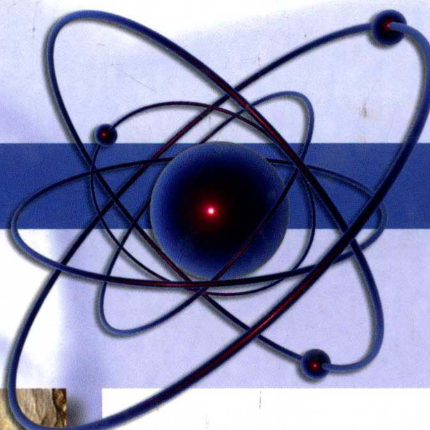
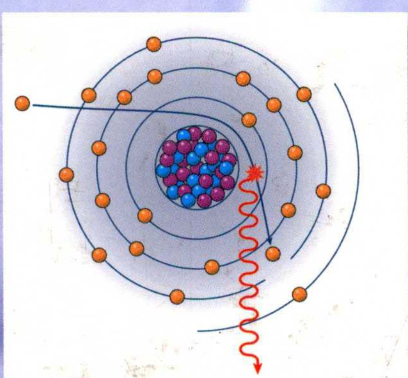
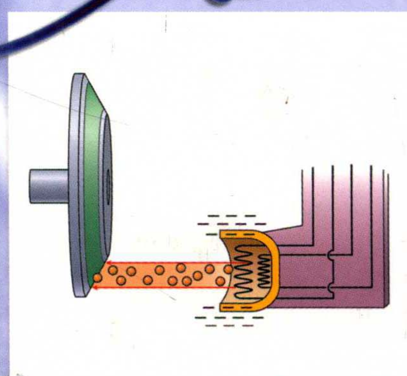
Essentials of

Radiologic Science







Robert Fosbinder • Denise Orth

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Essentials of Radiologic Science

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Essentials of

Radiologic Science

Preface

Essentials of Radiologic Science has been designed with students and educators in mind. The textbook is designed to distill the information in each of the content-specific areas down to the essentials and to present them to the student in an easy-to-understand format. We have always believed that the difference between professional radiographers and "button pushers" is that the former understand the science and technology of radiographic imaging. To produce quality images, a student must develop an understanding of the theories and concepts related to the various aspects of using radiation. They should not rely on preprogrammed equipment and blindly set technical factors, as this is the practice of "button pushers." We have made a special effort to design a text that will help the students achieve technical competence and build their professional demeanor. We have placed the chapters in an order to help the student and educator progress from one topic to another. The chapters can be used in consecutive order to build comprehension; however, each chapter can stand alone and can be used in the order that is appropriate for any program.

From the discovery of x-rays by Wilhelm Roentgen to modern day, there have been major changes in how radiography is performed and the responsibilities of the radiographer. The advancement of digital imaging and the elimination of film in a majority of imaging departments in the country have changed the required knowledge base for radiographers, which is different today than just a few years ago. This text addresses those changes and the way radiography students must be educated.

Our goal is to make this text a valuable resource for radiography students during their program of study and in the future. To this end, the text covers four of the five content-specific areas contained in the registry examination: Physics, Radiographic Image Production, Radiation Protection, and Patient Care. The sections are independent and designed to be combined in whatever fits the instructor's current syllabus. We believe the area of Patient Positioning and Procedures is so extensive and complex that it requires a separate text.

It is our hope that this text will exceed the expectations of students and educators in their use of this book. We hope that instructors find this book easy for their students to read and understand, and we know they will find it a useful addition to their courses.

Features

The text has many features that are beneficial to students as they learn about the fascinating world of radiography. Key terms are highlighted with **bold text** and are located at the beginning of each chapter as well as inside the chapter material. A glossary provides definitions for each key term. Other features include objectives, full-color design, in-text case studies with critical thinking questions, critical thinking boxes with clinical/practical application questions and examples, video and animation callouts, chapter summaries, and chapter review questions. One of the most exciting features of this text is the use of over 250 illustrations, radiographic images, photographs, and charts that provide graphic demonstration of the concepts of radiologic science while making the text visually appealing and interesting.

Ancillaries

The text has ancillary resources available to the students to further assist their comprehension of the material. Student ancillaries include full text online, a registry exam–style question bank, a chapter review question bank, videos, and animations. These animations complement the text with action-packed visual stimuli to explain complex physics concepts. For example, the topic of x-ray interactions contains an animation demonstrating the x-ray photon entering the patient and then undergoing photoelectric absorption, Compton scattering, or through transmission. Thus, the student can see how the exit radiation is made up of a combination of through transmitted and scattered photons. Videos provide the student with the "real world" example of different scenarios including venipuncture, taking vital signs, using correct body mechanics, hand hygiene, and patient rights.

We have also included valuable resources for educators to use in the classroom. Instructor resources include PowerPoint slides, lesson plans, image bank, test generator, answer key for text review questions, and Workbook answer key. Their purpose is to provide instructors with detailed lecture notes that tie together the textbook and all the other resources we are offering with it.

Workbook

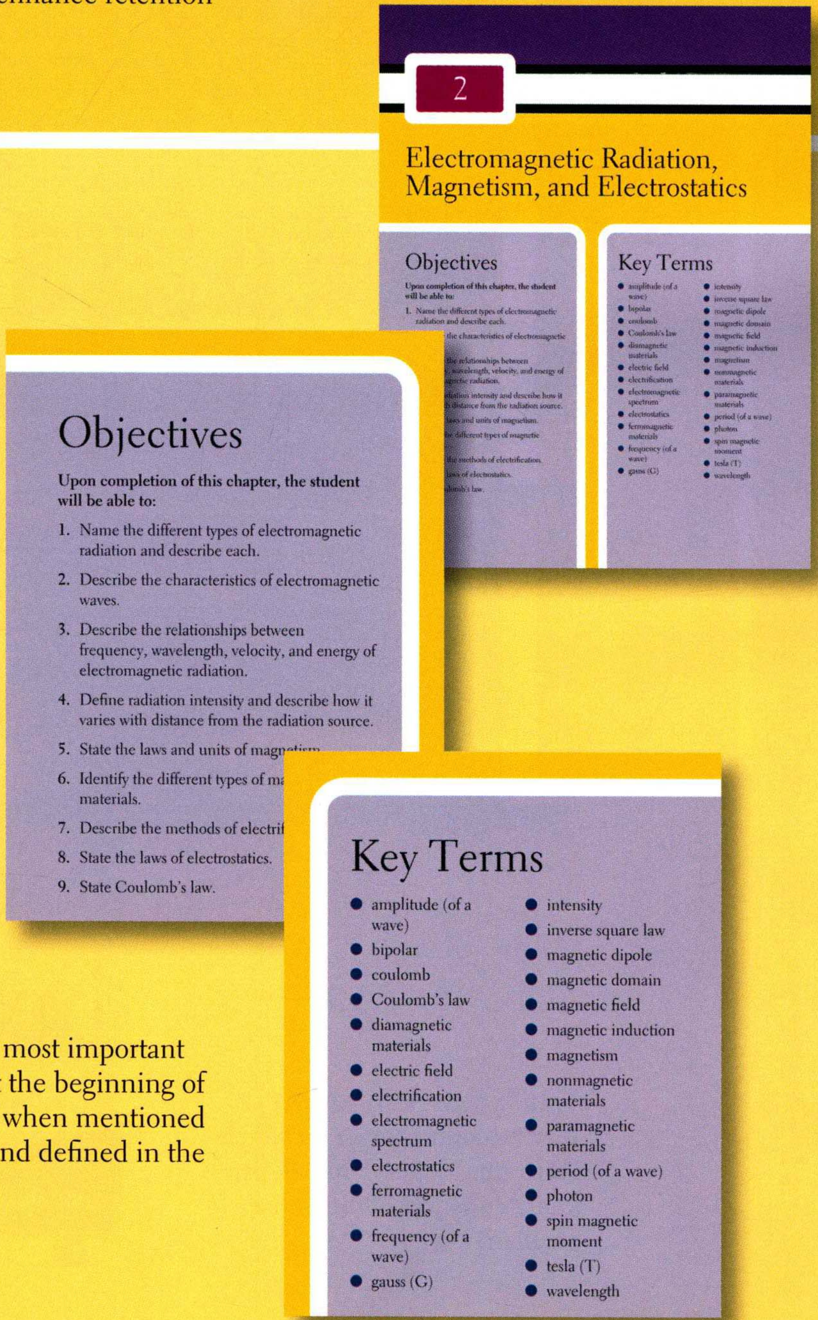
An ***Essentials of Radiologic Science Workbook*** is available separately to supplement the text and to help the students apply knowledge they are learning. The *Workbook* provides additional practice and preparation for the ARRT exam and includes registry-style review questions, as well as other exercises (crossword puzzles, image labeling) and a laboratory experiments section. All the questions in the *Workbook* are correlated directly with the text. Use of the *Workbook* will enhance learning and the enjoyment of radiologic science concepts.

Robert Fosbinder
Denise Orth

User's Guide

This User's Guide introduces you to the helpful features of *Essentials of Radiologic Science* that enable you to quickly master new concepts and put your new skills into practice.

Chapter features to increase understanding and enhance retention of the material include: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Electromagnetic Radiation, Magnetism, and Electrostatics

Objectives

Upon completion of this chapter, the student will be able to:

1. Name the different types of electromagnetic radiation and describe each.
2. Describe the characteristics of electromagnetic waves.
3. Describe the relationships between frequency, wavelength, velocity, and energy of electromagnetic radiation.
4. Define radiation intensity and describe how it varies with distance from the radiation source.
5. State the laws and units of magnetism.
6. Identify the different types of magnetic materials.
7. Describe the methods of electrification.
8. State the laws of electrostatics.
9. State Coulomb's law.

Key Terms

- amplitude (of a wave)
- bipolar
- coulomb
- Coulomb's law
- diamagnetic materials
- electric field
- electrification
- electromagnetic spectrum
- electrostatics
- ferromagnetic materials
- frequency (of a wave)
- gauss (G)
- intensity
- inverse square law
- magnetic dipole
- magnetic domain
- magnetic field
- magnetic induction
- magnetism
- nonmagnetic materials
- paramagnetic materials
- period (of a wave)
- photon
- spin magnetic moment
- tesla (T)
- wavelength

Objectives help you focus on the most important information to glean from the chapter.

Key Terms for the most important concepts are listed at the beginning of the chapters, bolded when mentioned first in the chapter, and defined in the Glossary.

Critical Thinking boxes provide the opportunity to apply chapter material by answering practical application questions.

CRITICAL THINKING

What is the frequency of a 56-keV x-ray photon?

Answer

$$E = h \times f$$
$$f = \frac{E}{h}$$
$$f = \frac{56\,\text{keV}}{4.15 \times 10^{-15}\,\text{eVs}}$$
$$f = \frac{56 \times 10^{4}\,\text{eV}}{4.15 \times 10^{-15}\,\text{eVs}}$$
$$f = 1.34 \times 10^{19}\,\text{Hz}$$

CRITICAL THINKING

How much energy is found in one photon of radiation during a cell phone transmission of 900 kHz?

Answer

$$E = h \times f$$
$$E = (4.15 \times 10^{-15}\,\text{eV s})(9 \times 10^{5}\,\text{s})$$
$$E = 3.7 \times 10^{-9}\,\text{eV}$$

Radioisotopes can emit electromagnetic radiation, beta particles, or alpha particles. The unit of radioactive decay is the Becquerel or curie.

Case Study

An x-ray photon with energy of 3.86 keV interacts with an atom of lead.

Critical Thinking Questions

The energy is sufficient to remove an electron from which shell?

How many keV are required to remove an O-shell electron?

What is the maximum number of electrons found in the L shell?

Case Studies with Critical Thinking Questions use real-life scenarios to encourage learning and application of chapter concepts.

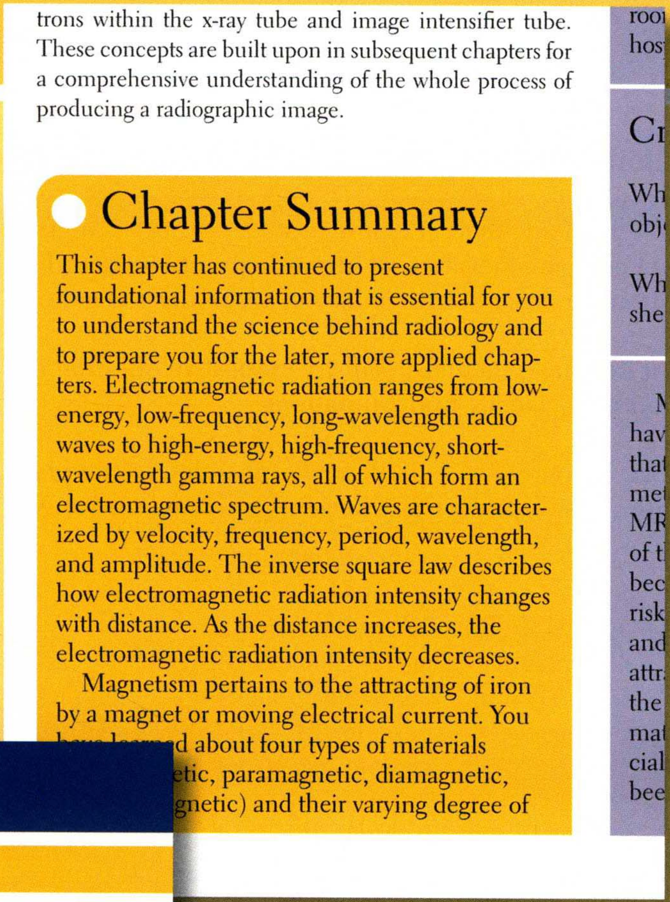
Video and Animation Icons identify topics for which there are videos or animations available as part of the online ancillaries.

Electric Generators

An animation for this topic can be viewed at http://thepoint.lww.com/FosbinderText

An electric **generator** converts mechanical energy into electrical energy. A simple generator is made of a con-

Chapter Summaries provide a synopsis of the chapter content and help to reinforce learning.

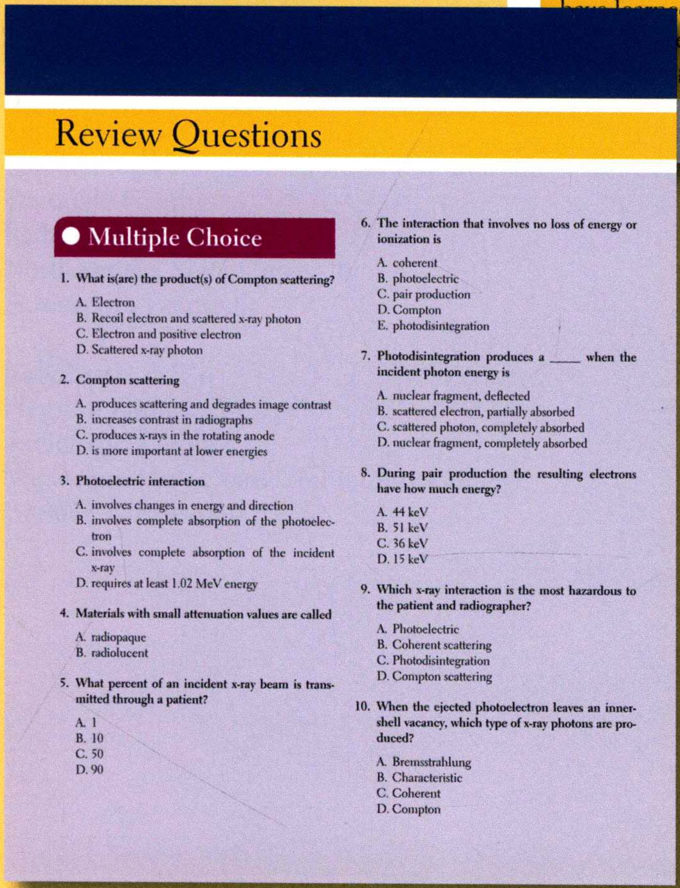


trons within the x-ray tube and image intensifier tube. These concepts are built upon in subsequent chapters for a comprehensive understanding of the whole process of producing a radiographic image.

Chapter Summary

This chapter has continued to present foundational information that is essential for you to understand the science behind radiology and to prepare you for the later, more applied chapters. Electromagnetic radiation ranges from low-energy, low-frequency, long-wavelength radio waves to high-energy, high-frequency, short-wavelength gamma rays, all of which form an electromagnetic spectrum. Waves are characterized by velocity, frequency, period, wavelength, and amplitude. The inverse square law describes how electromagnetic radiation intensity changes with distance. As the distance increases, the electromagnetic radiation intensity decreases.

Magnetism pertains to the attracting of iron by a magnet or moving electrical current. You ...d about four types of materials ...etic, paramagnetic, diamagnetic, ...gnetic) and their varying degree of



Review Questions

Multiple Choice

1. What is(are) the product(s) of Compton scattering?
   A. Electron
   B. Recoil electron and scattered x-ray photon
   C. Electron and positive electron
   D. Scattered x-ray photon
2. Compton scattering
   A. produces scattering and degrades image contrast
   B. increases contrast in radiographs
   C. produces x-rays in the rotating anode
   D. is more important at lower energies
3. Photoelectric interaction
   A. involves changes in energy and direction
   B. involves complete absorption of the photoelectron
   C. involves complete absorption of the incident x-ray
   D. requires at least 1.02 MeV energy
4. Materials with small attenuation values are called
   A. radiopaque
   B. radiolucent
5. What percent of an incident x-ray beam is transmitted through a patient?
   A. 1
   B. 10
   C. 50
   D. 90
6. The interaction that involves no loss of energy or ionization is
   A. coherent
   B. photoelectric
   C. pair production
   D. Compton
   E. photodisintegration
7. Photodisintegration produces a _____ when the incident photon energy is
   A. nuclear fragment, deflected
   B. scattered electron, partially absorbed
   C. scattered photon, completely absorbed
   D. nuclear fragment, completely absorbed
8. During pair production the resulting electrons have how much energy?
   A. 44 keV
   B. 51 keV
   C. 36 keV
   D. 15 keV
9. Which x-ray interaction is the most hazardous to the patient and radiographer?
   A. Photoelectric
   B. Coherent scattering
   C. Photodisintegration
   D. Compton scattering
10. When the ejected photoelectron leaves an inner-shell vacancy, which type of x-ray photons are produced?
    A. Bremsstrahlung
    B. Characteristic
    C. Coherent
    D. Compton

Review Questions at the end of each chapter help you assess your knowledge.

Additional Learning Resources

Valuable ancillary resources for both students and instructors are available on thePoint companion website at **http://thepoint.lww.com/FosbinderText**. See the inside front cover for details on how to access these resources.

Student Resources include a **registry exam-style question bank, a chapter review question bank, videos, and animations.**

Instructor Resources include **PowerPoint slides, lesson plans, image bank, test generator, answer key for text Review Questions, and answer key for Workbook questions.**

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Finally, to my husband Mark and our family, I wish to express my true appreciation for your unwavering support, encouragement, and understanding during the process of writing this text.

Denise Orth

Contents

PART I

Basic Physics

1

Radiation Units, Atoms, and Atomic Structure

Objectives

Upon completion of this chapter, the student will be able to:

1. Identify the units of exposure, dose, and effective dose.
2. Define atomic mass and atomic number.
3. Describe the Bohr model of the atom and its components.
4. Define electron binding energy.
5. Describe the process of ionization.
6. Identify the types of ionizing radiation.

Key Terms

- absorbed dose
- activity
- alpha particle
- atomic mass number (A)
- atomic number (Z)
- beta particle
- effective dose
- electron binding energy
- electron volt
- exposure
- half-life
- ion
- ionization
- isotopes
- nucleons
- radioactive decay
- radioisotopes

Introduction

An understanding of nuclear and atomic structure together with how nuclei and atoms interact is fundamental to an understanding of how medical imaging uses radiation to produce diagnostic images. In this chapter, we discuss the fundamental units of radiation and how atomic structure and the ionization of atoms affect the formation of the radiographic image.

Units of Radiation

Historically, the quantities and units utilized to measure ionizing radiation included the roentgen (R), the rad, and the rem. In 1948, an international system of units based on the metric system was developed. These units are called SI units or Systems Internationale d'Unites. Although the SI units were formally adopted, the older traditional units are still in use today. This may cause confusion in understanding which units to use and how they are related to each other. The following discussion reviews both systems of measurement.

Radiography utilizes the units of radiation to determine the amount of exposure that reached the patient, how much radiation was deposited in tissue, and how much damage occurred. The four fundamental units of radiation used in radiology are:

1. **Exposure**
2. **Absorbed Dose**
3. **Effective dose**
4. **Activity**

Exposure

Exposure is defined as the amount of ionization produced by radiation in a unit mass of air. We could count the number of x-rays, but it is easier to measure the amount of ionization produced by the x-rays. Ionization is discussed in more detail later in this chapter. Exposure is measured in the SI system by coulombs per kilogram (C/kg) or in the conventional system using roentgens (R). The relationship between the roentgen and coulombs per kilogram is 1 R = 2.58×10^{-4} C/kg. The roentgen is a fairly large unit so a smaller unit, the milliroentgen (mR), is more commonly used. One mR is 1,000 times smaller than a roentgen.

Absorbed Dose

The units of **absorbed dose** or absorbed energy are the gray (Gy) in the SI system and the rad (radiation absorbed dose) in the conventional system. Absorbed dose measures the amount of energy deposited in the patient by the x-rays. One gray is equivalent to 100 rads and 1 rad equals 10 mGy. Because the gray and rad are so large, the milligray (mGy) and the millirad (mrad) are more commonly used.

Effective Dose

The **effective dose** relates the risk from irradiating a part of the body to the risk of total body irradiation. In other words, the tissues of the body are not equally affected by ionizing radiation. Some tissues are more sensitive to the effects of ionizing radiation. We know that a dose of 6 sievert (Sv) to the entire body is fatal. However, a dose of 6 Sv to a patient's hand or foot is not fatal. The harm from a radiation dose depends on both the amount of radiation or dose and the part of the body irradiated. The combination of the dose and the body parts irradiated is measured by the effective dose.

The effective dose is calculated by using weighting factors (w_{et}) for various organs or tissues. The weighting factors are based on the organ sensitivities and importance of the organ to survival. The calculation multiplies the dose to the organ by its weighting factor. The effective dose has units of Sv in the SI system or rem (radiation equivalent man) in the conventional system. One sievert is equal to 100 rem. Because the units are so large, the millisievert (mSv) and the millirem (mrem) are often used.

The units in the conventional system are arranged so that 1 R is equal to 1 rad, which is equal to 1 rem.

Activity

Radioactive atoms spontaneously decay by transforming or disintegrating into different atoms. The amount of radioactive atoms present is measured by their **activity** or the number of disintegrations per second, dps. The units of activity are the Becquerel (Bq) in the SI system and the Curie (Ci) in the conventional system. One becquerel is equal to one disintegration per second. The Curie is based on the number of disintegrations per second from 1 g of radium. One Curie is equal to 3.7×10^{10} dps. Because the Curie is so large, the millicurie (mCi) is normally used (Table 1.1).