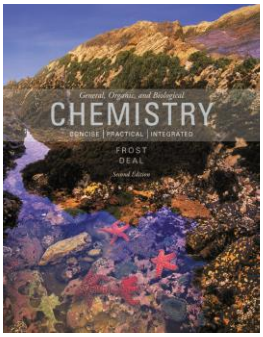


Lecture Presentation

Chapter 2

Atoms and Radioactivity

Julie Klare
Fortis College
Smyrna, GA

Outline

- 2.1 Atoms and Their Components
- 2.2 Atomic Number and Mass Number
- 2.3 Isotopes and Atomic Mass
- 2.4 Radioactivity and Radioisotopes
- 2.5 Nuclear Equations and Radioactive Decay
- 2.6 Radiation Units and Half-Lives
- 2.7 Medical Applications for Radioisotopes

2.1 Atoms and Their Components

- **Subatomic particles** organize to form all atoms.
  - The three basic subatomic particles are the proton, neutron, and electron.
  - **Protons** and **electrons** are charged particles.
  - **Neutrons** are neutral or uncharged.
  - Protons have a positive (+) charge, and electrons have a negative (-) charge.
  - NEUTRAL atoms have *NO CHARGE* because the number of protons is equal to the number of electrons.

2.1 Atoms and Their Components

- **Structure of an Atom**
  - Protons and neutrons are clustered together in the **nucleus**.
  - Electrons are dispersed throughout the area around the nucleus.
  - The space occupied by the electrons is called the electron cloud since the electrons are constantly moving and are difficult to pinpoint
  - Most of an atom consists of empty space.

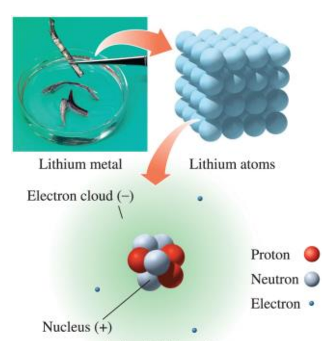
2.1 Atoms and Their Components

- **Structure of an Atom**
  - A unit called the atomic mass unit, or amu, is used when discussing atoms.
  - An amu is one-twelfth the mass of a carbon atom.
  - A proton and neutron each weigh 1 amu.
  - The mass of an electron is about 2000 times less than that of a proton or neutron.

TABLE 2.1 Properties of Particles in an Atom

Subatomic Particle	Symbol	Electrical Charge	Relative Mass	Location in Atom
Electron	e^-	1−	0.0005 (1/2000)	Outside nucleus
Proton	p or p^+	1+	1	Nucleus
Neutron	n or n^0	0	1	Nucleus

2.1 Atoms and Their Components



2.2 Atomic Number and Mass Number

- All atoms of the same element always have the same number of protons.
- **Atomic Number**
  - The number of protons in an atom of any element can be determined from the periodic table.
  - The number that appears above each element within its block is its **atomic number**.
  - The atomic number indicates the number of protons present.

2.2 Atomic Number and Mass Number

- The number of protons gives an atom its unique properties.
- A carbon atom, atomic number 6, contains six protons.
- All atoms of carbon have six protons.
- Because atoms are neutral (no charge), the number of electrons in an atom is equal to the number of protons.
- Carbon must contain six electrons.

2.2 Atomic Number and Mass Number

Symbolic Notation for Isotopes

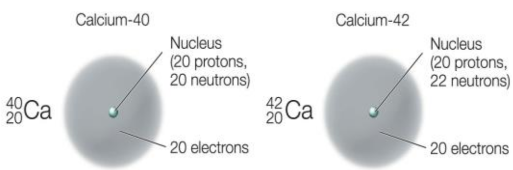
$^{A}_{Z}X$

A = Mass Number

Z = Atomic Number

X = Atomic symbol

Isotopes of Calcium and the Number of Particles in Each



2.3 Isotopes and Atomic Mass

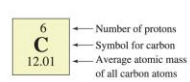
- Atoms of the same element *can* have different numbers of neutrons.
- Not all atoms of the same element have the same mass number.
- Atoms of the same element with different mass numbers are called **isotopes.**
- Isotopes can be indicated in two ways:
  - Symbolic notation
  - Stating the mass number after the element name: carbon-12

2.3 Isotopes and Atomic Mass

- The number below each element on the periodic table shows the *average* atomic mass for that element.
- The atomic mass depends on the proportion of each isotope.
- The **atomic mass** is the average atomic mass weighted for all the isotopes of that element found naturally.

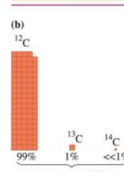
2.3 Isotopes and Atomic Mass

(a)



Isotope	^{12}C	^{13}C	^{14}C
Atomic number	6	6	6
Protons	6	6	6
Neutrons	6	7	8
Abundance	Most	1/100	1/1,000,000,000,000

(b)



2.4 Radioactivity and Radioisotopes

- Energy given off spontaneously from the nucleus of an atom is called **nuclear radiation.**
- Elements that emit radiation are said to be *radioactive*.
- Radiation is a form of energy that we get from natural and human-made sources.
- In 1896, Henri Becquerel got an exposure on a photographic plate by exposing the plate to a rock that contained uranium.

2.4 Radioactivity and Radioisotopes

- Most naturally occurring isotopes have a stable nucleus and are not radioactive.
- Isotopes that are not stable become stable by spontaneously emitting radiation from their nuclei.
- This is radioactive decay.
- Isotopes that emit radiation are also called radioisotopes.
- All the isotopes of elements with atomic number 83 and higher are radioactive.
- Some smaller elements also have radioisotopes.

2.4 Radioactivity and Radioisotopes

- **Forms of Radiation**
- The first three forms of nuclear radiation that were discovered are the following:
  - The positively charged alpha (α) particle
  - The negatively charged beta (β) particle
  - The neutral gamma (γ) ray
- There are two other less common forms:
  - The positron
  - The neutron (no charge)

2.4 Radioactivity and Radioisotopes

TABLE 2.4 Forms and Properties of Nuclear Radiation

Emission	Symbol	Charge
Alpha	α or ${}^{4}_{2}He$	2+
Beta	β or ${}^{0}_{-1}e$	1−
Gamma	${}^{0}_{0}\gamma$	0
Positron	${}^{0}_{1}e$	1+
Neutron	${}^{1}_{0}n$	0

2.4 Radioactivity and Radioisotopes

- An **alpha particle** is represented by the Greek letter α or as a helium nucleus containing two protons and two neutrons:

$$ {}^{4}_{2}He^{2+} $$

- A neutron may eject a high-energy electron called a **beta particle.**
- It is represented by the Greek letter β or symbolically as

$$ {}^{0}_{-1}e $$

- The neutron becomes a proton as a result.

2.4 Radioactivity and Radioisotopes

- **Gamma rays** are high-energy radiation emitted during radioactive decay.
- The gamma ray is represented by the Greek letter γ.
- Gamma rays are higher energy than X-rays.
- A **positron** has the same mass as a beta particle but is positively charged. It is represented as

$$ {}^{0}_{-1}e $$

- This decay will change a proton to a neutron and emit a positron. The positron then collides with an electron, emitting gamma rays.

2.4 Radioactivity and Radioisotopes

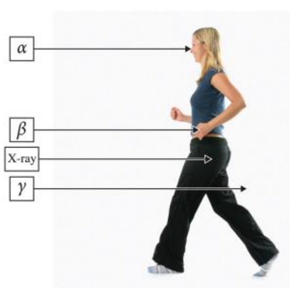
- **Biological Effects of Radiation**
  - Radioactive emissions contain a lot of energy and will interact with any atoms.
  - Alpha and beta particles, neutrons, gamma rays, and X-rays are **ionizing radiation.**
  - When they interact with another atom, they can eject one of that atom's electrons, making the atom more reactive and less stable.
  - The loss of electrons in living cells can affect a cell's chemistry and genetic material. In humans, this can cause problems, the most common of which is cancer.

2.4 Radioactivity and Radioisotopes

- **Biological Effects of Radiation**
  - Radiation of higher energy can penetrate farther into a tissue.
  - Persons who work with radioactive materials wear a heavy lab coat, lab glasses, and gloves and may stand behind a plastic or lead shield.
  - People who routinely work with radioactive materials or X-rays usually wear a film badge to monitor their total exposure.

2.4 Radioactivity and Radioisotopes

- **Biological Effects of Radiation**



2.4 Radioactivity and Radioisotopes

- **Biological Effects of Radiation**

TABLE 2.5 Properties of Common Ionizing Radiation

	Travel Distance through Air	Tissue Penetration	Protective Shielding
Alpha (α)	A few centimeters	Stops at the skin surface; only dangerous if inhaled or eaten	Paper, clothing
Beta (β)	A few meters	Will not penetrate past skin layer	Heavy clothing, plastic, aluminum foil, gloves
X-ray	Several meters	Penetrates tissues, but not bone	Lead apron, concrete barrier
Gamma (γ)	Several hundred meters	Fully penetrates body	Thick lead, concrete, layer of water

2.5 Nuclear Equations and Radioactive Decay

- How is a nuclear decay equation written?

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

- Uranium decays into thorium with the emission of an alpha particle.
- The mass number of the reactant must equal the mass numbers of the products.
- The element symbol changes because the number of protons changed.

2.5 Nuclear Equations and Radioactive Decay

- ***Writing a Nuclear Decay Equation for Alpha Decay***
  - **Step 1:** Write the symbolic notation for the radioisotope undergoing decay on the reactant side of the equation
  - **Step 2:** Place the ionizing radiation on the product side of the equation.
  - **Step 3:** Determine the missing product radioisotope. Remember that the mass and atomic numbers must be equal on both sides of the equation.

2.5 Nuclear Equations and Radioactive Decay

- ***Beta Decay and Positron Emission***
  - In beta decay, a high-energy electron is emitted from the nucleus, and a neutron becomes a proton.
  - Step 1: Write the symbolic notation for the radioisotope undergoing decay.
  - Step 2: Place the ionizing radiation on the product side of the equation.
  - Step 3: Determine the missing product radioisotope.

2.5 Nuclear Equations and Radioactive Decay

- ***Gamma Decay***
  - Gamma rays are energy only.
  - An isotope that is a pure gamma emitter will not change its atomic number or mass number upon decay.
  - By emitting a gamma ray, the element becomes more stable. An equation for gamma decay is

$$^{99m}_{43}\text{Tc} \rightarrow {}^{99}_{43}\text{Tc} + {}^{0}_{0}\gamma$$

2.5 Nuclear Equations and Radioactive Decay

- ***Producing Radioactive Isotopes***
  - Although some radioisotopes occur in nature, many more are prepared in chemical laboratories.
  - Radioisotopes can be prepared by bombarding stable isotopes with fast-moving alpha particles, protons, or neutrons.

$$^{98}_{42}\text{Mo} + {}^{1}_{0}\text{n} \rightarrow {}^{99}_{42}\text{Mo}$$

2.5 Nuclear Equations and Radioactive Decay

Emission	Symbol	Charge	Mass Number
Alpha	α or ${}^{4}_{2}\text{He}$	2+	4
Beta	β or ${}^{0}_{-1}e$	1−	0
Gamma	${}^{0}_{0}\gamma$	0	0
Positron	${}^{0}_{1}e$	1+	0
Neutron	${}^{1}_{0}n$	0	1

2.6 Radiation Units and Half-Lives

- **Radioactivity Units**
  - The activity of a radioactive sample is measured as the number of radioactive emissions in a second.
  - The unit for measuring disintegrations is called the **curie (Ci)** for the Polish scientist Marie Curie, who studied radioactivity in France at the turn of the twentieth century.
  - The SI unit for measuring disintegrations is called the **becquerel (Bq)** after Henri Becquerel.
  - The *activity* of an isotope defines how quickly (or slowly) it emits radiation.

2.6 Radiation Units and Half-Lives

- **Radioactivity Units**

TABLE 2.6 Units for Radiation Activity

Common Unit	Relationship to Other Units
becquerel (Bq)	1 Bq = 1 disintegration per second
curie (Ci)	1 Ci = 3.7×10^{10} disintegrations per second
millicurie (mCi)	1 Ci = 1000 mCi
microcurie (μCi)	1 Ci = 1,000,000 μCi

2.6 Radiation Units and Half-Lives

- **Half-Life**
  - Every radioactive isotope emits radiation, at a different rate.
  - Unstable isotopes emit radiation more rapidly.
  - The rate of decay is measured as **half-life,** the time it takes for one-half (50%) of the atoms in a sample to decay.
  - Decay is measured on a Geiger counter.

2.6 Radiation Units and Half-Lives

- **Half-Life**
  - Natural radioisotopes have long half-lives.
  - Radioisotopes used in medicine have short half-lives; radioactivity is eliminated quickly.

TABLE 2.7 Half-Lives of Some Radioisotopes

Radioisotope	Symbol	Half-Life	Radioisotope	Symbol	Half-Life
Naturally occurring radioisotopes			***Radioisotopes used in medicine***		
Hydrogen-3 (tritium)	^{3}H	12.3 years	Chromium-51	^{51}Cr	28 days
Carbon-14	^{14}C	5730 years	Fluorine-18	^{18}F	110 minutes
Radium-226	^{226}Ra	1600 years	Iron-59	^{59}Fe	45 days
Uranium-238	^{238}U	4.5 billion years	Phosphorus-32	^{32}P	14.3 days
			Technetium-99m	^{99m}Tc	6.0 hours
			Iodine-123	^{123}I	13.2 hours
			Iodine-131	^{131}I	8 days

2.6 Radiation Units and Half-Lives

- Determining Half-Life
  - **Step 1:** Determine the total number of half-lives.
  - **Step 2**: Determine the amount of isotope remaining.
- Another way this can be solved is by using the equation

$$\text{isotope remaining} = \left(\frac{1}{2}\right)^{n} \times \text{starting amount}$$

where n = the number of half-lives determined

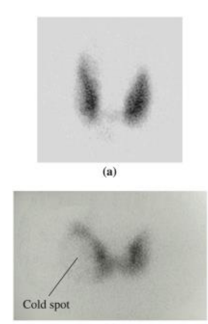
2.7 Medical Applications for Radioisotopes

- Nuclear radiation can be high-energy particles or high-energy rays.
- Some radioisotopes of elements are useful in medical imaging, as they concentrate in particular tissues.
- The radiation can create an image on a photographic plate or be detected by scanning sections of the body.

2.7 Medical Applications for Radioisotopes

2.7 Medical Applications for Radioisotopes

- It is important to expose patients to the smallest possible dose of radiation for the shortest time period.
- Radioisotopes with short half-lives are selected for use in nuclear medicine.
- Iodine is used only by the thyroid gland:



(a) (b)

2.7 Medical Applications for Radioisotopes

- The two main uses of medical radioisotopes are the following:
  - Diagnosing diseased states
  - Therapeutically treating diseased tissues
- When diagnosing a diseased state, a minimum amount of radioisotope is administered.
- The isotope is for detection only and should have minimal effects on body tissue.
- A radioisotope used this way is a **tracer.**

2.7 Medical Applications for Radioisotopes

- Gamma emitters are useful for diagnosis because gamma radiation can easily exit the body.
- If tissue is functioning normally, the radioisotope will be evenly distributed throughout the organ.
- If there is a nonfunctioning area in the tissue, a “cold” spot is seen.
- Unusual activity, like rapidly dividing cancer cells, shows up as a “hot” spot.

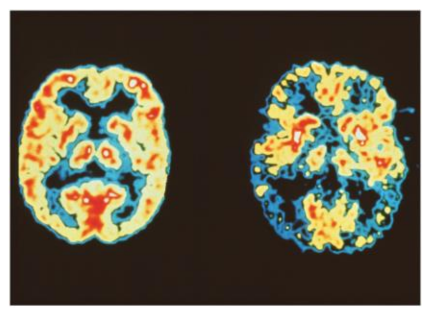
2.7 Medical Applications for Radioisotopes

- **Radioisotopes and Cancer Treatment**
- In *external beam radiation therapy*, gamma radiation generated from cobalt-60 is aimed at a tumor, destroying the tissue.
- In *brachytherapy*, small titanium “seeds” containing radioisotopes are implanted in a tumor.

In brachytherapy, small titanium seeds containing a radioisotope like Pd-103 or I-125 are implanted at the tumor site.

2.7 Medical Applications for Radioisotopes

- **Positron Emission Tomography**



2.7 Medical Applications for Radioisotopes

- **Positron Emission Tomography**
  - PET scans are used to identify functional abnormalities in organs and tissues.
  - Fluorine-18 has a half-life of 110 min.
  - The fluorine isotope emits a positron as it decays to form oxygen-18.
  - The positron comes into contact with an electron, and gamma radiation is produced and detected by the scanner.
  - This type of scan is commonly used for the brain.

Chapter Two Summary

- **2.1 Atoms and Their Components**
  - An atom consists of three subatomic particles: protons, neutrons, and electrons.
  - Protons have a positive charge, neutrons have no charge, and electrons have a negative charge.
  - Most of the mass of an atom comes from the protons and neutrons located in the center, or nucleus, of an atom.
  - The unit for the mass of an atom is the atomic mass unit (amu); each proton and neutron in an atom weighs approximately 1 amu.

Chapter Two Summary (continued)

- **2.2 Atomic Number and Mass Number**
  - The atomic number of an atom defines the number of protons present in an atom.
  - All atoms of a given element have the same number of protons.
  - The mass number of an atom is the total number of protons and neutrons in a given atom of an element.
- **2.3 Isotopes and Atomic Mass**
  - The mass number is the number of protons and neutrons for a *given* isotope.
  - For example, nitrogen-14 has seven protons and seven neutrons.
  - The atomic mass is the average atomic mass for *all* the isotopes of an element found in nature.
  - This number is found on the periodic table often below the element symbol.

Chapter Two Summary (continued)

- **2.4 Radioactivity and Radioisotopes**
  - Some atomic isotopes emit radiation (a form of energy) spontaneously from their nucleus in a process called radioactive decay.
  - Isotopes that undergo radioactive decay are called radioisotopes, and the high-energy particles given off in this process are referred to as ionizing radiation, or radioactivity.
  - Three common forms of radioactivity are alpha (α) and beta (β) particles and gamma (γ) rays.
  - An X-ray is also a form of ionizing radiation, although it is not caused by a radioactive decay event.
  - Different forms of ionizing radiation penetrate the body differently, producing different biological effects.

Chapter Two Summary (continued)

- **2.5 Nuclear Equations and Radioactive Decay**
  - The radioactive decay of a radioisotope can be represented symbolically in the form of a nuclear decay equation.
  - The number of protons and the mass number found in the reactant (the decaying radioisotope) is equal to the sum of the number of protons and the mass numbers found in the products (the stable isotope and the radioactive particle).

Chapter Two Summary (continued)

- **2.6 Radiation Units and Half-Lives**
  - Radioactive decay is measured as the number of decay events, or disintegrations, that occur in 1 second.
  - The common unit for measuring radioactive decay is the curie (Ci), and the SI unit is the becquerel (Bq).
  - For the smaller quantities in medical applications, the microcurie (μCi) is often used. A curie is 3.7×10^{10} becquerels.
  - A becquerel is equal to a disintegration per second.
  - The half-life of a radioisotope is the amount of time it takes for one-half of the radiation in a given sample to decay.
  - Most radioisotopes used in medicine have short half-lives, allowing the radioactivity to be more quickly eliminated from the body.

Chapter Two Summary (continued)

- **2.7 Medical Applications for Radioisotopes**
  - Certain elements concentrate in particular organs of the body.
  - If a radioisotope of this element can be made, this area of the body can be imaged using that radioisotope.
  - A patient can be injected with a trace amount of a radioisotope to diagnose a diseased state.
  - Radioisotopes can also be used to treat diseases.
  - Radioisotopes can be applied externally (external beam radiation therapy) or internally (brachytherapy) by applying radiation directly at the tumor site in high doses, eliminating cancerous cells.
  - Positron emission tomography (PET) uses a radioisotope to image tissues that are not functioning normally.

Chapter Two Study Guide

- **2.1 Atoms and Their Components**
  - Name the kind of subatomic particles that make up an atom.
  - Locate the subatomic particles in an atom.
  - Predict the mass of an atom from the number of subatomic particles.
- **2.2 Atomic Number and Mass Number**
  - Define atomic number.
  - Determine the mass number for a given atom.
- **2.3 Isotopes and Atomic Mass**
  - Define isotope.
  - Distinguish between mass number and atomic mass.

Chapter Two Study Guide (continued)

- **2.4 Radioactivity and Radioisotopes**
  - Define radioactivity.
  - Distinguish between the forms of ionizing radiation.
  - Differentiate the penetrating power of the forms of ionizing radiation.
- **2.5 Nuclear Equations and Radioactive Decay**
  - Write a balanced nuclear decay equation for alpha, beta, gamma, and positron emissions.
- **2.6 Radiation Units and Half-Lives**
  - Perform dosing calculations using radiation activity units.
  - Determine the remaining dose of a radioactive isotope given the half-life.
- **2.7 Medical Applications for Radioisotopes**
  - Contrast the use of radioisotopes for the diagnosis and treatment of disease.