RADIOLOGIC SCIENCE FOR TECHNOLOGISTS

PHYSICS, BIOLOGY, AND PROTECTION 6TH EDITION

STEWART C. BUSHONG

Mosby

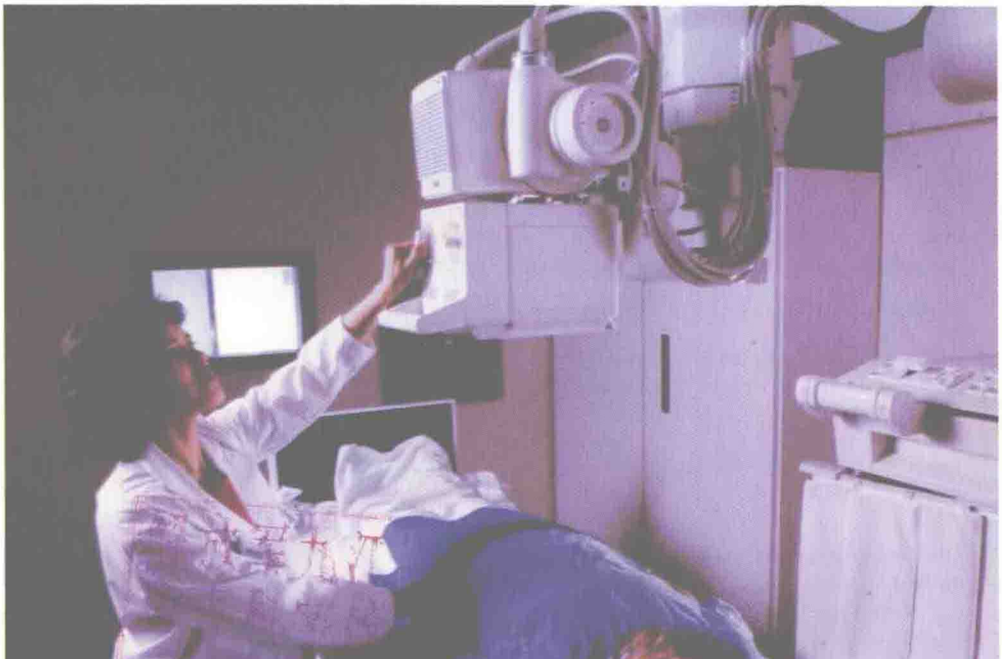
RADIOLOGIC SCIENCE FOR TECHNOLOGISTS

PHYSICS, BIOLOGY, AND PROTECTION 6TH EDITION

STEWART C. BUSHONG, Sc.D., FACR, FACMP

Professor, Department of Radiology
Baylor College of Medicine
Houston, Texas

with 693 illustrations



Mosby

St. Louis Baltimore Boston Carlsbad Chicago Naples New York Philadelphia Portland
London Madrid Mexico City Singapore Sydney Tokyo Toronto Wiesbaden

Mosby
Dedicated to Publishing Excellence

A Times Mirror
Company

Vice President and Publisher: Don Ladig
Senior Editor: Jeanne Rowland
Senior Developmental Editor: Lisa Potts
Developmental Editor: Linda Woodard
Project Manager: Mark Spann
Production Editor: Julie Eddy
Designer: Judi Lang
Manufacturing Supervisor: Karen Boehme

Cover Photos: Custom Medical Stock Photos, Inc.

Part Opener Photos: Custom Medical Stock Photos, Inc.

SIXTH EDITION

Copyright © 1997 by Mosby–Year Book, Inc.
A Mosby imprint of Mosby–Year Book, Inc.

Previous editions copyrighted 1975, 1980, 1984, 1988, 1993

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher.

Permission to photocopy or reproduce solely for internal or personal use is permitted for libraries or other users registered with the Copyright Clearance Center, provided that the base fee of $4.00 per chapter plus $.10 per page is paid directly to the Copyright Clearance Center, 27 Congress Street, Salem, MA 01970. This consent does not extend to other kinds of copying, such as copying for general distribution, for advertising or promotional purposes, for creating new collected works, or for resale.

Printed in the United States of America

Composition by Graphic World Inc.
Printing/Binding by Von Hoffmann Press

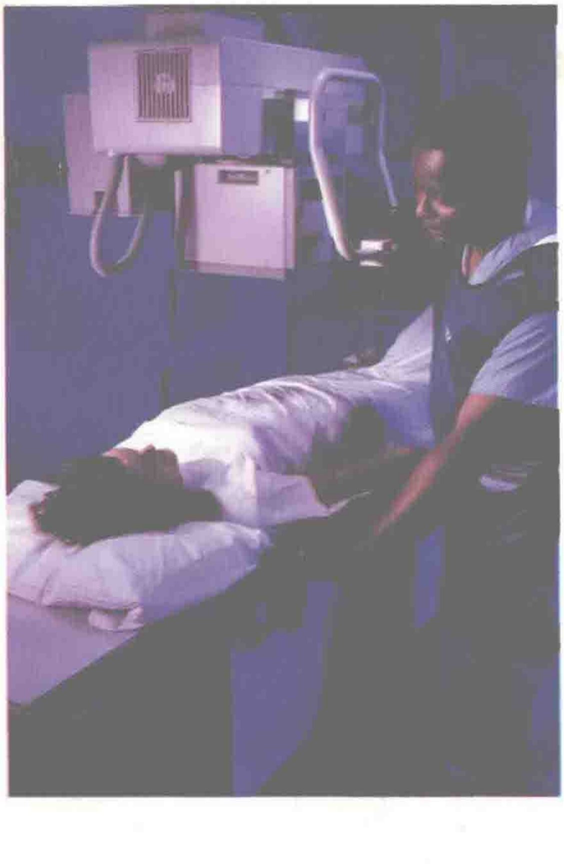
Mosby–Year Book, Inc.
11830 Westline Industrial Drive
St. Louis, MO 63146

Library of Congress Cataloging-in-Publication Data
Bushong, Stewart C.
Radiologic science for technologists: physics, biology, and protection / Stewart C. Bushong.—6th ed.
p. cm.
Includes bibliographical references and index.
ISBN 0-8151-1579-2
1. Radiology, Medical. 2. Medical physics. 3. Radiology, Medical—Safety measures. I. Title
[DNLM: 1. Technology, Radiologic. 2. Radiation Protection. 3. Radiation. WN 160 B979r 1997]
R895.B86 1997
616.07'57—dc21
DNLM/DLC
for Library of Congress 96-29488
CIP

98 99 00 01 / 9 8 7 6 5 4 3 2

RADIOLOGIC SCIENCE FOR TECHNOLOGISTS

PHYSICS, BIOLOGY, AND PROTECTION 6TH EDITION



Preface

Imagine a radiographer evaluating body habitus and disease process and selecting technical factors on the x-ray tube control panel. Imagine a radiographer examining a patient using ionizing radiation. Imagine a radiographer evaluating the finished radiograph for diagnostic quality. Imagine if this radiographer had never studied physics. Physics is the basic science for understanding how ionizing radiation fits into the electromagnetic spectrum, how x-rays are formed from the interaction of electrons and the tungsten target of and x-ray tube, and for explaining the effect of ionizing radiation on matter. A radiographer without a background in the fundamentals of physics is not able to make the decisions required in the diagnostic imaging workplace. Radiologists, radiology managers, and patients depend on radiographers to make informed decisions and educated assessments of technical factors and diagnostic image quality. Much is learned from experience but even more is gained from accredited radiography programs with clinical assignments and classwork including extensive study of radiologic physics. The principle purpose of this textbook is to convey a working knowledge of radiologic physics while preparing radiography students as painlessly as possible for the certification examination by the American Registry of Radiologic Technologists (AART). This book will also be a valuable resource for the practicing technologist.

This textbook resulted from lectures from radiologic science courses for students and radiographers in the programs of the University of Houston, the Houston Community College, and for radiology residents at Baylor College of Medicine. These students receive their clinical training in one of the several hospitals and assemble together for much of the instruction. This textbook, therefore, is designed to meet the needs of students who may be receiving clinical training in a wide spectrum of environments and whose classwork may be presented on several levels of difficulty.

HISTORICAL PERSPECTIVE

The practice and the equipment of diagnostic radiology remained relatively stable during the first seven decades following the discovery of x-rays. Truly great changes during that time can be counted on the fingers of one hand: the Crookes tube, the Potter-Bucky diaphragm, and image intensification.

However, since the publication of the first edition of this book in 1975, several great and innovative types of examinations have come into routine use in medical imaging: computed tomography, computed radiography, digital fluoroscopy, and most recently spiral computed tomography. These examinations have been made possible by our truly spectacular technology—computer advances, new x-ray tube designs, and improved image receptors. These developments have transformed radiology into an imaging science.

NOMENCLATURE

Although the United States has not formally adopted the International Systems of Units (SI units), this textbook presents SI units. With this system come the corresponding units of radiation and radioactivity. The roentgen, the rad, and the rem are being replaced by the coulomb/kilogram (C/kg), the gray (Gy), and the sievert (Sv), respectively. Radioactivity is to be expressed in bequerels (Bq). Consequently, throughout this sixth edition, where there has been reference to units other than SI, the SI equivalent will follow in parentheses. A summary of SI and the factors necessary to convert from conventional to SI units is given in the inside front cover of the text.

Additional nomenclatures are continually being introduced into diagnostic radiology, and where appropriate, newer forms are used in this text. SID (source-to-image receptor distance), PBL (positive beam limitation), linearity, reproducibility, and HU (Hounsfield unit) are examples of some of the new vocabulary. In many instances, when conversion from English to metric is made, the result is rounded off. For example, 40 inches target-to-film distance (TFD) is actually 101.6 cm, but it is identified throughout as being equivalent to 100 cm SID.

试读结束：需要全本请在线购买： www.ertongbook.com

NEW TO THIS EDITION

Learning Aids

Those readers who have used previous editions of *Radiologic Science for Technologists* will find some significant improvements in this new edition. The most important goal in preparing the sixth edition has been to make the text even more accessible to radiography students. The language used to present information is direct, concise, and easy to understand. To encourage and to make the text reader-friendly, each chapter opens with a list of learning objectives, an outline, and an introduction that overviews the chapter. Each chapter ends with a chapter summary that recaps the major points presented in the chapter. Answering the review questions provided at the end of each chapter can help the reader assess his or her comprehension of the chapter's contents. Because radiologic science cannot be totally separated from mathematics, there are many formulas to learn. In this book formulas and easy-to-understand mathematic equations are clearly highlighted in the text and are followed by problems with clinical significance using these equations. The answers to the problems are calculated line by line to lead the student through to the answer. The review questions at the end of the chapter also include math problems. Key concepts are highlighted in colored boxes throughout the book.

The sixth edition also contains an important new chapter on spiral CT, an innovation of computed tomography that is now routinely used. Other recent innovations in medical imaging described in the textbook are digital fluoroscopy, computed radiography, and advances in film and intensifying screen technology.

Improved Organization

The overall organization of the book is intended to lead the student from less complex subject matter in the beginning to more complex subject matter at the end. The learning is progressive. Chapter introductions and outlines allow the student to survey the material before reading the chapter. Chapter outlines refer to specific headings throughout the chapter so information can be found quickly. Important information in the chapter is boxed and highlighted to allow for quick reference and increased retention of information. Each chapter is concisely reviewed in the chapter summary and is followed by lists entitled "Additional Reading," to encourage the reader to research topics of interest.

New Illustrations

One of the most exciting new features of this new book is the addition of full-color art, which provides better graphic demonstration of the difficult concepts of radiologic science while making the text more attractive and interesting.

ANCILLARIES

Student Workbook

A completely revised edition of *Radiologic Science Workbook and Laboratory Manual* is available. It contains worksheets, fill-in-the blank questions, multiple choice questions, matching items, word problems, and crossword puzzles. All the questions in the accompanying workbook are correlated directly with the text. Use of the workbook will enhance learning and enjoyment of radiologic science.

Related Multimedia

Instructional materials to support teaching and learning radiologic physics have been developed by Mosby and may be obtained by contacting the publisher directly. Multimedia presentations of basic physics, imaging, radiobiology, and radiation protection are available in both slide/audiotape and CD-ROM formats.

Stewart C. Bushong

Acknowledgments

For the preparation of the sixth edition, I am indebted to the many readers of the earlier editions who submitted suggestions, criticisms, corrections, and compliments. For this edition I enlisted the help of many clinical radiographers and educators. I am grateful to the following people: Karen Brown, St. Joseph's Medical Center; Quinn B. Carroll, Midland College; Geoffrey Clarke, UT Health Science Center; Charles Collins, San Diego Mesa College; Patricia Duffy, College of Health Related Professions; Pamela Eugene, Delgado Community College; Kae Fleming, Columbia State Community College; Regina Freidman, Mercy Medical Center; Richard Gwilt, Indian Health Service; Jim Heck, Angelina College; Wayne Hedrick, Aultman Hospital; Carolyn Holdsworth, Portland Community College; John Lampignano, Gateway Community College; Suzanne McIntire, Mercy Hospital Center; Rod Roemer, Triton College; Lil Rossadillo, Pima Medical Institute; Euclid Seesam, British Columbia Institute of Technology; Linda Shields, El Paso Hospital Center; Mel Siedbaud, University of Wisconsin; Sandra Strickland, Pima Medical Institute; Rues Stuteville, Oregon Institute of Technology; Christl Thompson, El Paso Community College; Jean Toth-Allen, CDRH-MQSA; and Judy Williams, Grady Memorial Hospital.

Mosby would also like to thank the following reviewers and consultants: William J. Callaway, Lincoln Land Community College; Wayne R. Hedrick, Northeastern Ohio University College of Medicine and Aultman Hospital; Eugene D. Frank, Mayo Medical School; Kevin C. Sisler, Mayo Medical School; John Lampignano, Gateway Community College; Eric Anderson, Avila College; Cheri Dyke, St. Luke's Hospital; Andrew Shappell, Lima Technical College; Elwin Tilson, Armstrong State College; Adam Bede, College of St. Catherine; Alberto Bell, Jr., Oregon Institute of Technology; Richard Hone, Oregon Institute of Technology; Steve Bollin, El Paso Community College; TerriAnne Linn-Watson, Chaffey College; Deborah Martin, Rapid City Regional Hospital; Tina Phillips, Brandywine Hospital; Douglas Hughes, Mountain State Tumor Institute; Starla Mason, Laramie County Community College; John Clouse, Owensboro Community College; Nancy Perkins, Bakersfield College; David Lahman, Midwestern State University; Robert Luke, Boise State University; Linda Pearson, Midwestern State University; Robert Parelli, Cypress College; Debra Reese, A-B Tech; Joe Dielman, Triton College; Gloria Strickland, Armstrong State College; Joseph Bittengle, University of Arkansas for Medical Science; Mary Reagan, Meridian Technology Center; Paul Bober, Labette Community College; Suzanne Sturdivant; Christopher Gould, San Jacinto College; Nadia Bugg, Midwestern State University, and John Hartwein, St. Louis Community College at Forest Park.

Art Haus, Eastman Kodak Company, and Lee Kitts, Sterling Diagnostic Imaging, were very helpful with the material concerning image receptors and image quality. Their expertise is much appreciated.

I am particularly appreciative of the exceptional effort by Joanna Bligh, M.Ed., R.T.(R). Ms. Bligh reviewed the entire manuscript and did much to adjust the reading level. The pedagogical additions, including chapter outlines, introductions, objectives, summaries, and review questions were written by her. Ms. Bligh wishes to thank Adolphe, the one person who encouraged her to undertake the work on this book. Others who helped her include Janet Salerno, typist, of Waterbury, CT; Jim Merello of Dupont; Lois Powell and Phil Bunch of Kodak; Dr. Peck of the Arthritis Center and John Smith, photographer, of Waterbury, CT; James Thorne, Concord Hospital, Concord NH; Napoleon Martin, Fairview Hospital, Great Barrington, MA; and her daughters, Amanda and Kate. She would also like to thank Lisa Potts, developmental editor, of Mosby. She is indebted to Lisa for her infectious enthusiasm and ability to laugh amid difficulty.

I am deeply indebted to my associates Robert Parry, Sharon Glaze, and Benjamin Archer, who have assisted me with this revision. The illustrations are the work of Crystal Depew, who worked exceptionally hard to render all illustrations in full color. The cartoons by Kraig Emmert help ease any pain associated with physics.

I am also particularly indebted to Judy Matteau Faldyn for the many times she had to struggle through my handwritten notes and unfamiliar symbols and equations. I appreciate her conscientious approach in preparing the final manuscript.

"Physics is fun" is the motto of my radiologic science courses, and I believe this text will help make physics enjoyable for the student radiographer.

To:
Bettie,
Leslie,
Stephen,
Andrew,
Butterscotch†
Jemimah,†
Geraldine,†
Casper,†
Ginger,†
Sebastian,†
Buffy,†
Brie,†
Linus,†
Midnight,†
Boef,†
Cassie,†
Lucy,†
Toto,†
Choco,†
Molly,†
Maxwell† and my lenses,
Bandit,†
Kate,†
Misty,†
Chester,†
Petra,†
Travis,†
and Ebony†

†R.I.P.

RADIOLOGIC SCIENCE FOR TECHNOLOGISTS

PHYSICS, BIOLOGY, AND PROTECTION 6TH EDITION

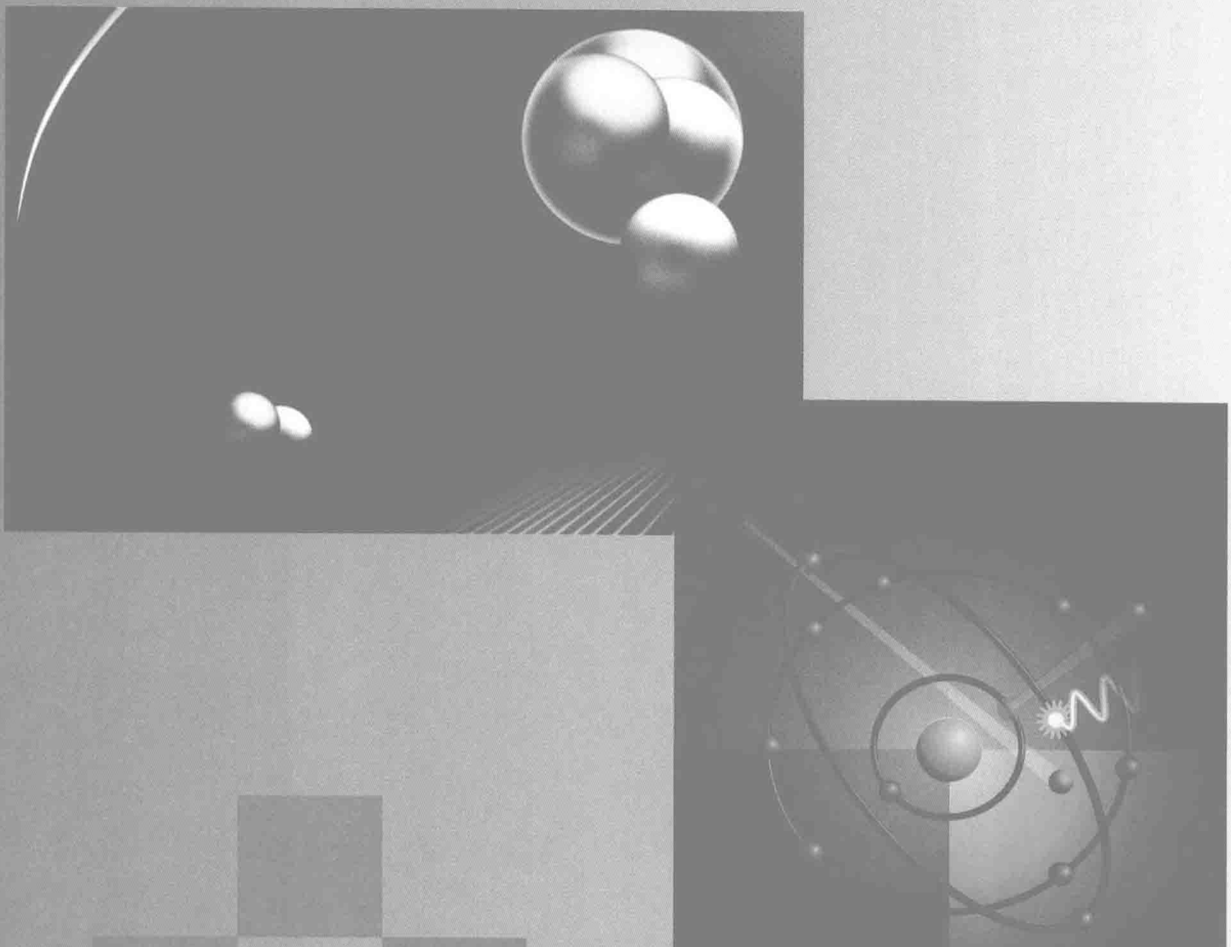
Contents

PART FIVE: RADIATION PROTECTION

APPENDICES

试读结束：需要全本请在线购买： www.ertongbook.com

RADIOLOGIC PHYSICS



CHAPTER

Basic Concepts of Radiation Science

OBJECTIVES

At the completion of this chapter the student will be able to:

1. Identify the difference between matter and energy
2. Define electromagnetic radiation and, specifically, ionizing radiation
3. Explain how x-rays were discovered accidently
4. Discuss human injury caused by radiation
5. List basic radiation protection equipment
6. Describe a brief history of modern radiography and discuss what behaviors are required of a radiographer

OUTLINE

Matter and Energy
- Matter and mass
- Energy

Ionizing Radiation
- Natural sources of ionizing radiation
- Medical x-ray

Chapter 1 explores the basic concepts underlying the science of radiography. These basic concepts include the study of matter, energy, and the electromagnetic spectrum, of which ionizing radiation is a part. The production of ionizing radiation and its use as a diagnostic tool is the basis of radiography. Radiographers have a great responsibility in performing x-ray examinations using established radiation protection standards with consideration for the safety of patients and medical personnel.

Radiography is a career choice with diverse opportunities. Welcome to the field of diagnostic imaging.

MATTER AND ENERGY

Matter and Mass

Matter is anything that occupies space. It is the material substance with form and shape composing physical objects. The fundamental, complex building blocks of matter are **atoms** and **molecules**. The primary characteristic of matter is **mass**, which is defined as the quantity of matter contained in a physical object.

Mass or the quantity of matter within a physical object is constant within the universe.

The term *weight* is used to describe the mass of an object in a gravitational field. In other words, weight is the force exerted by a physical object under the influence of gravity. On earth a person weighs 200 pounds because of the mutual attraction or gravity between the earth's mass and the mass of the person; however, on the moon, which has a mass one sixteenth that of the earth, the person would weigh 34 pounds ($\frac{1}{6} = 0.17$; 0.17×200 pounds = 34 pounds). The mass of the person remains the same. It is only the weight of the person that is less on the moon. Mass remains unchanged in another instance. Mass remains unchanged when matter changes from one form to another. Consider a block of ice. The shape of the ice changes as it melts into a puddle of water. If the puddle dries, the water disappears. The ice is transformed from a solid to a liquid to water vapor. If all the particles making up the ice, water, and water vapor were measured separately, the quantity of particles in each form would be the same. Each form has the same mass, although the shape may be different. Mass is constant. It does not change under the influence of gravity or when matter changes state.

Energy

Energy
The ability to do work.

Like matter, energy can exist in many forms. The following is a list of the forms of energy:

- **Potential energy** is the capacity to do work because of the position of an object. In Figure 1-1 the heavy guillotine blade held in the air by a rope and pulley is an example of an object possessing potential energy. If the rope is cut, the blade will descend and do its ghastly task. Work was required to get the blade to its high position. Because of this position, the blade has potential energy. Other examples of potential energy include a roller coaster on the top of the incline and the stretched spring of an open screen door.
- **Kinetic energy** is the energy of motion. An automobile in motion, a turning windmill wheel, or the falling guillotine blade are all examples of kinetic energy. These systems all do work because of their motion.
- **Chemical energy** is the energy released in a chemical reaction. One way to illustrate the release of chemical energy is to consider the violent burst resulting from the lighting of dynamite. Nitroglycerine and ammonium nitrate combine in the presence of heat or a flame. The violent chemical reaction increases the internal pressure in the dynamite tubes, causing the explosion or energy release.
- **Electrical energy** is the work done when an electron (negative particle) moves through a wire. This is discussed further in Chapter 5. All electric appli-

FIGURE 1-1 The blade of a guillotine offers a dramatic example of both potential and kinetic energy. When the blade is pulled to its maximum height and locked in place, it has potential energy. When the blade is allowed to fall, kinetic energy is released.

ances like heaters, dryers, stoves, and refrigerators use electrical energy.

- **Thermal energy** is the energy of motion at the molecular level. It is the kinetic energy of molecules. Thermal energy or heat is measured by temperature. The faster the molecules of matter are moving, the more thermal energy the matter contains and the higher the temperature of the substance.
- **Nuclear energy** is the energy contained in the nucleus of atom. The atomic bomb is an example of the power of nuclear energy.
- **Electromagnetic energy** is the most important form of energy in radiography because it is the type of energy in the x-ray beam and used in magnetic resonance imaging.

In addition to x-rays used in radiography and radio waves used in magnetic resonance imaging, electromagnetic energy spectrum includes microwaves and visible light. Just as matter can be transformed from one form or shape to another, so can energy. For example, the electrical energy in the x-ray unit produces electromagnetic energy in the form of an x-ray beam, which is then converted into light and chemical energy, resulting in an image on the x-ray film. Electromagnetic energy emitted by a source and transferred through space is called ***electromagnetic radiation.*** Examples of radiation emitted by a source are ultraviolet rays from the sun, heat from a stove, and radio waves from a radio tower.

Albert Einstein combined the concepts of mass and energy in his famous theory of relativity. He won the Nobel Prize in physics in 1921 by describing the mass-energy equivalence. The cornerstone of that theory is the equation $E = mc^2$ where E is energy, m is mass, and c is the speed of light.

IONIZING RADIATION

There are special types of electromagnetic radiation like x-rays, which can **ionize** matter.

Ionization
A reaction in which radiation interacts with matter.

As radiation passes through matter, it is capable of removing an orbital electron from an atom within the substance (Figure 1-2). As radiation passes close enough to an orbital electron of an atom, it may transfer energy to that electron, causing the atom to escape from its orbit. This free electron may further destabilize surrounding atoms by transferring energy to them. The free electron is a **negative ion.** The destabilized atom is a **positive ion.** The orbital electron and the atom from which it was separated are called an ***ion pair.*** X-rays and gamma rays are the only forms of electromagnetic radiation with enough energy to ionize matter, although some fast-moving particles like **alpha** and **beta** are also capable of ionization.

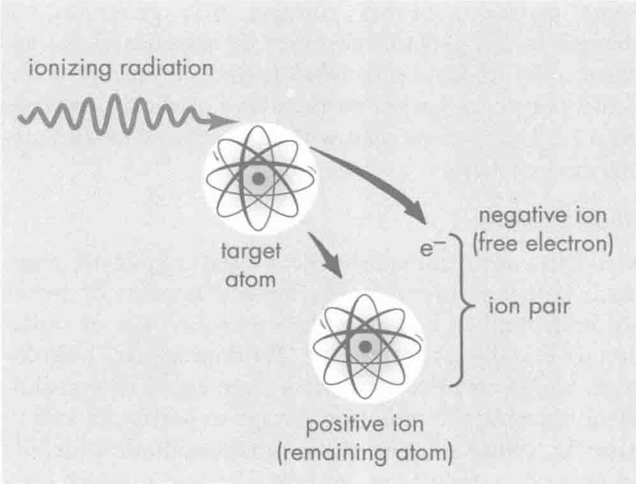


FIGURE 1-2 Ionization is the removal of an electron from an atom. The ejected electron and the resulting positively charged atom are called an *ion pair.*

Many types of radiation are harmless, like radio waves and light waves, although ultraviolet light can cause harmful sunburn. Ionizing radiation, however, can seriously injure humans; thus radiographers study radiation protection and radiation biology to learn ways to protect themselves and to limit patient exposure. There are two main sources of radiation harmful to humans—natural sources and man-made sources.

Natural Sources of Ionizing Radiation

Natural environmental radiation comes from three sources—**cosmic rays, terrestrial radiation,** and naturally occurring **radionuclides** (radioactive nucleus) in the human body. Cosmic rays are particles that are emitted by the sun and stars. The intensity of cosmic rays increases with the increase in altitude from the earth and the increase in latitude on the earth, that is, toward the poles. Terrestrial radiation is emitted from deposits of uranium, thorium, and other radioactive substances in the earth. The intensity of the terrestrial radiation depends on the geology of the area where deposits are located. The largest component of terrestrial radiation is **radon.** Radon, a **radioactive** gas that emits alpha particles, is produced by the natural decay of uranium and is present in trace quantities in the ground. All ground-based materials such as concrete, bricks, and gypsum wallboard contain radon. Radon gas can be harmful if inhaled in sufficient quantities. Radionuclides, mainly potassium-40, are part of the human metabolism and have been part of the environmental radiation source as long as man has been on earth—100,000 years. Human evolution has undoubtedly been influenced by this natural environmental radiation.

Some genetic scientists contend that evolution, or changes in the genetic substance of organisms, was influenced by ionization of DNA (deoxyribonucleic acid.) If this is true, radiation workers and medical personnel must be highly concerned with unnecessary medical radiation exposure.

Medical X-ray

Medical x-rays constitute the largest source of man-made ionizing radiation. The medical benefits of x-rays are indisputable; however, the controlled use of radiation is equally as important. **Radiographers, radiologists,** and **biomedical engineers** have equal responsibility in reducing the radiation dosage to personnel and to patients. Other sources of man-made radiation include nuclear power plants and industrial sources, which contribute only insignificantly to the human population's annual radiation dose. Consumer items like watch dials, smoke detectors, televisions, and airport surveillance systems actually contribute more significantly to the annual radiation dose (Figure 1-3).

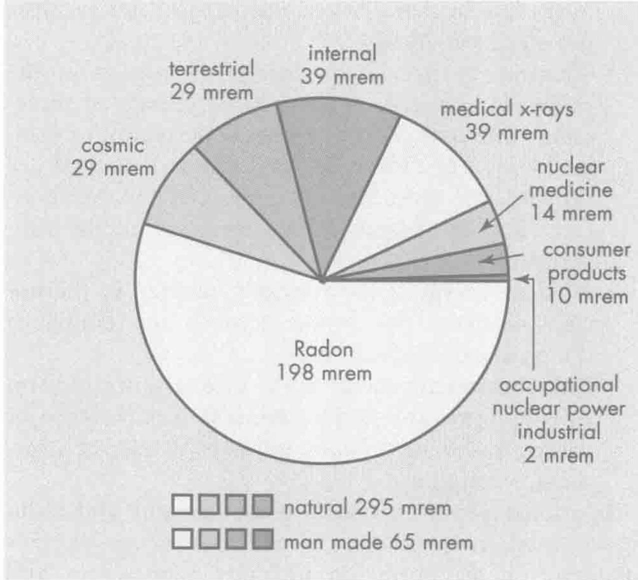


FIGURE 1-3 The contribution of various radiation sources to the total average U.S. population dose equivalent (mrem).

The ionizing radiation dose to humans is measured in **rads** or **mrads** ($^1\!/_{1000}$ rad). The rad is the unit of radiation absorbed dose or the quantity of radiation absorbed by the human body. Most recently the unit rad has been changed to an international unit called a gray (Gy).

Natural radiation sources contribute approximately 360 mrad to the average **absorbed dose** to each human. Medical x-rays on average contribute 40 mrad.

What percentage of the average radiation exposure to a human is due to medical x-rays?

$$\frac{40 \text{ mrad}}{360 \text{ mrad}} = 0.128 \text{ or } 13\%$$

Even though only 13% of all radiation exposure is due to medical x-ray and medical procedures, radiation workers still need to be concerned about limiting the radiation to personnel and to patients.

Discovery of x-rays. X-rays were not developed. They were discovered by accident. During the 1870s and 1880s, university physics professors were investigating the conduction of **cathode rays** (electrons) through a glass tube that was only partially filled with gasses. The glass tube was called a ***Crookes' tube*** after an Englishman, Sir William Crookes, who led one of the many experiments. The Crookes' tube is the forerunner of the modern fluorescent light. Experimenting with a Crookes' tube, Wilhelm Roentgen accidently discovered x-rays.

On November 8, 1895, Roentgen was working in his laboratory at Würzburg University in Germany. So that he could better see the effects of the cathode rays in the Crookes' tube, he darkened his laboratory. Several feet away on a bench was a photographic plate coated with **barium platinocyanide,** a fluorescent material. Roentgen covered the Crookes' tube with paper so no visible light escaped from it. Then he activated the Crookes' tube and noticed that the plate on the nearby bench glowed. The intensity of the glow or **fluorescence** increased as the plate was brought closer to the tube. There was little doubt about the origin of the fluorescence, but the kind of light was unclear. Roentgen called the rays *x-light* because it was an unknown ray. He feverishly continued his investigation for several weeks. His initial investigation was extremely thorough, and he was able to report his experimental results to the scientific community before the end of 1895. In 1901, he received the Nobel Prize in physics. He also published the first medical x-ray—an image of his wife Bertha's hand (Figure 1-4).

Figure 1-5 is a photograph of what is reported to be the first x-ray examination in the United States. It was conducted in early February 1896 in the physics laboratory at Dartmouth College, Hanover, New Hampshire.

The discovery of x-rays ranks high among the amazing events of human history. First of all, x-rays were discovered by accident. Secondly, at least twelve of Roentgen's contemporaries had observed x-rays but none had recognized their significance. Thirdly, Roentgen studied his discovery with such scientific vigor that within little more than a month he had described all the properties of x-rays that are recognized today.

Reports of radiation injury to humans. Unfortunately, in the early years radiation injuries from overexposure occurred fairly frequently. Most injuries were skin damage (**erythema**), loss of hair (**alopecia**), and low red-cell blood count (**anemia**). Physicians and, more commonly, patients were injured because of the low-energy radiation produced by the early tubes and the long exposure times required to get an acceptable radiograph. By

试读结束：需要全本请在线购买： www.ertongbook.com