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Radiation Physics

Chapter 2

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Learning Objectives

Lesson 2.1: Atoms, Ionization, and Radiation

1. Define the key terms associated with radiation physics.
2. Identify the structure of the atom.
3. Describe the process of ionization.
4. Discuss the difference between radiation and radioactivity.
5. List the two types of ionizing radiation and give examples of each.
6. List the characteristics of electromagnetic radiation.

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Introduction

- Purpose
 - To present the fundamental concepts of atomic and molecular structure
 - To define and characterize x-radiation
 - To introduce the x-ray machine
 - To describe in detail how x-rays are produced

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Atomic and Molecular Structure

- Matter
 - Matter is anything that occupies space and has mass.
 - When matter is altered, energy results.
- Atom
 - An atom is the fundamental unit of matter.
 - All matter is composed of atoms.

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Atomic Structure

- Atom
 - Atom is a central nucleus and orbiting electrons.
 - The identity is determined by the composition of the nucleus and the arrangement of orbiting electrons.

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Nucleus

- Nucleus is composed of protons and neutrons.
 - Protons have positive electrical charges.
 - Neutrons carry no electrical charge.
- Most of the atom is empty space.

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Nucleus (Cont.)

- The number of protons and neutrons in the nucleus of an atom determines its mass number or atomic weight.
- The number of protons inside the nucleus equals the number of electrons outside the nucleus and determines the atomic number.
 - Atoms are arranged in increasing atomic number on the periodic table of the elements.

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Electrons

- Electrons are tiny, negatively charged particles.
 - These have very little mass, approximately $1/1800$ as much as a proton or neutron.
 - Electrons travel around the nucleus in well-defined paths known as *orbits* or *shells*.
 - The shell located closest to the nucleus has the highest energy level.

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Electrons (Cont.)

- Electrons are maintained in their orbits by electrostatic force between the positive nucleus and negative electrons.
 - They are known as the *binding energy* of an electron.
- Binding energy is determined by the distance between the nucleus and the orbiting electron.
 - The strongest binding energy is found closest to the nucleus in the K shell.
 - It is measured in electron volts or kilo electron volts.

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Molecular Structure

- Atoms are capable of combining with one another to form molecules.
 - Molecules are two or more atoms joined by chemical bonds, or the smallest amount of a substance that possesses its characteristic properties.

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Molecular Structure (Cont.)

- Molecules are formed in two ways.
 - The transfer of electrons
 - The sharing of electrons between the outermost shells of atoms

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Ionization

- Ionization
 - Normally, most atoms are neutral.
 - A neutral atom contains an equal number of protons and electrons.
 - An atom with an incompletely filled outer shell attempts to capture an electron from an adjacent atom.

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Ionization (Cont.)

- If the atom gains an electron, it has a negative charge.
- If the atom loses an electron, it has a positive charge.
- An atom that gains or loses an electron and becomes electrically unbalanced is called an *ion*.

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Ionization (Cont.)

- Ionization is the production of ions, or the process of converting an atom into ions.
- When an electron is removed from an atom in the ionization process, an ion pair results.
 - The atom becomes the positive ion.
 - The ejected electron becomes the negative ion.

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Radiation and Radioactivity

- Radiation
 - Radiation is the emission and propagation of energy through space or a substance in the form of waves or particles.
- Radioactivity
 - Radioactivity is the process by which certain unstable atoms or elements undergo spontaneous disintegration, or decay, in an effort to attain a more balanced nuclear state.

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Ionizing Radiation

- Radiation is capable of producing ions by removing or adding an electron to an atom.
 - Classified into two groups
 - Particulate radiation
 - Electromagnetic radiation

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Particulate Radiation

- Particulate radiation is tiny particles of matter that possess mass and travel in straight lines and at high speeds.
 - There are four types.

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Particulate Radiation (Cont.)

- (1) Electrons
 - Beta particles are fast-moving electrons emitted from nucleus of radioactive atoms.
 - Cathode rays are streams of high-speed electrons that originate in an x-ray tube.
 - Electrons emitted by a manufactured device
- (2) Alpha particles
 - Alpha particles are emitted from the nuclei of heavy metals.
 - They exist as two protons and neutrons, without electrons.

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Particulate Radiation (Cont.)

- (3) Protons
 - Accelerated hydrogen nuclei
 - Mass of 1 and charge of +1
- (4) Neutrons
 - Accelerated particles
 - Mass of 1, no electrical charge

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Electromagnetic Radiation

- This is the propagation of wavelike energy (without mass) through space or matter.
 - Oscillating electric and magnetic fields are positioned at right angles to one another.
- They may be artificial or occur naturally.
 - They are arranged in the electromagnetic spectrum according to their energies.

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Electromagnetic Radiation (Cont.)

- All have common characteristics.
 - They may be classified as ionizing or non-ionizing.
- Only high-energy radiations are capable of ionization.
- They are believed to move through space as both a particle and a wave; both concepts must be considered.

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Particle Concept

- Particle concept characterizes electromagnetic radiation in terms of discrete bundles of energy called *photons* or *quanta*.
 - Photons are bundles of energy with no mass or weight.
 - Photons travel as waves at the speed of light and move through space in a straight line.

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Wave Concept

- Characterizes electromagnetic radiations as waves
 - Velocity
 - The speed of the wave
 - Wavelength
 - The distance between the crest of one wave and the crest of the next
 - Frequency
 - The number of wavelengths that pass a certain point in a given length of time

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Learning Objectives

Lesson 2.2: Dental X-Rays

7. List the properties of x-radiation.
8. Identify the component parts of the x-ray machine.
9. Label the parts of the dental x-ray tubehead and the dental x-ray tube.
10. Describe in detail how dental x-rays are produced.
11. List and describe the possible interactions of x-rays with matter.

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X-Radiation

- X-radiation is high-energy, ionizing electromagnetic radiation.
- X-rays
 - X-rays are weightless bundles of energy without an electrical charge that travel in waves with a specific frequency at the speed of light.
- X-ray photons interact with the materials they penetrate and cause ionization.

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X-Ray Machine: Component Parts

- Control panel
- Extension arm
- Tubehead

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Control Panel

- Contains an on-off switch
- Indicator light
- Control devices
 - Time, kilovoltage, milliamperage
- Plugged into an electrical outlet

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Extension Arm

- Suspends the x-ray tubehead
- Houses the electrical wires that extend from the control panel to the tubehead
- Allows for movement and positioning of the tubehead

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Tubehead

- A tightly sealed, heavy metal housing
 - Contains the x-ray tube that produces dental x-rays
- Metal housing
 - Surrounds the x-ray tube and transformers, protects tube and grounds high-voltage components
- Insulating oil
 - Surrounds x-ray tube and transformers, prevents overheating

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Tubehead (Cont.)

- Tubehead seal
 - Permits exit of x-rays from tubehead, seals the oil, filters x-ray beam
- X-ray tube
 - Heart of generating system
- Transformer
 - Alters voltage of incoming electricity

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Tubehead (Cont.)

- Aluminum disks
 - Filter out nonpenetrating, longer wavelength x-rays
- Lead collimator
 - Restricts size of x-ray beam
- Position-indicating device (PID)
 - Aims and shapes the x-ray beam

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X-Ray Tube

- A glass vacuum tube
 - Measures several inches long by 1 inch in diameter
- Includes:
 - Leaded-glass housing
 - Cathode
 - Anode

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Leaded-Glass Housing

- A leaded-glass vacuum tube
 - Prevents x-rays from escaping in all directions
 - One area has a “window” that permits the x-ray beam to exit the tube and directs the beam toward the aluminum disks, lead collimator, and PID.

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Cathode (-)

- The negative electrode
 - Consists of a tungsten wire filament in a cup-shaped holder made of molybdenum
 - Supplies the electrons necessary to generate x-rays
 - The tungsten filament produces electrons when heated.
 - The molybdenum cup focuses electrons into a narrow beam and directs the beams toward the tungsten target.

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Anode (+)

- The positive electrode
 - Consists of a wafer-thin tungsten plate embedded in a solid copper rod
 - Converts electrons into x-ray photons
 - The tungsten target serves as a focal spot and converts electrons into photons.
 - The copper stem functions to dissipate heat away from the tungsten target.

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X-Ray Generating Apparatus

- Electricity and electrical currents
- Circuits
- Transformers

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Electricity and Electrical Currents

- Electricity
 - The energy used to make x-rays
- Electrical current
 - A flow of electrons through a conductor

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Electricity and Electrical Currents (Cont.)

- Direct current (DC)
 - When electrons flow in one direction through a conductor
- Alternating current (AC)
 - When electrons flow in two opposite directions
- Rectification
 - The conversion of alternating current to direct current

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Electricity and Electrical Currents (Cont.)

- Amperage
 - Amperage is the measurement of the number of electrons moving through a conductor.
 - Current is measured in amperes (A) or milliamperes (mA).
- Voltage
 - Voltage is the measurement of electrical force that causes electrons to move from a negative pole to a positive one.
 - Voltage is measured in volts (V) or kilovolts (kV).

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Electricity and Electrical Currents (Cont.)

- Milliamperage adjustment
 - Can increase or decrease the number of electrons passing through the cathode filament
- Kilovoltage peak (kVp) adjustment
 - Can control the current passing from the cathode to the anode

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Circuits

- Circuit
 - A path of electrical current
 - Filament circuit
 - Uses 3 to 5 volts
 - Regulates flow of electrical current to the filament
 - Controlled by milliamperage settings
 - High-voltage circuit
 - Uses 65,000 to 100,000 volts
 - Provides high voltage required to generate x-rays
 - Controlled by kilovoltage settings

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Transformers

- A transformer is a device used to either increase or decrease the voltage in an electrical circuit.
- Three transformers are used to adjust the electrical circuits.
 - Step-down transformer
 - Step-up transformer
 - Autotransformer

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Step-Down Transformer

- Used to decrease voltage from the incoming 110- or 220-line voltage to the 3 to 5 volts used by the filament circuit
 - More wire coils in the primary coil than in the secondary coil

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Step-Up Transformer

- Used to increase incoming voltage to 65,000 to 100,000 volts used by the high-voltage circuit
 - More wire coils in the secondary coil than in the primary coil

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Autotransformer

- A voltage compensator
 - Corrects for minor fluctuations in current

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Production of X-Radiation

- Production of dental x-rays
- Types of x-rays produced
- Definitions of x-radiation

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Production of Dental X-Rays

- Electricity from the wall outlet supplies the power to generate x-rays.
- The current is directed to the filament circuit and step-down transformer in the tubehead.
- The filament circuit uses 3 to 5 volts to heat the tungsten filament in the cathode.
- Thermionic emission occurs, and the release of electrons.

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Production of Dental X-Rays (Cont.)

- The electrons stay in an electron cloud until the high-voltage circuit is activated.
- When the exposure button is pushed, the high-voltage circuit is activated.
- The molybdenum cup in the cathode directs electrons to the tungsten target in to anode.
- When electrons strike the tungsten target, less than 1% of the energy is converted to x-rays, and the remaining 99% is lost as heat.

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Production of Dental X-Rays (Cont.)

- A small number of x-rays are able to exit the x-ray tube through the unleaded glass window portion of the tube.
- X-rays travel through the unleaded glass window, the tubehead seal, and aluminum disks.
- The size of the x-ray beam is restricted by the lead collimator.
- The x-ray beam exits the tubehead at the opening of the PID.

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Types of X-Rays Produced

- X-rays differ in energy and wavelength.
- Two mechanisms
 - General (braking) radiation
 - Characteristic radiation

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General Radiation

- Many electrons that interact with the tungsten atoms undergo not one but many interactions within the target.
 - Most x-rays (about 70%) are produced in this manner.
- Reduced when an electron hits the nucleus of a tungsten atom or passes very close to the nucleus of a tungsten atom

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Characteristic Radiation

- Characteristic radiation is produced when a high-speed electron dislodges an inner-shell electron from a tungsten atom and causes ionization of that atom.
 - The remaining orbiting electrons are rearranged to fill the vacancy.
 - This occurs only at 70 kVp and above.

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Definitions of X-Radiation

- Primary radiation
 - The penetrating x-ray beam that is produced at the target of the anode
- Secondary radiation
 - X-radiation created when the primary beam interacts with matter
- Scatter radiation
 - A form of secondary radiation, the result of an x-ray that has been deflected from its path by an interaction with matter

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Interactions of X-Radiation

- No interaction
- Absorption of energy and photoelectric effect
- Compton scatter
- Coherent scatter

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No Interaction

- The x-ray photon passes through the atom unchanged and leaves the atom unchanged.
 - These photons are responsible for producing densities on film and make dental radiography possible.

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Absorption of Energy and Photoelectric Effect

- The x-ray photon is completely absorbed within matter or the tissues of the patient.
 - Absorption
 - The total transfer of energy from photon to the atoms of matter
 - Photoelectric effect
 - An x-ray photon collides with a tightly bound, inner-shell electron and gives up all its energy to eject the electron from its orbit.
 - The ejected photoelectron is absorbed by other atoms.

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Compton Scatter

- The x-ray photon is deflected from its path during its passage through matter.
 - In Compton scatter, ionization takes place.
 - An x-ray photon collides with a loosely bound, outer-shell electron and gives up part of its energy to eject the electron from its orbit.
 - The x-ray photon loses energy and continues in a different direction at a lower energy level.
 - The ejected electron is termed a *Compton electron*.

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Coherent Scatter

- Coherent scatter is an x-ray photon that has its path altered by matter.
 - A low-energy x-ray photon interacts with an outer-shell electron.
 - No change in the atom occurs, and an x-ray photon of scatter radiation is produced.

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Questions?

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