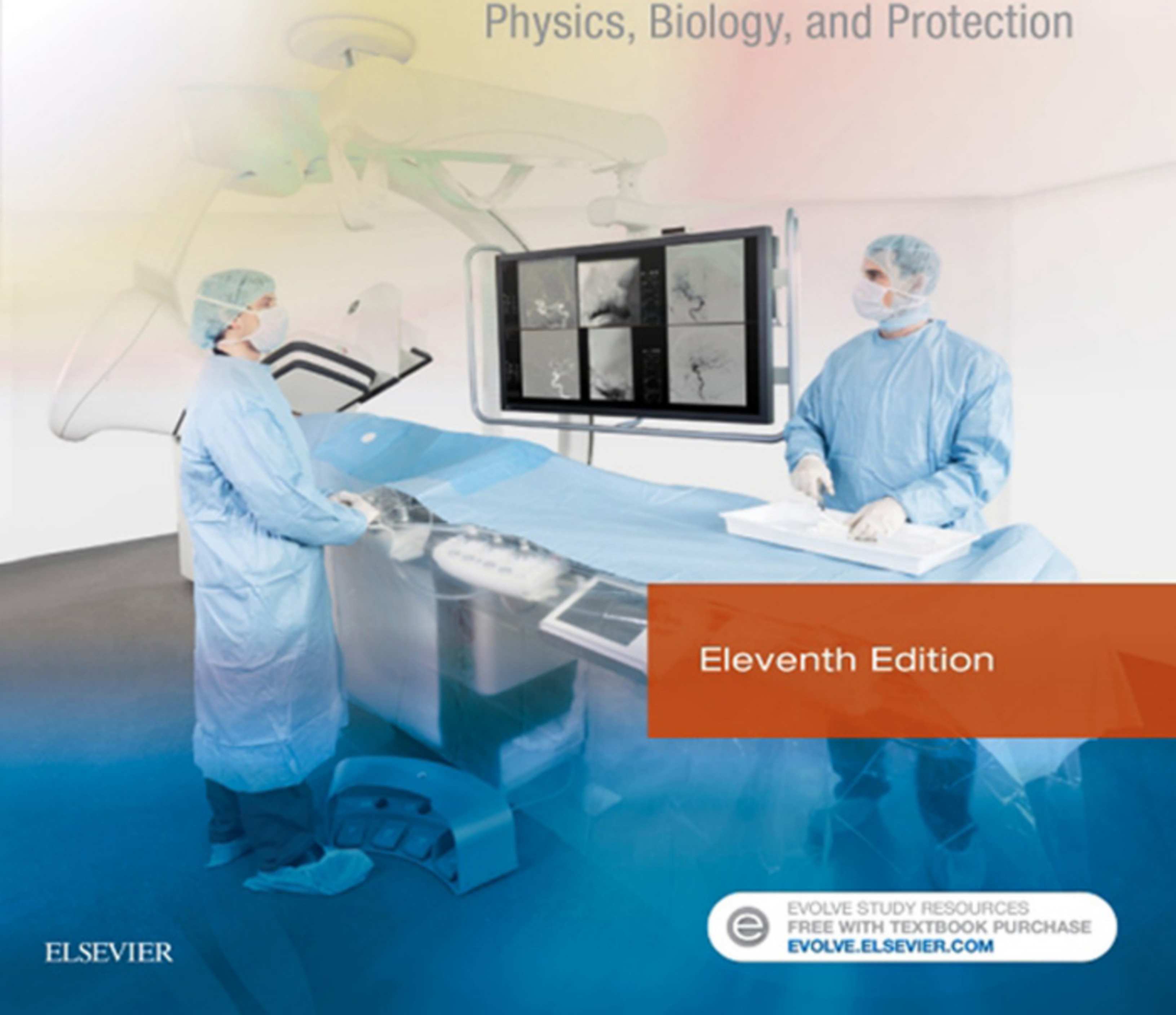
STEWART CARLYLE BUSHONG

Radiologic Science for Technologists

Physics, Biology, and Protection



Eleventh Edition

ELSEVIER

Review of Basic Physics

ELECTROSTATICS

1. The addition or removal of electrons is called electrification.
2. Like charges repel; unlike charges attract.
3. Coulomb's law of electrostatic force:

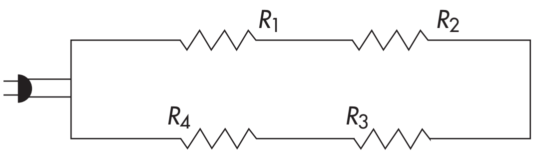
$$F = c\frac{Q_A Q_B}{d^2}$$

4. Only negative charges can move in solids.
5. Electrostatic charge is distributed on the outer surface of conductors.
6. The concentration of charge is greater when the radius of curvature is smaller.

ELECTRODYNAMICS

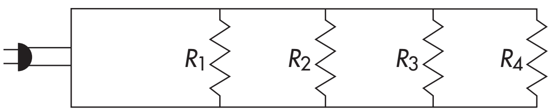
Ohm's Law: V = *IR*

A series circuit:



1. $V_t = V_1 + V_2 + V_3 + V_4$
2. I is the same through all elements.
3. $R_t = R_1 + R_2 + R_3 + R_4$

A parallel circuit:



1. V is the same across each circuit element.
2. $I_t = I_1 + I_2 + I_3 + I_4$
3. $\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$

Electric power: $P = IV = I\ 2\ R$ [(A) (V) = W]
Work: Work = QV [(C) (V) = J]
Potential: $V = W/Q$ [J/C = V]
Capacitance: $C = Q/V$ [C/V = F]

MAGNETISM

1. Every magnet has a north pole and a south pole.
2. Like poles repel; unlike poles attract.
3. Gauss's law:

$$F = k\frac{M_1 M_2}{d^2}$$

ELECROMAGNETISM

1. A magnetic field is always present around a conductor in which a current is flowing.
2. Changing magnetic fields can produce an electric field.
3. Transformer law:

$$\frac{V_P}{V_S} = \frac{N_P}{N_S}$$

CLASSICAL PHYSICS

Linear force: $F = ma$ [(kg)(m/s ^{2}) = N]
Momentum: $p = mv$ [(kg)(m/s)]
Mechanical work (or energy):
Work (or E) = Fs [(N)(m) = J]
Kinetic energy: $E = \frac{1}{2}\ mv^2$ [(kg)(m^2/s^2) = J]
Mechanical power: $P = Fs/t$ [(N)(m)/s = J/s = W]
Conservation of momentum between A and Bfn1*:

$$m_A v_A + m_B v_A = m_A v_A{}' = m_B v_B{}'$$

Conservation of kinetic energy between A and Bfn1*:

$$\tfrac{1}{2} m_A (v_A)^2 + \tfrac{1}{2} m_B (v_B)^2 = \tfrac{1}{2} m_A (v_A{}')^2 = \tfrac{1}{2} m_B (v_B{}')^2$$

*v, Initial velocity; v', Final velocity.

Useful Units in Radiology

SI Prefixes

Factor	Prefix	Symbol
10^{18}	Exa	E
10^{15}	Peta	P
10^{12}	Tera	T
10^{9}	Giga	G
10^{6}	Mega	M
10^{3}	Kilo	k
10^{2}	Hecto	h
10^{1}	Deca	da
10^{-1}	Deci	d
10^{-2}	Centi	c
10^{-3}	Milli	m
10^{-6}	Micro	μ
10^{-9}	Nano	n
10^{-12}	Pico	p
10^{-15}	Femto	f
10^{-18}	Atto	a

SI Base Units

Quantity	Name	Symbol
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s
Electric current	Ampere	A

SI Derived Units Expressed in Terms of Base Units

	SI UNIT	
Quantity	**Name**	**Symbol**
Area	Square meter	m^2
Volume	Cubic meter	m^3
Speed, velocity	Meter per second	m/s
Acceleration	Meter per second squared	m/s^2
Density, mass density	Kilogram per cubic meter	kg/m^3
Current density	Ampere per square meter	A/m^2
Concentration (of amount of substance)	Mole per cubic meter	$Mole/m^3$
Specific volume	Cubic meter per kilogram	m^3/kg

Special Quantities of Radiologic Science and Their Associated Special Units

	CUSTOMARY UNIT			SI UNIT	
Quantity	**Name**		**Symbol**	**Name**	**Symbol**
Exposure	roentgen		R	air kerma	Gy_a
Absorbed dose	rad		rad	gray	Gy_1
Effective dose	rem		rem	sievert	Sv
Radioactivity	curie		Ci	becquerel	Bq
Multiply	R	by	0.01	to obtain	Gy_a
Multiply	rad Gy	by	0.01	to obtain	Gy_t
Multiply	rem	by	0.01	to obtain	Sv
Multiply	Ci	by	3.73×10^{10}	to obtain	Bq
Multiply	R	by	2.583×10^{-4}	to obtain	C/kg

Radiologic Science for Technologists

Physics, Biology, and Protection

Eleventh Edition

This page intentionally left blank

Radiologic Science for Technologists

Physics, Biology, and Protection

Eleventh Edition

Stewart Carlyle Bushong, ScD, FAAPM, FACR

Professor of Radiologic Science
Baylor College of Medicine
Houston, Texas

ELSEVIER

ELSEVIER

3251 Riverport Lane
St. Louis, Missouri 63043

RADIOLOGIC SCIENCE FOR TECHNOLOGISTS: PHYSICS, BIOLOGY, AND PROTECTION, ELEVENTH EDITION

ISBN: 978-0-323-35377-9

Library of Congress Cataloging-in-Publication Data

Names: Bushong, Stewart C., author.
Title: Radiologic science for technologists : physics, biology, and protection / Stewart Carlyle Bushong.
Description: Eleventh edition. | St. Louis, Missouri : Elsevier, [2017] | Includes bibliographical references and index.
Identifiers: LCCN 2016034345 | ISBN 9780323353779 (hardcover : alk. paper)
Subjects: | MESH: Technology, Radiologic | Radiation Protection | Radiography—methods
Classification: LCC R895 | NLM WN 160 | DDC 616.07/57—dc23 LC record available at https://lccn.loc.gov/2016034345

Executive Content Strategist: Sonya Seigafuse
Content Development Manager: Billie Sharp
Content Development Specialist: Kristen Mandava
Publishing Services Manager: Julie Eddy
Project Manager: Abigail Bradberry
Design Direction: Paula Catalano

Printed in Canada

Last digit is the print number: 9 8 7 6 5 4 3 2 1

Reviewers

Amy Crofts, MHa/Ed; RT (R)(QM)
Clinical Teaching Faculty
Owens Community College
Toledo, Ohio

Joy Menser, MSM, RT(R) (T)
Radiography Program Director
Owensboro Community and Technical College
Owensboro, Kentucky

Jeffery E. Tillotson, BS RT (R)
Clinical Coordinator
Nashville General Hospital School of Heath Sciences
Nashville, Tennessee

This page intentionally left blank

Baylor College of Medicine

Dedication

I wrote the first edition of this textbook in 1974 not expecting anyone to read it much less buy it! I wrote it to get promoted. My academic chairman explained to me that in order to be promoted to full professor at Baylor College of Medicine one had to write a textbook (Bushong, SC. A Book Report. Radiologic Technology pg. 405-409, March/April 2013).

The greatest reward I have received in writing this 11th edition and the previous ten is the many new friends I now have because of this textbook. So I dedicate this edition to you, my friends in radiologic education. Many have contributed to this textbook and many have shared with me the speaking platform at educational meetings. Thank you very much for your friendship and I apologize to those I have left out because I'm late in the fourth quarter and I can't remember!!!

Kenneth Abramovitch, University of Texas
Nancy Adams, Louisiana State University
Arlene M. Adler, Indiana University Northwest
Christian Allard, Universidat de Arica, Chile
Carla Allen, University of Missouri
Felipe Allende, Universidad Centrale, Chile
Kelly Angel, Kaiser Permanente
Richard S. Angulo, Pima Medical Institute
Sebastian Arancibia, Universidad Centrale, Chile
Alex Backus, Gateway Community College
Philip Ballinger, Ohio State University
Stephen Balter, Columbia University
Ed Barnes, Medical Technology Management Institute
Gary Barnes, University of Alabama
Marcy Barnes, Lexington Community College
Cecilia Munoz Barabino, Universidad Nacional Mayor, Peru
Shirley A. Bartley, Hillyard Technical Center
Tammy Bauman, Banner Thunderbird Medical Center
Richard Bayless, University of Montana
Chris Beaudry, Yakima Valley Community College
Rochel Becker, Johns Hopkins School of Medical Imaging
Alberto Bello, Jr., Danville Area Community College
Bobbie Lynnette Biglane, US Air Force
Melanie Billmeier, North Central Texas College
Nathaniel L. Bishop, Jefferson College of Health Sciences
George Bissett, Texas Children's Hospital
Christie Bolton, Jefferson State College
Denise Bowman, Community Hospital of Monterrey Peninsula
Colleen Brady, Minnesota State College
Jett Brady, The Methodist Hospital
Jeffrey Brown, Kaiser Permanente
Karen Brown, Gateway Community College
Norman L. Burgess, Brookhaven College
Barry Burns, University of North Carolina
Deanna Butcher, St. Cloud Hospital
Priscilla Butler, American College of Radiology
James Byrne, Houston Community College
Cisca Bye, Montgomery County Community College
Andres Cabezas Cabrera, Universidad Centrale, Chile
Robert Cahalan, Iowa Society of Radiologic Technologists
Donna L. Caldwell, Arkansas State University
Shaun T. Caldwell, UT MD Anderson Cancer Center
William J. Callaway, Lincoln Land Community College
Richard R. Carlton, Arkansas State University
Mary Ellen Carpenter, Essex County College

Quinn Carroll, Midland College
Richard Carson, Oregon Institute of Technology
Christi Carter, Brookhaven College
Timothy C. Chapman, Gateway Community College
Christian Chavez, Universidat de Arica, Chile
Alexandro Cerda, Clinicas las Condes, Chile
Jean Christensen, Mercy Medical Center
Valerie Christensen, Association of Educators in Imaging and Radiologic Sciences
Carolyn L. Cianciosa, Niagara County Community College
David Clayton, UT MD Anderson Cancer Center
Brenda M. Coleman, Columbia State Community College
Edgar Colon, Universidad Central del Carribian
Judy Cook, Tarrant County College
Cathy Cooper, Alabama Society of Radiologic Technologists
Charles Coulston, Bluegrass Community and Technical College
Anuja Cox, Dona Ana Community College
Tracy Crandall, Atlanta Society of Radiologic Technologists
Russell Crank, Rockingham Memorial Hospital Healthcare
Suzanne E. Crandall, Iowa Methodist Medical Center
Angela Culliton, Mercy Medical Center
Cheryl V. Cunningham, Virginia Western Community College
Jacklyn Scott Darling, Morehead State University
Lynne Davis, Houston Community College
Denise DeGennaro, Lone Star College
Ann Delaney, University of Montana
Jenny Delawalla, Gwinnett Technical College
Tammy Delker, Indian Hills Community College
Lois Depouw, Rasmussen College
Steve Deutsch, Spencer Hospital
Randall D. Dings, Pima Community College
Martha Dollar, Columbus Technical College
Sarajane Doty, Kentucky Community and Technical College
Mary Doucette, Great Basin College
Marsha Dougherty, Lone Star College
Eric Douglas, St. Luke's Episcopal Hospital
Cheryl DuBose, Arkansas State University
Pat Duffy, Roxbury Community College
Andrea Guillen Dutton, Chaffey College
Ursula Dyer, Kilgore College
John W. Eichinger, Technical College of the Low Country
Karen Emory, Grady Memorial Healthcare
Michael A. Enriquez, Merced Community College
Rodrigo Espinoza, Universidad Centrale, Chile
Lisa S. Fanning, Massachusetts College of Health Sciences
Shanna Farish, Medical RT Board of Examiners
Terri Fauber, Virginia Commonwealth University
Bill Faulkner, University of Tennessee
Scott Flamm, Texas Heart Institute
Kae Brock Fleming, Columbia State Community College
Sherry Floerchinger, Dixie State College of Utah
M. Ella Flores, Blinn College
Mike Frain, Northern New Mexico College
Eugene Frank, Riverland Community College
Richard Fucillo, Burlington Community College
Michael Fugate, University of Florida
Rodrigo Antonio Galaz, University of Santiago
Marcelo Galvez, Clinica las Condes, Chile
Ismael Garcia, Del Mar College
Sandra Garcia, Fort Sam Houston
Andrew Gardner, Atlanta Technical College
Joe Garza, Lone Star College
Rudy Garza, Austin Community College
Camille Gaudet, Hospital Regional Dr-Georges-L-Dumont
Pamela Gebhart-Cline, Riverside School
Diane George, Jackson State College
Susan Giboney, Kaiser Permanente
Tim Gienapp, Apollo College
Julie A. Gill, ASRT
Laci Giroir, Beaumont Baptist Hospital
Yvonne Grant, Iowa Society of Radiologic Technologists
Joel Gray, Medical Physics Consulting
Ginger Griffin, Jacksonville, FL
LaVern Gurley, Shelby State Community College
Jennyfer Gutierrez, University of Peru
Dick Gwilt, Indian Health Service
Jeff Hamzeh, Keiser University
Loretta Hanset, Harris County Hospital District
Nancy Harvey, University of Iowa
Michael D. Harpin, University of South Alabama
Kenya Haugen, Baptist Health System
Art Haus, Ohio State University
Nancy Hawking, University of Arkansas
Joyce O. Hawkins, Bon Secours Richmond Health System
John Hazle, UT MD Anderson Cancer Center
Clyde R. Hembree, University of Tennessee
Ed Hendrick, Northwestern University
Chad Hensley, University of Nevada-Las Vegas
Tracy Herrmann, University of Cincinnati
Victoria Holas, Arizona Western College
Peggy Hoosier, Advanced Health Education Center
Miguel Iglesias, Colegio Technologo Medico del Peru
Keith Indeck, Norwalk Radiology Center
Janie Jackson, Tarrant County College
Donald Jacobson, Medical College of Wisconsin
Jeniesa Johnson, Tarrant County College
Nancy Johnson, Gateway Community College
Starla Jones, Medical College of Georgia
Linda Joppe, Rasmussen College
Helen Schumpert Kauchak, Ashville MRI

Dianne M. Kawamura, Weber State University
Leslie E. Kendrick, Boise State University
Cheryl Kerr, San Diego Naval Station
April D. Kidd, USFDA/CDRH
Jeannie Kilgore, Clovis Community College
Jeffery B. Killian, Midwestern State University
Paul A. Kusber, Mills Peninsula School
Ruth Kusterer, Virginia Society of Radiologic Technologists
Kent Lambert, Drexel University
Tim Lambrecht, Baylor Grapevine Diagnostic Imaging
John P. Lampignano, Gateway Community College
Paul Laudicina, College of DuPage
Gary Leach, Memorial Hermann Hospital
Lois Lehman, Texas Scottish Rite Hospital for Children
Deborah Leighty, Hillsborough Community College
Patricia Lenza, Concord's Community College
Theresa Levitsky, St. Francis Medical Center
Kurt Loveland, Southern Illinois University
Michelle Luciano, UNE Puerto Rico
Rodrigo Marchant, Universidad Centrale, Chile
Victor Ruiz Marquez, University of Peru
Mark. J. Martone, Massachusetts College of Health Sciences
Eileen M. Maloney, American Registry of Radiologic Technologists
Ron Marker, Wheaton Franciscan Healthcare
Valerie Martin, Brookhaven College
Starla Mason, Laramie County Community College
William May, Mississippi State University
Allyson Matheaus, Wharton County Junior College
Chris B. Martin, Oklahoma Health Sciences Center
LeAnn Maupin, Oregon Institute of Technology
Cynthia McCullough, Mayo Clinic
Dave McLaren, Polk State College
Francisco Mena, Clinicas las Condes, Chile
Darrly Mendoza, Mills Peninsula School
Joy Menser, Owensboro Community College
Robert Meisch, Indiana State University
Kim Metcalf, George Washington University
Massimo Midiri, University of Palermo
Becky Miller, Horry-Georgetown Technical College
Debbie K. Miller, Spokane Community College
Ruby Montgomery, Marion County Community College
Dawn Moore, Atlanta Society of Radiologic Technologists
Fernando A. Morales, Universidad Diego Portales
Jose Rafael Moscoso, Universidad Central del Caribe
C. William Mulkey, Midlands Technical College
Mindy Mutschler, Mercy Medical Center
Glenna Neumann, Atlanta Society of Radiologic Technologists
Charles Newell, University of South Alabama
Mary Ellen Newton, St. Francis School
Edward Nickoloff, Columbia University
Jon Nissenbaum, Massachusetts Eye and Ear Infirmary
Tanya Nolan, Weber State University
Larry Norris, Lone Star College
Sandra Ochoa, Del Mar College
Cyndee Oliver, Lone Star College
Lori Oswalt, Covenant School of Radiography
Francis Ozor, Lone Star College
George Pales, University of Nevada
Paula Pate-Schloder, Misericordia University
Brenda L. Pfeiffer, Loma Linda University
Rob Posteraro, Covenant School of Radiography
Chase Poulsen, Jefferson College of Health Sciences
Jerilyn J. Powell, Rapid City Regional Hospital
Valerie J. H. Powell, Robert Morris University
Kevin Powers, American Society of Radiologic Technologists
Perri Preston, University of Florida
Roger A. Preston, Reid Hospital & Health Services
Cheryl Pressly, Grady Health School of Imaging Technology
James Pronovost, Naugatuck Valley Community College
Barbara Smith Pruner, Portland Community College
John Radtke, Louisiana State University
Eytan Raz, University of Rome
Roland Rhymus, Loma Linda University
Teresa Rice, Houston Community College
Jennifer A. Rigsby, Austin Community College
Cynthia Robertson, Lone Star College
Ted Robertson, Washoe Medical Center
Rita Robinson, Memorial Hermann Hospital
Jeannean Rollins, Arkansas State University
Veronica Rosales, Universidad Austal de Chile
Donna Rufsholm, South Peninsula Hospital
Bonnie Rush, Educational Enterprise
Francesca Russo, Sant Marcia Dilicodia
Loren A. Sachs, Orange Coast College
Marilyn Sackett, Advanced Health Education Center
Dorothy Saia, Stamford Hospital
Ehsan Samei, Duke University
Thomas Sandridge, University of Illinois
Jim Sass, Gwinnett Technical College
Bette Schans, Colorado Mesa University
Jill Schulz, Covenant Medical Center
Eric J. Shepard, Fort Sam Houston
Lana Scherer, Covenant Health
Martin Schotten, Yuma Medical Center
Euclid Seeram, British Columbia Institute of Technology
Kim Seigman, Covenant Health
Joseph Shackelford, Jackson Community College
Elizabeth Shields, Presbyterian Hospital
Linda Shields, El Paso Community College
Anthony Siebert, University of California, Davis
Marcelo Zenteno Silva, Universidad Austal de Chile
Mark A. Sime, Mercy Medical Center

Kathryn M. Slagle, University of Alaska-Anchorage
Dawn Stark, Mississippi State University
Mike Stewart, New Mexico State University
Rees Stuteville, Oregon Institute of Technology
Donald Summers, Lincoln Land Community College
Raquel Tapia, Del Mar College
Christl Thompson, El Paso Community College
Kyle Thornton, City College of San Francisco
Gina Tice, Gadsden State Community College
Kimberly Todd, Jackson State Community College
Renee Tossell, Pima Community College
Brenna Travis, Tarrant County College
William Tyler, Savannah Technical Institute
Virginia Vanderford, Portland Community College
Beth L. Veale, Midwestern State University
Susan Sprinkle Vincent, Advanced Health Education Center
Donna Vitetta, White Plains College
Louis Wagner, University of Texas Medical School
Jeff Walmsley, Lorain Community College
Steven D. Walters, Regional Medical Center of San Jose
Cheryl Dutton Walton, Huntsville Hospital
Patti Ward, Colorado Mesa University
Brenda Watson, Camosun College
Lynette K. Watts, Midwestern State University
Laurie Weaver, Casper College
Stephanie A. Wells, Brookhaven College
Diana S. Werderman, Trinity College
Amy D. Westbury, Oregon Technical College
Mark White, University of Nebraska
Tracey B. White, Arkansas State University
Christine Wiley, North Shore Community College
Carla Williams, Carteret Community College
Judy Williams, Grady Memorial Hospital
Bettye G. Wilson, ARRT
Leslie F. Winter, JRCERT
Ray Winters, Arkansas State University
Ken Wintch, Colorado Mesa University
Mary E. Wolfe, Catholic Medical Center
Andrew Woodward, Wor-Wic Community College
Erica K. Wight, University of Alaska-Anchorage
Raymond Wilenzek, Tulane University
Charles Willis, UT MD Anderson Cancer Center
Robert Wilson, University of Tennessee
Ray Winters, Arkansas State University
Melinda Wren, Del Mar College
Donna Lee Wright, Midwestern State University
Jennifer Yates, Merritt College
Brad York, Houston Community College
Brian Zawislak, Northwestern University Medical School
Xie Nan Zhu, Guangzhou Medical College
Kelly J. Zuniga, Houston Community College

This Book is also Dedicated to My Friends Here and Gone:

Abby Kuramoto
Arlo Carlyle Hopkinson
Baily Schroth (†)
Baily Spaulding
Bandit Davidson (†)
Bella Bushong
Biscuit Carlyle Martin
Boef Kuipers (†)
Brittney Prominski
Brownie Hindman (†)
Brutus Payne (†)
Buffy Jackson (†)
Butterscotch Bushong (†)
Casper Miller (†)
Cassie Kronenberger (†)
Chandon Davis (†)
Chester Chase (†)
Choco Walker (†)
Clifford Carlyle Devoe
Coco Winsor
Cookie Lake (†)
Colonel Travis
Desi Lohrenz
Dually Jackson
Dude Carlyle Schwartz
Duke Carlyle McMullin
Duncan Hindman (†)
Ebony Bushong (†)
Emme Carlyle Couch
Flap Maly
Fonzie Schroth (†)
Frank Edlund
Geraldine Bushong (†)
Ginger Chase (†)
Grayton Friedlander
Gretchen Scharlach (†)
Guadalupe Tortilla Holmberg
Heidi Carlyle Couch
Jemimah Bushong (†)
Kate Davidson (†)
Kokopelli Carlyle Hames
Linus Black (†)
Lizzie Carlyle Bryan
Lizzy Carlyle Prominski
Loftus Meadows
Louie Carlyle Edlund
Lucy Spaulding (†)
Lupe Tortilla Holmberg
Maddie Bushong
Maxwell Haus (†) and my lenses
Maxwell Carlyle McMullin
Midnight Lunsford (†)
Mimi Hana (Indian Princess)
Molly Holmberg (†)
Muttly Chase (†)
Olive Carlyle Aswad
Pancho Villa Holmberg (†)
Peanut Schroth (†)
Penny Carlyle Friedlander (†)
Pepper Miller
Percy Lohrenz
Petra Chase (†)
Powers Jackson
Queenie Carlyle Reed
Sadie Carlyle Reed
Sammie Chase
Sapphire Miller (†)
Sebastian Miller (†)
Sophie Carlyle Archer
Susi Bueso
Teddy Schroth
Tigger Carlyle Brice
Toby Schroth (†)
Toto Walker (†)
Travis Chase (†)
Tuffy Beman

(†) = R.I.P.

Dedication – Saintly Stitchers

This eleventh edition of *Radiologic Science for Technologists* is dedicated to my new friends at St. Martin's Episcopal Church, Houston, which is not even my church. I discovered that their project to knit kneelers for their new sanctuary needed additional stitchers. They taught me to stitch and that one can stitch while in conversation, while in church, while watching TV, and during many other activities. It is easy to do and easy to multi-task when stitching is one of the activities.

A recent article in the Houston Chronicle included an interview with me, one of two Saintly Stitching males. "It's a total chick magnet." When I break out my stitching at the airport or wherever, the chicks, mostly in the fourth quarter, do come flocking with lots of questions and compliments.

More importantly I've been promised that when I finish my kneeler I will be a slam-dunk to get into Heaven. I've been at it for a year now and plot my progress - that's my kneeler hanging on the railing below. At the present pace I will finish in March, 2031.

From left:
Row 1: Ada Grundy, Barbara Bush, Betty Workman, Ann Thurmond, Lee Hunnell, Marthann Weaber, Susan Rovello, Karen Fast, Nancy Marymee. Row 2: Joyce Jackson, Gerri Utterson, Bette Fryar, Pam Bentley, Clem McIver, Joan Hilley, Shirley Hopkins, Gerry Eversol, Ann Cochran, Fran Smith. Row 3: Shirley Allen Anne McFaddin, Sue Rea, Barbara Svetlik. Row 4: Michele Roberts, Stewart Bushong, Bobbie Adams, Martha Ann Linden, Dorothy Browne, Mary Epps, Kay Handley, Carroll Selander, Betty Ann Graves.

Preface

PURPOSE AND CONTENT

The purpose of ***Radiologic Science for Technologists: Physics, Biology, and Protection*** is threefold: to convey a working knowledge of radiologic physics; to prepare radiography students for the certification examination by the ARRT; and to provide a base of knowledge from which practicing radiographers can make informed decisions about technical factors, diagnostic image quality, and radiation management for both patients and personnel.

This textbook provides a solid presentation of radiologic science, including the fundamentals of radiologic physics, diagnostic imaging, radiobiology, and radiation management. Special topics include mammography, fluoroscopy, interventional radiology, helical computed tomography, and the various modes of digital imaging.

The fundamentals of radiologic science cannot be removed from mathematics, but this textbook does not assume a mathematics background for the readers. The few mathematical equations presented are always followed by sample problems with direct clinical application. As a further aid to learning, all mathematical formulas are highlighted with their own icon.

Likewise, the most important ideas under discussion are presented with their own colorful penguin icon and box. A PENGUIN is a very important fact that you should place on your iceberg.

The eleventh edition improves this popular feature of information bullets by including even more key concepts and definitions in each chapter. This textbook also presents learning objectives, chapter overviews, and chapter summaries that encourage students and make the text user-friendly for all. Challenge Questions at the end of each chapter include definition exercises, short-answer questions, and a few calculations. These questions can be used for homework assignments, review sessions, or self-directed testing and practice. Answers to all questions are provided on the Evolve site at http://evolve.elsevier.com.

HISTORICAL PERSPECTIVE

For seven decades after Roentgen's discovery of x-rays in 1895, diagnostic radiology remained a relatively stable field of study and practice. Truly great changes during that time can be counted on one hand: the Crookes tube, the radiographic grid, radiographic intensifying screens, and image intensification.

Since the publication of the first edition of this textbook in 1975, however, newer systems for diagnostic imaging have come into routine use: multislice helical computed tomography, computed radiography, digital radiography, digital radiographic tomosynthesis, and digital fluoroscopy. Truly spectacular advances in computer technology and x-ray tube and image receptor design have made these innovations possible, and they continue to transform diagnostic imaging.

NEW TO THIS EDITION

The eleventh edition has been reorganized, consolidated, and updated to reflect the current imaging environment. Currently we are essentially engaged in digital imaging. Digital radiography has replaced screen-film radiography rapidly and this requires that radiologic technologists acquire a new and different fund of knowledge in addition to what has been required previously—and in the same length of training time! Two new chapters were added on digital imaging, primarily focusing on patient dose safety with these newer techniques. Though the trend is to replace film/screen radiography with digital radiography, chapters concerning film/screen radiography were left in this 11th edition for reference purposes and those schools still teaching film/screen radiography.

In addition, the targeted focus on this necessary new content and closer alignment with ASRT core curriculum ensures student technologists are prepared to take the ARRT exam and have the background they need to perform well in the clinical environment.

ANCILLARIES

Student Workbook

This resource has been updated to reflect the changes in the text and the rapid advancements in the field of radiologic science. Part I offers a complete selection of worksheets organized by textbook chapter. Part II, the Math Tutor, provides an outstanding refresher for any student. The Laboratory Experiments collect experiments designed to demonstrate important concepts in radiologic science. These are now available on the Evolve site at http://evolve.elsevier.com for ease of use.

Evolve Resources

Instructor ancillaries, including an ExamView Test Bank of over 900 questions, an image collection of all of the images in the text, and a PowerPoint lecture presentation are all available to instructors at http://evolve.elsevier.com.

Students and instructors have access to the textbook challenge questions answer keys, laboratory experiments, the workbook math tutor answer key, and the workbook worksheet answer keys.

A NOTE ON THE TEXT

Although the ARRT has not formally adopted the International System of Units (SI units), they are presented in this eleventh edition. With this system come the corresponding units of radiation and radioactivity.

The roentgen and the rad are being replaced by the gray (Gy_a and Gy_t respectively) and the rem by the sievert (Sv). In this edition, the SI units are presented first, followed by the earlier units in parentheses. A summary of special quantities and units in radiologic science can be found on the inside front cover of the text.

Radiation exposure is measured in SI units of C/kg, measured in mGy. Because mGy is also a unit of dose, a measurement of radiation exposure is distinguished from tissue dose by applying a subscript ***a*** or ***t*** to mGy, according to the recommendations of Archer and Wagner (***Minimizing Risk From Fluoroscopic X-rays,*** **PRM, 2007**). Therefore radiation exposure is measured in mGy_a and tissue dose in mGy_t.

ACKNOWLEDGMENTS

For the preparation of the eleventh edition, I am indebted to the many readers of the previous editions who submitted suggestions, criticisms, corrections, and compliments.

I am particularly indebted to the following radiologic science educators, whom I have identified on the Dedication page of this eleventh edition. Their suggestions for change and clarification were always right on target. Many supplied illustrations, and they are additionally acknowledged with the illustration in this eleventh edition.

My friend and colleague, Ben Archer, is the author of the Penguin Tale (Page 3), which for me has become a particularly effective teaching tool. And that, in turn, has led to some 30 Penguintoons suggested by educators and students, which I now show regularly during lectures. I'll never forget the first. Three of Ruby Montgomery's students interrupted me at Judy William's Atlanta SRT Student and Educators' Conference in 2002. "Do polar bears eat penguins?" they asked. "Sure they do, they're carnivorous," I responded. "No, polar bears live at the North Pole, penguins at the South Pole!" … intense audience laughter.

The drawing of the Penguintoons and the illustrations in this book are the work of another close friend and colleague, Kraig Emmert. Thanks, Kraig, for your exceptional time and effort.

When I am in the audience of a lecture and leave with a single Penguin, I consider the lecture successful. Please send me your Penguins!

As you, student or educator, use this text and have questions or comments, I hope you will email me at *sbushong@bcm.edu* so that together we can strive to make this very difficult material easier to learn. I may not respond immediately, but I promise I will respond.

"Physics is fun" is the motto of my radiologic science courses.

Stewart Carlyle Bushong

Contents

This page intentionally left blank

PART

I

RADIOLOGIC PHYSICS

CHAPTER

1

Essential Concepts of Radiologic Science

OBJECTIVES

At the completion of this chapter, the student should be able to do the following:

1. Describe the characteristics of matter and energy.
2. Identify the various forms of energy.
3. Define electromagnetic radiation and ionizing radiation.
4. State the relative intensity of ionizing radiation from various sources.
5. List the concepts of basic radiation protection.
6. Discuss the derivation of scientific systems of measurement.
7. List and define units of radiation and radioactivity.

OUTLINE

THIS CHAPTER explores the basic concepts of the science and technology of x-ray imaging. These include the study of matter, energy, the electromagnetic spectrum, and ionizing radiation. The production and use of ionizing radiation as a diagnostic tool serve as the basis for radiography. Radiologic technologists who deal specifically with x-ray imaging are radiographers. Radiographers have a great responsibility in performing x-ray examinations in accordance with established radiation protection standards for the safety of patients and medical personnel.

The instant an x-ray tube produces x-rays, all of the laws of physics are evident. The projectile electron from the cathode hits the target of the anode producing x-rays. Some x-rays interact with tissue, and other x-rays interact with the image receptor, forming an image. The physics of radiography deals with the production and interaction of x-rays.

Radiography is a career choice with great opportunities in a number of diverse fields. Welcome to the field of medical imaging!

NATURE OF OUR SURROUNDINGS

In a physical analysis all things can be classified as matter or energy. Matter is anything that occupies space and has mass. It is the material substance of which physical objects are composed. All matter is composed of fundamental building blocks called *atoms,* which are arranged in various complex ways. These atomic arrangements are considered at great length in Chapter 2.

A primary, distinguishing characteristic of matter is **mass,** the quantity of matter contained in any physical object. We generally use the term *weight* when describing the mass of an object, and for our purposes we may consider mass and weight to be the same. Remember, however, that in the strictest sense they are not the same. Whereas mass is actually described by its energy equivalence, weight is the force exerted on a body under the influence of gravity.

Mass is measured in kilograms (kg). For example, on Earth, a 200-lb (91-kg) man weighs more than a 120-lb (55-kg) woman. This occurs because of the mutual attraction, called *gravity,* between the Earth's mass and the mass of the man or woman. On the moon, the man and the woman would weigh only about one-sixth what they weigh on Earth because the mass of the moon is much less than that of the Earth. However, the mass of the man and the woman remains unchanged at 91 kg and 55 kg, respectively.

Mass is the quantity of matter as described by its energy equivalence.

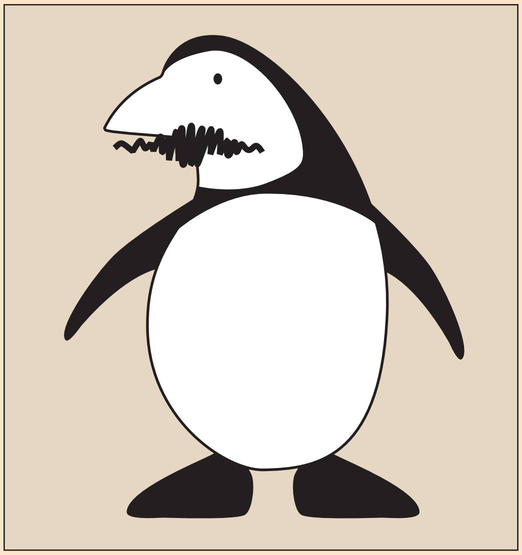
MATTER AND ENERGY

Matter is anything that occupies space. It is the material substance having mass of which physical objects are composed. The fundamental, complex building blocks of matter are **atoms** and **molecules**. The kilogram, the

A PENGUIN TALE BY BENJAMIN RIPLEY ARCHER, PhD

In the vast and beautiful expanse of the Antarctic region, there was once a great, isolated iceberg floating in the serene sea. Because of its location and accessibility, the great iceberg became a Mecca for penguins from the entire area. As more and more penguins flocked to their new home and began to cover the slopes of the ice field, the iceberg began to sink farther and farther into the sea. Penguins kept climbing on, forcing others off the iceberg and back into the ocean. Soon the iceberg became nearly submerged owing to the sheer number of penguins that attempted to take up residence there.

Moral: The **PENGUIN** represents an important fact or bit of information that we must learn to understand a subject. The brain, similar to the iceberg, can retain only so much information before it becomes overloaded. When this happens, concepts begin to become dislodged, like penguins from the sinking iceberg. So, the key to learning is to reserve space for true "penguins" to fill the valuable and limited confines of our brains. Thus key points in this book are highlighted and referred to as **"PENGUINS."**



scientific unit of mass, is unrelated to gravitational effects. The prefix **kilo** stands for 1000; a kilogram (kg) is equal to 1000 grams (g).

Although mass, the quantity of matter, remains unchanged regardless of its state, it can be transformed from one size, shape, and form to another. Consider a 1-kg block of ice, in which shape changes as the block of ice melts into a puddle of water. If the puddle is allowed to dry, the water apparently disappears entirely. We know, however, that the ice is transformed from a solid state to a liquid state and that liquid water becomes water vapor suspended in air. If we could gather all the molecules that make up the ice, the water, and the water vapor and measure their masses, we would find that each form has the same mass.

Similar to matter, energy can exist in several forms. In the International System (SI) energy is measured in joules (J). In radiology the unit electron volt (eV) is often used.

Potential energy is the ability to do work by virtue of position. A guillotine blade held aloft by a rope and pulley is an example of an object that possesses potential energy (Figure 1-1). If the rope is cut, the blade will descend and do its ghastly task. Work is required to get the blade to its high position, and because of this position, the blade is said to possess potential energy. Other examples of objects that possess potential energy include a rollercoaster on top of the incline and the stretched spring of an open screen door.

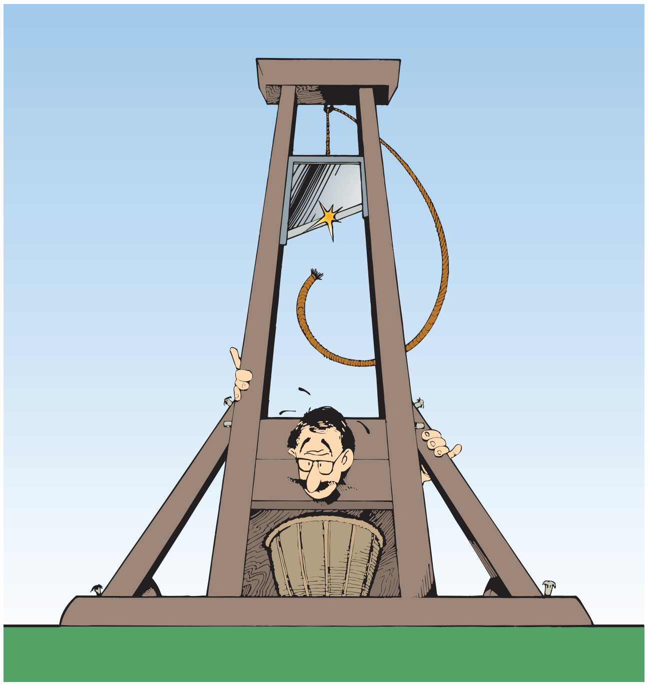


FIGURE 1-1 The blade of a guillotine offers a dramatic example of both potential and kinetic energy. When the blade is pulled to its maximum height and is locked into place, it has potential energy. When the blade is allowed to fall, the potential energy is released as kinetic energy.

> Energy is the ability to do work.

Kinetic energy is the energy of motion. It is possessed by all matter in motion: a moving automobile, a turning windmill wheel, a falling guillotine blade. These systems can all do work because of their motion.

Chemical energy is the energy released by a chemical reaction. An important example of this type of energy is that which is provided to our bodies through chemical reactions involving the foods we eat. At the molecular level, this area of science is called **biochemistry.** The energy released when dynamite explodes is a more dramatic example of chemical energy.

Electrical energy represents the work that can be done when an electron moves through an electric potential difference (voltage). The most familiar form of electrical energy is normal household electricity, which involves the movement of electrons through a copper wire by an electric potential difference of 110 volts (V). All electric apparatus, such as motors, heaters, and blowers, function through the use of electrical energy.

Thermal energy (heat) is the energy of motion at the molecular level. It is the kinetic energy of molecules and is closely related to temperature. The faster the molecules of a substance are vibrating, the more thermal energy the substance has and the higher is its temperature.

Nuclear energy is the energy that is contained within the nucleus of an atom. We control the release and use of this type of energy in electric nuclear power plants. An example of the uncontrolled release of nuclear energy is the atomic bomb.

Electromagnetic energy is perhaps the least familiar form of energy. It is the most important for our purposes, however, because it is the type of energy that is used in x-ray imaging. In addition to x-rays and gamma rays, electromagnetic energy includes radio waves; microwaves; and ultraviolet, infrared, and visible light. Electromagnetic energy does not include sound or diagnostic ultrasound.

Just as matter can be transformed from one size, shape, and form to another, so too can energy be transformed from one type to another. In radiology, for example, electrical energy in the x-ray imaging system is used to produce electromagnetic energy (the x-ray), which then is converted to chemical energy in the radiographic film or an electrical signal in a digital image receptor.

Reconsider now the statement that all things can be classified as matter or energy. Look around you and think of absolutely anything, and you should be convinced of this statement. You should be able to classify anything as matter, energy, or both. Frequently, matter and energy exist side by side—a moving automobile has mass and kinetic energy; boiling water has mass and thermal energy; the Leaning Tower of Pisa has mass and potential energy.

Perhaps the strangest property associated with matter and energy is that they are interchangeable, a characteristic first described by Albert Einstein in his famous theory of relativity. Einstein's **mass-energy equivalence** equation is a cornerstone of that theory.

This mass-energy equivalence serves as the basis for the atomic bomb, nuclear power plants, and certain nuclear medicine imaging modalities.

MASS-ENERGY

$E = mc^2$

where *E* is energy, *m* is mass, and *c* is the velocity (speed) of electromagnetic radiation (light) in a vacuum.

Energy emitted and transferred through space is called **radiation.** When a piano string vibrates, it is said to radiate sound; the sound is a form of radiation. Ripples or waves radiate from the point where a pebble is dropped into a still pond. Visible light, a form of electromagnetic energy, is radiated by the sun and is **electromagnetic radiation.** Electromagnetic energy is usually referred to as electromagnetic radiation or, simply, *radiation.*

Matter that intercepts radiation and absorbs part or all of it is said to be *exposed* or **irradiated.** Spending a day at the beach exposes you to ultraviolet light. Ultraviolet light is the type of radiation that causes sunburn. During a radiographic examination, the patient is exposed to x-rays. The patient is said to be *irradiated.*

Radiation is the transfer of energy.

Ionizing radiation is a special type of radiation that includes x-rays. Ionizing radiation is any type of radiation that is capable of removing an orbital electron from the atom with which it interacts (Figure 1-2). This type of interaction between radiation and matter is called **ionization.** Ionization occurs when an x-ray passes close to an orbital electron of an atom and transfers sufficient energy to the electron to remove it from the atom. The ionizing radiation may interact with and ionize additional atoms. The orbital electron and the atom from which it was separated are called an **ion pair.** The electron is a negative ion, and the remaining atom is a positive ion.

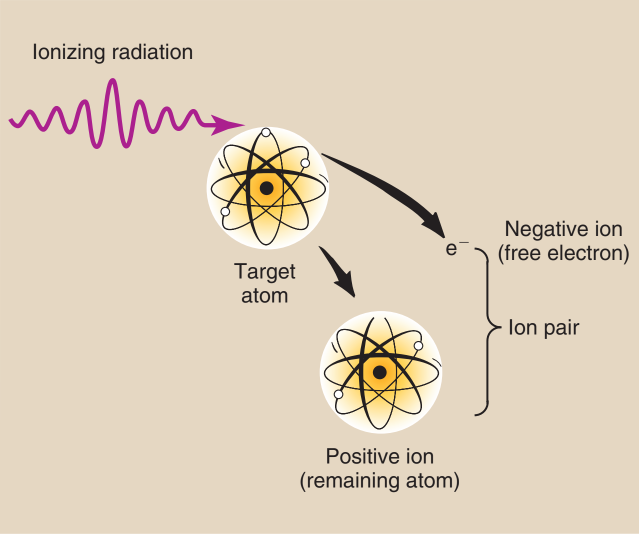


FIGURE 1-2 Ionization is the removal of an electron from an atom. The ejected electron and the resulting positively charged atom together are called an *ion pair.*

Ionization is the removal of an electron from an atom.

Thus any type of energy that is capable of ionizing matter is known as ionizing radiation. X-rays, gamma rays, and ultraviolet light are the only forms of electromagnetic radiation with sufficient energy to ionize. Some fast-moving particles (particles with high kinetic energy) are also capable of ionization. Examples of particle-type ionizing radiation are alpha and beta particles (see Chapter 2). Although alpha and beta particles are sometimes called *rays,* this designation is incorrect.

SOURCES OF IONIZING RADIATION

Many types of radiation are harmless, but ionizing radiation can injure humans. We are exposed to many sources of ionizing radiation (Figure 1-3). These sources can be divided into two main categories: **natural environmental radiation** and **man-made radiation.**

Natural environmental radiation results in an annual dose of approximately 3 millisieverts (mSv). Man-made radiation results in 3.2 mSv annually. An mSv is the unit of effective dose. It is used to express radiation exposure of populations and radiation risk in those populations.

Natural environmental radiation consists of four components: **cosmic rays, terrestrial radiation, internally deposited radionuclides, and radon.** Cosmic rays are particulate and electromagnetic radiation emitted by the sun and stars. On Earth, the intensity of cosmic radiation increases with altitude and latitude. Terrestrial radiation results from deposits of uranium, thorium, and other radionuclides in the Earth. The intensity is