CHAPTER 3
THE STRUCTURE OF MATTER

CENTURIES OF DISCOVERY

Greek Atom
- Atomos means indivisible
- Four Substances: earth, water, air, & fire
- Four Essences: wet, dry, hot, & cold

Substances/Elements
- 112 identified
- 92 naturally occurring
- 20 artificially produced

An atom is the smallest particle that has all the properties of an element!

Subatomic Particles
- Particles smaller than atom

Dalton Atom
- Hook-and-eye affair

John Dalton (1808)
- He showed that elements could be classified according to integral values of atomic mass

Dmitri Mendeleev
- First periodic table of elements

Alkali Metals
- Group 1 elements
- All soft metals that combine readily with oxygen & react violently with water

Halogens
- Group VII elements
- Easily vaporized & combine with metals to form water-soluble salts

Noble Gas
- Group VIII elements
- Highly resistant to reaction with other elements

Thomson Atom
- Plum pudding
- Plum: negative electric charges (electrons)

J.J. Thomson (1890)
- He investigated the physical properties of cathode rays (electrons)
- He concluded that electrons were integral parts of all atoms

Ernest Rutherford (1911)
- Nuclear model
- He disproved Thomson’s model
- He described the atom as containing a small, dense, positively charged center surrounded by a negative cloud of electrons
- He called the center of the atom the nucleus

Bohr Atom (1913)
- Miniature solar system
- He improved Rutherford’s description of the atom
- The electrons revolved about the nucleus in prescribed orbits or energy levels

Quantum-chromodynamics (QCD)
- More accurately described the details of atomic structure

FUNDAMENTAL PARTICLES

Particle Accelerator
- Atom smasher
- It is used in mapping the structure of atomic nucleus

Nucleons
- Protons (+) & neutrons (O)
- It is composed of quarks & gluons (subatomic particles)

The fundamental particles of an atom are the electron, proton & the neutron!
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Electron
- Location: orbital shells
- Relative: 1
- Mass in kg: 9.1 x 10^{-31}
- Mass in amu: 0.000549
- Number: 0
- Charge: -1
- Symbol: -

Proton
- Location: nucleus
- Relative: 1836
- Mass in kg: 1.673 x 10^{-27}
- Mass in amu: 1.00728
- Number: 1
- Charge: 1
- Symbol: +

Neutron
- Location: nucleus
- Relative: 1838
- Mass in kg: 1.675 x 10^{-27}
- Mass in amu: 1.00867
- Number: 1
- Charge: 0
- Symbol: O

Atomic Mass Unit
- The mass of a neutral atom of an element
- Symbol: amu
- 1 amu: ½ the mass of a carbon-12 atom

Atomic Mass Number
- Number of protons plus number of neutrons in the nucleus
- Symbol: A
- Formula: protons + neutrons

Number of Protons
- Determine the chemical behavior of an atom
- Determine the chemical element

Isotopes
- Same number of protons, but different number of neutrons

In their normal state, atoms are electrically neutral; the electric charge on the atom is zero!

Electron Arrangement
- The number of electrons in the outermost shell of an atom = group in the periodic table & determines the valence of an atom
- The number of outermost electron shell of an atom = period in the periodic table

Maximum Electrons Per Shell
- Formula: 2n²

Principal Quantum Number
- The shell number (n)

No outer shell can contain more than eight electrons!

Orderly Scheme of Atomic Progression
- Interrupted in fourth period

Transitional elements
- Atoms associated with the phenomenon mentioned above

Centripetal Force
- Center-seeking force
- The force that keeps an electron in orbit

Centrifugal Force
- Flying-out-from-the-center force
- The force that causes an electron to travel straight and leave the atom

Neutral Atom
- Same number of electrons & protons
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Electron Binding Energy
- The strength of attachment of an electron to the nucleus
- Symbol: \( E_b \)

Tungsten (W-74) & Molybdenum (Mo-42)
- The primary constituents of x-ray tube target

Barium (Ba-56) & Iodine (I-53)
- Radiographic & fluoroscopic contrast agents

Carbon (C-6)
- The important component of human tissue

Ionization Potential
- The amount of energy (34 keV) necessary to ionize tissue atoms

**ATOMIC NOMENCLATURE**

Chemical Symbols
- The alphabetic abbreviations of an element

Number & Arrangement of Electrons
- It determines the chemical properties of an element

Atomic number
- Number of Protons
- Symbol: \( Z \)

Atomic Mass Number
- Number protons plus number of neutrons
- Symbol: \( A \)

The atomic number & the precise mass of an atom are not equal!

Carbon-12 Atom
- Its A & Z are equal
- Rationale: it is the arbitrary standard for atomic measure

Elemental Mass
- It is determined by the relative abundance of isotopes & their respective atomic masses

Protocol for Representing Elements in a Molecule
- **Upper Left**: atomic mass (A)
- **Lower Left**: atomic number (Z)
- **Upper Right**: valence state (+/-)
- **Lower Right**: number of atoms/molecules

<p>| CHARACTERISTICS OF SOME ELEMENTS IMPORTANT TO RADIOLOGIC SCIENCE |
|------------------------|---------|------|-----------------|</p>
<table>
<thead>
<tr>
<th>Element</th>
<th>Chemical Symbol</th>
<th>Z</th>
<th>A</th>
<th>Naturally Occurring Isotopes</th>
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<tbody>
<tr>
<td>Beryllium</td>
<td>Be</td>
<td>4</td>
<td>9</td>
<td>1</td>
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<tr>
<td>Carbon</td>
<td>C</td>
<td>6</td>
<td>12</td>
<td>3</td>
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<tr>
<td>Oxygen</td>
<td>O</td>
<td>8</td>
<td>16</td>
<td>3</td>
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<tr>
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<td>13</td>
<td>27</td>
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<tr>
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<td>Ruthenium</td>
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<td>10</td>
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<td>53</td>
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<td>74</td>
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<tr>
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<td>Au</td>
<td>79</td>
<td>197</td>
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<tr>
<td>Lead</td>
<td>Pb</td>
<td>80</td>
<td>208</td>
<td>4</td>
</tr>
<tr>
<td>Uranium</td>
<td>U</td>
<td>92</td>
<td>238</td>
<td>3</td>
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</tbody>
</table>

<p>| CHARACTERISTICS OF VARIOUS NUCLEAR ARRANGEMENTS |
|-------------------------------|-----|-------|--------|</p>
<table>
<thead>
<tr>
<th>Arrangement</th>
<th>Atomic Number</th>
<th>Atomic Mass Number</th>
<th>Neutron Number</th>
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<tbody>
<tr>
<td>Isotope</td>
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<td>different</td>
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<tr>
<td>Isobar</td>
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<td>same</td>
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</tr>
<tr>
<td>Isotone</td>
<td>different</td>
<td>different</td>
<td>same</td>
</tr>
<tr>
<td>Isomer</td>
<td>same</td>
<td>same</td>
<td>same</td>
</tr>
</tbody>
</table>

Technetium-99m (Tc-43)
- It decays to technetium-99
- Energy Emitted: 140 keV gamma rays
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COMBINATIONS OF ATOMS

Molecules
- The group of atoms of various elements
- The smallest unit of a compound

Sodium chloride (NaCl)
- Common table salt

Chemical Compound
- Any quantity of one type of molecule

CHON (C-6, H-1, O-8, N-7)
- Carbon, Hydrogen, Oxygen, Nitrogen
- 90% of the human body

Water
- 80% of the human body

Covalent Bond
- The chemical union between atoms formed by sharing one or more pairs of electrons
  - Example: H₂O

Ionic Bond
- The bonding that occurs because of an electrostatic force between ions
  - Example: NaCl

Sodium bicarbonate (NaHCO₃)
- Baking soda

The smallest particle of an element is an atom; the smallest particle of a compound is a molecule!

RADIOACTIVITY

Radioactivity
- The emission of particles & energy in order to become stable

Radioactive Decay/Radioactive Disintegration
- The process by which the nucleus spontaneously emits particles & energy & transforms itself into another atom to reach stability
- It occurs when the nucleus contains too few or too many neutrons

Radioisotopes
- Radioactive atoms that have the same number of protons

Uranium (U-92) & Carbon-14
- Two primary source of naturally occurring radioisotopes

Beta Emission
- It occurs in all radioisotopes
- It occurs more frequently than alpha emission
  - Results:
    - Loss of small quantity of mass & one unit of negative electric charge
    - To increase the Z by one while A remains the same
    - Changing of an atom from one type of element to another
    - Neutron undergoes conversion to a proton

Alpha Emission
- It occurs only in heavy radioisotopes
- It is much more violent process
- It consists of 2 protons & 2 neutrons
- Atomic Mass Number: 4
  - Results:
    - Nucleus loses 2 units of positive charge & 4 units of mass
    - Chemically different atom & an atom lighter than 4 amu

Radioactive Half-life
- The time required for a quantity of radioactivity to be reduced to one-half its original value
- Symbol: T₁/₂
- I-131: T₁/₂ = 8 days
- C-14: T₁/₂ = 5730 days
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Radioactive Decay Law
- It describes the rate of radioactive decay & the quantity of material present at any given time
- Formula: Activity Remaining = Original Activity \((0.5)^n\)
- \(n\): number of half lives

TYPES OF IONIZING RADIATION

Five Physical Characteristics
- Mass, Energy, Velocity, Charge & Origin

Particulate Radiation
- It has finite range in matter
- Examples: alpha & beta Particles

Alpha Particle
- Equivalent to a helium nucleus
- It contains 2 protons & 2 neutrons
- Symbol: \(\alpha\)
- Mass: 4 amu
- Charge: +2
- Origin: nucleus of heavy radioactive nuclei
- Energy: 4-7 MeV
- Range: 1-10 cm (air); <0.1 mm (soft tissue)
- Ionization Rate: 40,000 atoms/cm

Beta Particle
- Light particles
- Symbol: \(\beta^-\) or \(\beta^+\)
- Mass: 0 amu
- Charge: -1 or +1
- Origin: nucleus of radioactive nuclei
- Energy: 0-7 MeV
- Range: 10-100 cm (air); 1-2 cm (soft tissue)
- Ionization Rate: several hundred of atoms/cm

Negative Beta Particles
- The same with electrons, they only differ in origin

Positive Beta Particles
- The same mass with electrons
- Positrons

Electromagnetic Radiation
- Examples: x-rays & gamma rays
- They only differ in origin
- It is often called photons
- It has unlimited range in matter

Photons
- No mass & no charge
- Travel at the speed of light \((c)\)
- \(c\): \(3 \times 10^8\) m/s or \(1.86 \times 10^5\) mi/s

X-rays and gamma rays are the only forms of ionizing electromagnetic radiation of radiologic interest!

X-rays
- Symbol: \(X\)
- Mass: 0
- Charge: 0
- Origin: electron cloud
- Energy: 0-25 MeV
- Range: 0-100 m (air); 0-30 cm (soft tissue)
- Ionization Rate: 100 ip/cm (equal to beta particles)

Gamma Rays
- Symbol: \(\gamma\)
- Mass: 0
- Charge: 0
- Origin: nucleus/radioactive nuclei
- Energy: 0-5 MeV
- Range: 0-100 m (air); 0-30 cm (soft tissue)
- Ionization Rate: 100 ip/cm (equal to beta particles)

Nonionizing Radiation
- A type of radiation used in UTZ & MRI