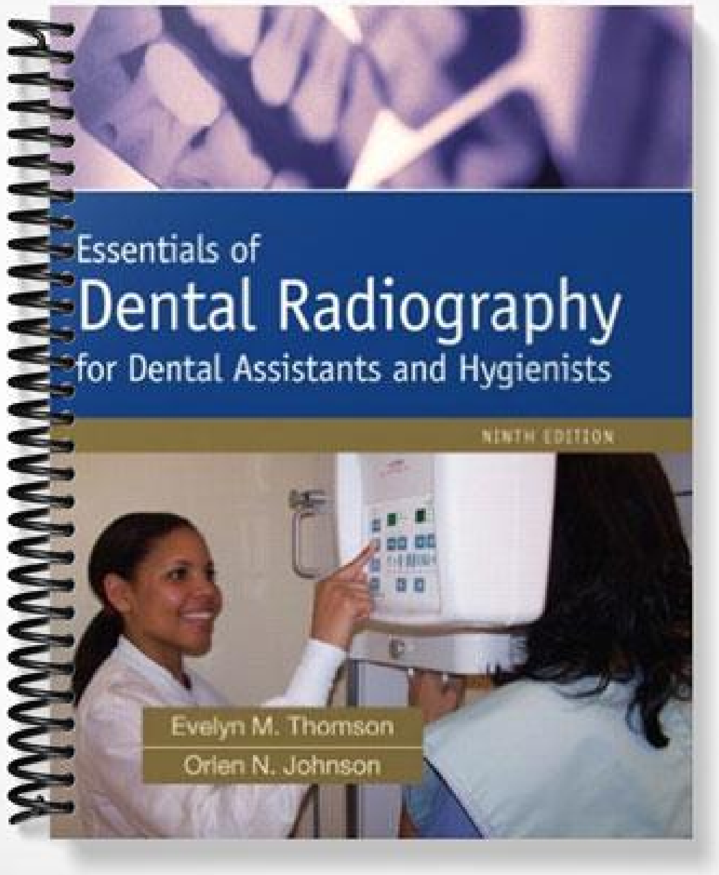
SOLUTIONS MANUAL



2
Characteristics and Measurement of Radiation

Objectives

Following successful completion of this chapter, the student should be able to:

1. Define the key words.
2. Draw and label a typical atom.
3. Describe the process of ionization.
4. Differentiate between radiation and radioactivity.
5. List the properties shared by all energies of the electromagnetic spectrum.
6. Explain the relationship between wavelength and frequency.
7. Explain the inverse relationship between wavelength and penetrating power of x-rays.
8. List the properties of x-rays.
9. Identify and describe the two processes by which kinetic energy is converted to electromagnetic energy within the dental x-ray tube.
10. List and describe the four possible interactions of dental x-rays with matter.
11. Define the terms used to measure x-radiation.
12. Match the Système Internationale (SI) units of x-radiation measurement to the corresponding traditional terms.
13. Identify three sources of naturally occurring background radiation.

Key Words

Absorbed dose

Absorption

Alpha particle

Angstrom (Å)

Atom

Atomic number

Atomic weight

Background radiation

Beta particle

Binding energy

Characteristic radiation

Coherent scattering

Compton effect (scattering)

Coulombs per kilogram (C/kg)

Decay

Dose

Dose equivalent

Effective dose equivalent

Electromagnetic radiation

Electromagnetic spectrum

Electron

Element

Energy

Energy levels

Exposure

Frequency

Gamma rays

General/bremsstrahlung radiation

Gray (Gy)

Hard radiation

Ion

Ion pair

Ionization

Ionizing radiation

Isotope

Kinetic energy

Microsievert (μSv)

Molecule

Neutron

Particulate radiation

Photoelectric effect

Photon

Proton

Rad

Radiation

Radioactivity

Radiolucent

Radiopaque

Rem

Roentgen (R)

Secondary radiation

Sievert (Sv)

Soft radiation

Système Internationale (SI)

Velocity

Wavelength

Weighting factor

Chapter Outline

I. Introduction

   A. Matter

      1. Anything that occupies space and has mass
      2. All things we see and recognize are forms of matter

B. Energy
   1. The ability to do work and overcome resistance
   2. Heat, light, electricity, and x-radiation are forms of energy

II. Atomic structure
   A. Currently 118 basic elements
   B. Each element is made up of atoms
   C. Atom is smallest particle of an element that still retains the properties of the element
   D. Molecule is the smallest particle of a substance that retains the properties of that substance
   E. Atoms combine to form molecules
   F. Atoms composed of three building blocks
      1. Electrons—negative charge
      2. Protons—positive charge
      3. Neutrons—no charge
   G. Atom has a nucleus that contains protons and neutrons
   H. Electrons orbit the nucleus of the atom in shells or energy levels
      1. The innermost shell is referred to as the “K” shell, the next is the “L” shell; this system continues for seven shells
      2. Electrons are held in their orbits by binding energy
      3. Binding energy is greatest in the “K” shell, which is closest to the nucleus, and gets weaker in the outer shells
   I. Atom is neutral when it has the same number of electrons and protons

III. Ionization
   A. Ion

1. Atom that has gained or lost an electron
2. Electrically unbalanced or unstable

B. Positive ion
    1. Neutral atom that has lost an electron
    2. More protons than electrons
    3. Positively charged

C. Negative ion—the electron that was separated from the neutral atom

D. Ion pair—the positively charged atom ion and the negatively charged electron ion

E. Ionization—the formation of ion pairs

F. The ejected high-speed electrons go on to expel electrons from other atoms creating more ion pairs

G. The unstable ions look to gain stability by combining with another oppositely charged ion

IV. Ionizing radiation

A. Radiation is the emission and movement of energy through space in the form of electromagnetic radiation (x and gamma rays) or particulate radiation (alpha and beta particles)

B. Ionizing radiation—any radiation that produces ions

C. In the electromagnetic spectrum only the x-rays, gamma rays, and cosmic rays are capable of causing ionization

D. Regarding dental radiography, concern is limited to the changes in cellular structure caused by the interaction of the x-rays with the patient's tissues

V. Radioactivity

A. The process whereby certain unstable elements undergo spontaneous disintegration (decay) in an effort to attain a stable nuclear state.

B. Dental x-rays do not involve radioactivity

VI. Electromagnetic radiation

   A. The movement of wavelike energy through space as a combination of electric and magnetic fields.
   B. Arranged according to their energies in the electromagnetic spectrum.
   C. Members of the electromagnetic spectrum include x-rays, gamma rays, cosmic rays, radio waves, television waves, microwaves, and visible light
      1. These share the same properties:
         a. Travel at the speed of light
         b. Have no electrical charge
         c. Have no mass or weight
         d. Pass through space as particles and in a wavelike motion
         e. Give off an electrical field at right angles to their path of travel and a magnetic field at right angles to the electric field
         f. Have energies that are measurable and different
   D. Electromagnetic radiations display two contradictory properties; move through space as both a particle and a wave
   E. The particle or quantum theory assumes the electromagnetic radiations are particles or quanta; these particles are called photons—bundles of energy that travel through space at the speed of light (186,000 miles/second)
   F. The wave theory assumes that the electromagnetic radiations move through space in the forms of waves
      1. Electromagnetic waves have three properties
         a. Wavelength—measured in angstroms (Å) units or the metric system (meters or nanometers)—distance between two crests of a wave—the

shorter the wavelength, the more penetrating the radiation

b. Frequency—measured in hertz (Hz)—one hertz equals 1 cycle per second—the number of waves that pass a given point in a specific unit of time—the higher the frequency the more penetrating the radiation

c. Velocity—in a vacuum, all electromagnetic radiations travel at the speed of light—refers to the speed of the wave

2. Wavelength and frequency are inversely related—long wavelength equals low frequency and short wavelength equals high frequency

G. Each form of radiation has a range of wavelengths
   1. Longer infrared waves measured in meters
   2. Shorter infrared waves measured in nanometers or angstroms

H. The longest x-ray waves are called the Grenz waves or soft radiation
   1. These waves have limited penetrating power
   2. Not useful for exposing dental radiographs

I. The shortest x-ray waves are referred to as hard radiation, which means great penetrating power

J. Wavelengths used in diagnostic dental radiography range from 0.1 to 0.5 angstroms (Å)

VII. Properties of x-rays

A. X-rays exist as minute "bundles of energy" or photons

B. Properties of x-rays
   1. Are invisible
   2. Travel in straight lines

3. Travel at the speed of light
4. Have no mass or weight
5. Have no charge
6. Interact with matter causing ionization
7. Can penetrate opaque tissues and structures
8. Can affect photographic film emulsion (causing a latent image)
9. Can affect biological tissue

C. X-ray photons can travel through gases, liquids, or solids

D. Ability to penetrate depends on
   1. Wavelength
   2. Density or thickness of the object
      a. Dense objects with a high atomic number will absorb more x-rays
         1) Image appears lighter gray or white
         2) Radiopaque images
         3) Bone and enamel are more dense
      b. Less dense objects with a low atomic number allow the passage of the x-ray through the object
         1) Image appears dark gray or black
         2) Radiolucent images
         3) Pulp chamber, muscles, skin, and gingival are less dense

VIII. Production of x-rays

A. Generated in the x-ray tube inside the tube head

B. X-rays are produced when high-speed electrons are stopped or slowed down

C. The kinetic energy of the electrons is converted to electromagnetic energy by the formation of general/bremsstrahlung and characteristic radiation

D. General/bremsstrahlung radiation is produced when high-speed electrons are stopped or slowed down by the tungsten atoms of the tungsten target, which is located in the dental tube
    1. When the high-speed electron collides with the nucleus of the tungsten atom, all of the kinetic energy of the electron is transferred into an x-ray photon
    2. When the high-speed electron is slowed down or deflected off course by the pull of the nucleus of the tungsten atom; the kinetic energy lost by the electron when it slows is transferred into an x-ray photon
    3. Most of the x-rays produced in dental x-ray machines are of this type

E. Characteristic radiation is produced when the high-speed electron collides with an electron in the "K" shell of the tungsten atom.
    1. This electron is dislodged from the atom; immediately an outer shell electron moves in to fill the void and an x-ray is emitted
    2. These x-ray photons are "characteristic" of the electron that was emitted
    3. Characteristic radiation can only be produced when the x-ray machine is set at or above 70 kVp as it takes this much energy to overcome the binding energy (energy holding it in its orbit) of the nucleus
    4. Characteristic radiation accounts for a very small part of the x-rays produced in the dental x-ray machine

IX. Interaction of x-rays with matter

A. Absorption—when an x-ray is weakened or dispersed when it interacts with matter

B. The basic method of absorption is ionization

C. The x-ray transfers energy or interacts with matter in one of four ways
    1. No interaction—the x-ray passes through the tissues unchanged; occurs 9 percent of the time
    2. Coherent scattering; occurs 8 percent of the time
        a. Also known as unmodified scattering or Thompson scattering
        b. When a low energy electron passes near an atom's outer electron, it may be scattered or have its course altered without losing any of its energy
        c. The outer shell electron vibrates at the same frequency as the incoming x-ray
        d. The incoming x-ray ceases to exist
        e. The vibration of the outer shell electron produces a new x-ray with the same frequency and energy as the first x-ray
        f. The new x-ray scatters off in a different direction than the first x-ray
        g. Since the new x-ray has the same frequency and energy as the first x-ray, it is said to be unchanged
    3. Photoelectric effect; occurs 30 percent of the time
        a. An incoming x-ray photon imparts all of its energy to an orbiting electron of an atom in the patient's tissues as it collides with the orbiting electron; this collision ejects the electron from its orbit
        b. The incoming x-ray photon ceases to exist

c. The electron that was ejected by the collision and the positive ion that remains form an ion pair

d. The ejected high-speed electron (photoelectron) goes on to eject other electrons from their orbits until all of its energy is used up

e. The positive ion created by these collisions combines with a free electron and is thereby restored to a neutral atom

4. Compton effect—Compton scattering; occurs 60 percent of the time

a. Similar to photoelectric effect, but only part of the energy from the incoming x-ray photon is imparted to the ejected electron

b. The result is a negatively charged, ejected Compton electron (traveling in a different direction from the original x-ray photon), a photon of scattered radiation, and a remaining atom that is now positively charged

c. The ejected Compton electron may then go on to interact with other atoms or may be absorbed by a positive ion looking for an electron to become neutral again

X. Units of radiation

A. The International Commission on Radiation Units and Measurements has established standards for measuring radiation units and quantities

B. There are two sets of terms used to measure radiation

1. Traditional units—older system—now considered obsolete

2. Systèmè Internationale (SI)—newer system—metric equivalent to traditional units

C. Traditional units are

1. Roentgen (R)
2. Rad (radiation absorbed dose)
3. Rem (roentgen equivalent [in] man)

D. Système Internationale units are

1. Coulombs per kilogram (C/kg)
2. Gray (Gy)
3. Sievert (Sv)

E. A quantity is a description of a physical concept. Four quantities are explained here:

1. Exposure—the measurement of ionization in air produced by x or gamma rays only
    a. SI unit is Coulombs per kilogram (C/kg)
    b. Traditional unit is the roentgen (R)
2. Absorbed dose—the amount of energy deposited in any form of matter by any type of radiation—how much energy is absorbed by tissues in the patient
    a. SI unit is the gray (Gy)—one gray equals one joule (J) per kilogram—one Gy = 100 rads
    b. Traditional unit is the rad—one rad equals 0.01 joule (J) per kilogram—one rad = 0.01 Gy
3. Dose equivalent—used for radiation protection purposes to compare the biological effects of the various types of radiation
    a. The product of the absorbed dose times a biological effect weighting factor

b. The weighting factor is a number assigned to each type of radiation to produce the same biological effect

c. The weighting factor for x-rays is 1—absorbed dose and dose equivalent are equal

d. SI unit is the sievert (Sv)—one Sv equals one Gy times the biological weighting factor—1 Sv = 100 rem

e. Traditional unit is the rem—one rem equals one rad times the biological weighting factor—1 rem = 0.01Sv

4. Effective dose equivalent—used to make more accurate comparisons between different types of radiation.

a. Compares the risk of radiation exposure producing a biological response

b. Compensates for the size of the area exposed and the presence of critical tissues within the path of the x-ray beam.

c. Expressed with the label microsievert (µSv).

F. Smaller multiples of these units are used in dental radiography. The word "milli" is often times used as a prefix—milligray (mGy), millisievert (mSv)

XI. Background radiation

A. 50 percent of exposure to the population in general is from naturally occurring (background) sources of ionizing radiation

B. Medical and dental x-rays (artificial or man-made) account for 5 percent of total radiation exposure

C. Medical and dental x-rays when grouped with all medical tests using ionizing radiation such as computed tomography (CT scans) and nuclear medicine account for 48 percent of total radiation exposure

D. Background radiation is ionizing radiation that is always present in our environment.
E. Sources of background radiation include
    1. Cosmic radiation from outer space
    2. Terrestrial radiations from the earth and its environments
    3. Radiations from naturally occurring radionuclides that are deposited in our bodies by inhalation and ingestion
    4. Average background radiation in United States is 6.2 mSv annually (1.7 mSv daily)
    5. Amount varies by altitude and latitude—based on its' altitude, Denver receives more cosmic radiation than a sea-level region

Learning Activities for Students

1. Direct students to draw diagrams of the production process for general/bremsstrahlung radiation and characteristic radiation produced inside the dental x-ray tube and describe how the kinetic energy of electrons is converted to electromagnetic energy.
2. Ask students what they think of when they hear the word "radiation." Record their answers on classroom media so all can see. To add to this list, conduct a brainstorming session where students anticipate patient questions regarding different types of radiation, such as CT scans, tanning beds, cell phones, and microwaves. Discuss and role play patient−radiographer conversations that utilize the information presented in this chapter regarding background and man-made radiations in response to patient questions and concerns regarding radiation exposure.

3. Using SI measurement labels, write various quantities of radiation measurements on slips of paper. Write the equivalent traditional measurement labels on corresponding slips of paper. Give each student a slip of paper, and direct him or her to find the equivalent partner.
4. Direct students to draw diagrams of the four different interactions between x-rays and matter discussed in this chapter.

Discussion Questions

1. What do x-rays have in common with visible light?
2. What is the significance of the electromagnetic spectrum?
3. What is the difference between general/bremsstrahlung and characteristic radiations?
4. How would you respond to a patient who expresses concern regarding radioactivity and who asks about the treatment chair and other objects located in the operatory where dental x-ray exposures take place day after day?
5. After penetrating the image receptor, where does the radiation go?

Teaching Tips

1. Use a model of the solar system to demonstrate atomic structure.
2. Utilizing a set of magnets of varying sizes, demonstrate the pull or attraction of the negative electron to the positive atom. The varying sizes will also allow demonstration of the binding energy of the electrons in the various shells to the nucleus.
3. Compare short and long wavelengths (different energy strengths) with the waves of the ocean. Wave crests that are short and frequent indicate a powerful sea, whereas longer wave crests represent calmer conditions.
4. Develop a list of natural and man-made objects that contain ionizing and non-ionizing radiations for a radiation trivia exercise. Sample items for the list that contain ionizing radiations include televisions,

camping lanterns, bananas, Brazil nuts, cigarettes; and that do not contain ionizing radiation include microwave ovens, MRI (magnetic resonance imaging) scanners, fast-food hamburgers that have undergone radiation to kill E coli bacteria.

5. Prepare a "Roving Radiographers" activity. Develop a student handout with a list of key words from this chapter. The number of key words should match the number of students in the class. Divide the class into an even number of rows. Choose 2, 4, or 6 (depending on the size of the class) rows of student partners facing each other. Direct the students to count off. The number they count should correspond to the numbered key word on the handout. Allow 2 or 3 minutes for the students to individually develop a definition for their key word and record this on the handout. When the 2- or 3-minute time period is up, direct the odd-numbered rows of students to get up and move one chair to their right. (The students in the even-number row(s) will not move throughout the exercise.) Now, sitting facing a new student partner, allow 2 or 3 minutes for each partner to identify his or her key word and "teach" his or her partner the meaning or the significance of that word. When the time is up, each of the students in the odd-numbered row(s) should once again get up and move one chair to the right and repeat the discussion with a new student partner. Continue until the students return back to their original seats and all of the key words are defined. The instructor should monitor the progress to be sure that the students are sharing correct definitions with their student partners.