CAT/CT scan (3D X-ray)

More advanced imaging techniques utilize a radioactive tracer + imaging together

- PET = positron emission tomography
- SPECT = single-photon emission computed tomography
COMBINATION IMAGING TECHNIQUES

- More advanced imaging techniques utilize a radioactive tracer + imaging together
  - PET/CT
  - SPECT/CT scan

FDG = $^{18}$F-fluorodeoxyglucose

Positron emission: $^{18}$F $\rightarrow ^{18}$O + $\gamma$, $\beta$

CHAPTER 16: Nuclear Chemistry and Medicine

RADIOThERAPY MEDICINE

- A number of diseases—in particular cancer—can be treated using radiation
- The more common radiotherapies are from external sources (usually $\gamma$-ray emitters):
  - External beam (EBRT) radiation therapy
  - Stereotactic radiation therapy
- Some cancers are treated with internal sources of radioactive material:
  - Brachytherapy (implanted radiation "seeds")
  - Systemic radiotherapy ($^{125}$I for thyroid cancer)

CHAPTER 16: Nuclear Chemistry and Medicine

STEREOTACTIC PRECISION RADIOThERAPY

- For inoperable or diffuse tumors, radiotherapy is often used as a cancer treatment

Cyber Knife or Gamma Knife therapies

Cobalt-60 ($^{60}$Co) is the common source of radiation for this treatment