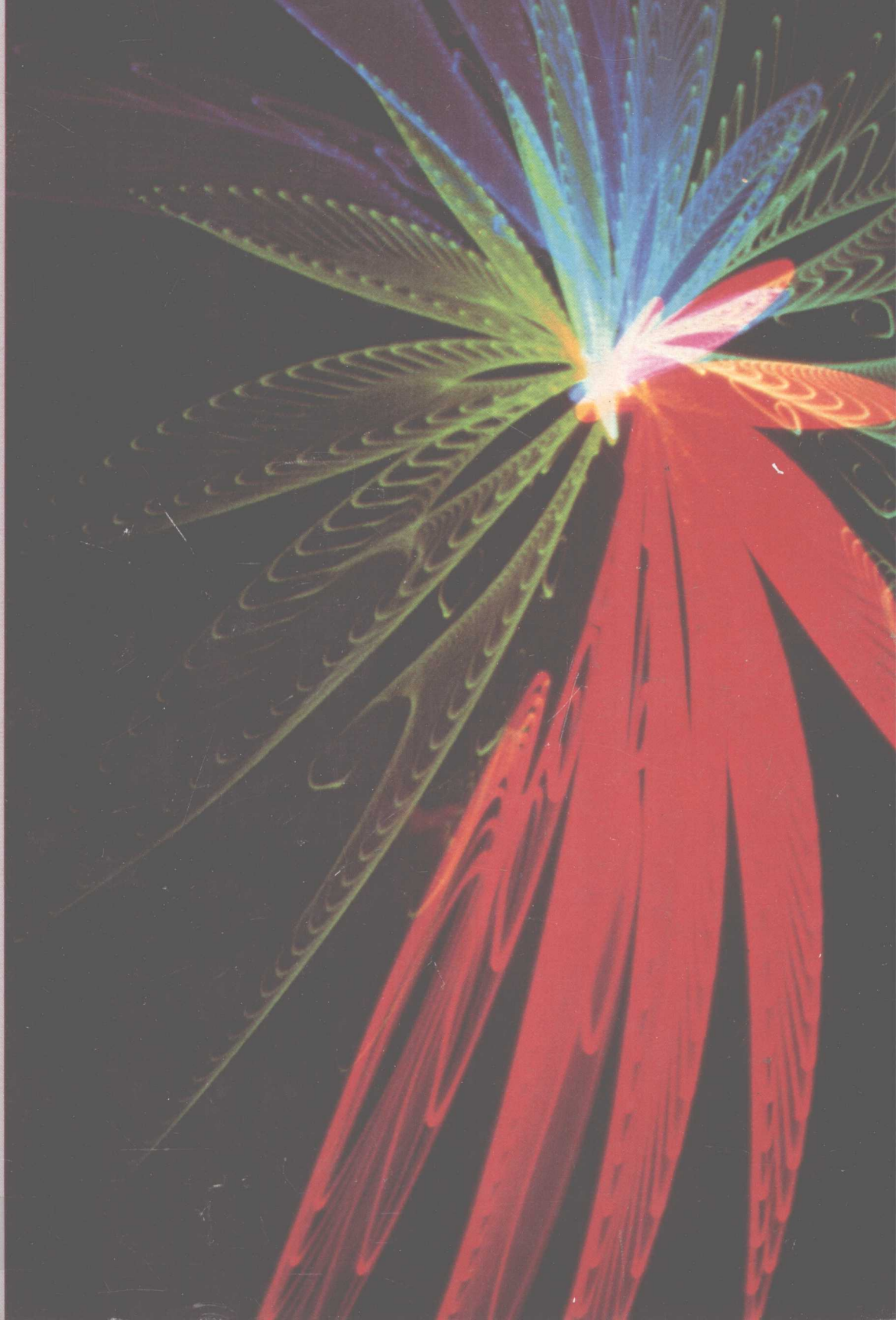


Second Edition

PHYSICS AND THE PHYSICAL PERSPECTIVE

HOOPER AND
GWYNNE



0
4
H785

Second Edition
PHYSICS
AND THE PHYSICAL
PERSPECTIVE

HENRY O. HOOPER
University of Maine at Orono
PETER GWYNNE

HARPER & ROW, PUBLISHERS

SAN FRANCISCO

Cambridge
Hagerstown
New York
Philadelphia



London
Mexico City
São Paulo
Sydney

1817

Sponsoring Editor: Malvina Wasserman
Project Editor: Eva Marie Strock
Production Coordinator: Marian Hartsough
Designer: Nancy B. Benedict
Illustrator: J & R Technical Services
Cover Designer: Nancy B. Benedict
Cover Laser Photograph: Laser Images, Inc.
Cover Separator: Focus 4
Compositor: York Graphic Services
Printer and Binder: Kingsport Press

PHYSICS AND THE PHYSICAL PERSPECTIVE, Second Edition
Copyright © 1980 by Harper & Row, Publishers, Inc.

All rights reserved. Printed in the United States of America. No part of this book may be used or reproduced in any manner whatsoever without written permission except in the case of brief quotations embodied in critical articles and reviews. For information address Harper & Row, Publishers, Inc., 10 East 53rd St., New York NY 10022.

Library of Congress Cataloging in Publication Data

Hooper, Henry O.
Physics and the physical perspective.

Includes index.

I. Physics. I. Gwynne, Peter, 1941- joint
author. II. Title.
QC23.H759 1980 530 79-24708
ISBN 0-06-042912-7

Preface

Physics and the Physical Perspective, second edition, is a textbook primarily for students who require a familiarity with but not an exhaustive knowledge of the science of physics: those who need the basics of physics for careers in medicine, dentistry, the biological sciences, agriculture, architecture, geology, oceanography, law, business, or as a general understanding of the physical world. Elementary physics texts and courses are often classified by the level of mathematics employed; this is a *noncalculus* text in which high school algebra is used extensively and trigonometry is used as necessary to provide insights and better understanding of the principles of physics. Because many students tend to have problems with the mathematics in this course, reviews of mathematical concepts are included where they are first used. In addition, Appendix A presents a detailed overview of mathematical concepts. Throughout the book, applications of a non-engineering nature should help students see the relevance of physics to their career goals.

Physics and the Physical Perspective, second edition, brings a new approach to teaching the subject at this level. The experience of a physics professor, who has taught this course for more than fifteen years at three very different universities, and the skills of a science writer trained in physical science have been combined to produce a text that is lively, readable, and informative for students while maintaining the intellectual integrity of the course. In addition, this edition benefitted greatly from the intense review of Mario Iona, professor of physics at the University of Denver and author of the "Would You Believe?" column concerned with textbook accuracy for *The Physics Teacher*. Mario contributed valuable suggestions for the text's revision. In addition, he reviewed substantial portions of the second edition text material during the first proof stages. Iona's critical comments increased greatly the clarity and exactness of the text.

Suggestions from first edition users were incorporated in expanding one or two sections of many chapters and clarifying a number of statements and problems. In addition, the comments from this extensive survey were used in restructuring the second edition. For example, based upon user comments, Chapter 2, Motion, was shortened by delaying a discussion of circular motion until Chapter 4, Universal Gravitation, where the circular motion and centripetal force are necessary applications to planetary motion. Power is introduced in Chapter 5, Energy, and is discussed again in several later chapters. A discussion of simple machines is introduced as a Special Topic in Chapter 5.

In Chapter 9, Fluids under Pressure, the presentation of topics was altered from the first edition so that viscous flow is now the last topic introduced. Thermodynamics was moved from Chapter 10, Thermal Energy and Thermal Properties of Matter, to the end of Chapter 11, Ideal Gases, and Thermodynamics, enabling simple examples of thermodynamics to be based upon the ideal gas law. The discussion of entropy was expanded. A Special Topic on home insulation, which introduces the R-factor and degree days, was added to Chapter 10. In Chapter 12 the discussion of simple harmonic motion (Section 12.2) was expanded to make it more complete.

Chapter 17 was completely reorganized and rewritten to include new material on ac circuits and ac power, along with material from the first edition's Chapter 25 on capacitance, inductance, diodes, and transistors. Chapter 17 ends with an introduction to electromagnetic waves via an elementary discussion of Maxwell's equations. The discussion of polarization formerly in Chapter 17 is now in Chapter 18, Section 18.5, after a discussion of the wave properties of light.

The Instructors Guide includes several suggestions for adapting the text to various academic-year calendars. Brief comments on the highlights of each chapter are presented to help instructors use the text in their courses. Suggestions for assignments, including lecture demonstrations and laboratory experiments, are also included, along with sample exam questions (some multiple choice) and answers to the even-numbered problems.

We use several features to brighten up what otherwise would be dry textual material. One element is the *narrative style* throughout the book, making each chapter a cohesive and complete story in itself. Each *chapter* is *outlined* on its opening page; unlike the first edition, the chapter contents now are contained within one page for concise reference.

At least two *Short Subjects* are interspersed throughout most chapters. These subjects are essentially "asides" to the text presentation. Although the subjects are not required reading—students can receive all the information they need from each chapter by concentrating solely on the basic text—they provide material that both interests the students and breaks up the text, making the going just a little easier. By showing how physics abuts the real world, the descriptive Short Subjects complement the text, ranging from 200 to 1000 words and including such topics as the history of the metric system, flywheels, holography, and biographies of Newton, Einstein, and Boyle.

There is a descriptive *Special Topic* at the end of each chapter. The Special Topics, from 1000 to 1500 words in length, treat, in greater depth, a subject of interest that is related to points discussed within chapters. Timely subjects the Special Topics cover include "The Urge to Unify," a discussion of a search for a unified field theory, "Producing Energy for the People," "Bone As a Building Material," and "Holding Down Those Heating Bills."

Within each chapter there are several other elements that serve both pedagogical and motivational purposes; these elements include definitions in **boldface**, important statements highlighted in color and placed in the margin, and important marginal notes and reminders. Each chapter contains many worked-out illustrative examples that clearly indicate techniques for setting up and solving typical problems. End-of-chapter material includes, besides a Special Topic, a summary, questions, and numerous problems. The extensive sets of problems are grouped by subject matter; within each group problems are graded from least to more difficult as the number of the problem increases. The appendixes are useful tables of physical constants, conversion factors, trigonometric tables, and, as mentioned, an extensive math review. Answers to all odd-numbered problems are at the end of the text. The answers were reviewed thoroughly by both authors, Mario Iona, and independent physicists.

As in the first edition, we use the mks system of units throughout the text, to attempt to minimize any confusion about units. The SI abbreviations are introduced at their first occurrence and thereafter used in the book. However, because the cgs and British systems are still used by many people, including scientists and engineers, we introduce them early in the book and use them occasionally in examples and problems.

Henry O. Hooper
Peter Gwynne

Useful Information

$$60 \text{ mi/h} = 88 \text{ ft/s}$$

$$1 \text{ mi} = 1.61 \text{ km}$$

$$1 \text{ kg weighs } 9.8 \text{ N at earth's surface}$$

$$1\text{-lb weight has mass of } 0.453 \text{ kg}$$

$$2.2 \text{ lb of weight has mass of } 1 \text{ kg}$$

$$1 \text{ cal} = 4.184 \text{ J}, 1 \text{ kcal} = 4184 \text{ J}$$

$$1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$$

$$1 \text{ atm} = 76.0 \text{ cmHg} = 1.01 \times 10^5 \text{ N/m}^2 = 14.7 \text{ lb/in.}^2$$

$$931.5 \text{ MeV} = 1 \text{ u} \times c^2 \text{ (speed of light)}$$

$$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$$

$$2\pi \text{ rad} = 1 \text{ r} = 360^\circ$$

$$\text{Area of circle} = \pi R^2$$

$$\text{Circumference of circle} = 2\pi R$$

$$\text{Volume of sphere} = \frac{4}{3}\pi R^3$$

$$\pi = 3.14 = \frac{22}{7}; \sqrt{2} = 1.41; \sqrt{3} = 1.73$$

$$\sin 0^\circ = \cos 90^\circ = 0$$

$$\sin 90^\circ = \cos 0^\circ = 1$$

$$\sin 30^\circ = \cos 60^\circ = \frac{1}{2}$$

$$\sin 60^\circ = \cos 30^\circ = 0.866 = \frac{\sqrt{3}}{2}$$

$$\sin 45^\circ = \cos 45^\circ = 0.707 = 1/\sqrt{2}$$

Physical

Constants

$$\text{Speed of light } c = 2.9979 \times 10^8 \text{ m/s}$$

$$\text{Planck's constant } h = 6.625 \times 10^{-34} \text{ J} \cdot \text{s}$$

$$\text{Charge on electron } e = 1.602 \times 10^{-19} \text{ C}$$

$$\text{Rest mass of electron } m_e = 9.11 \times 10^{-31} \text{ kg}$$

$$\text{Rest mass of proton } m_p = 1.67 \times 10^{-27} \text{ kg}$$

$$\text{Electric constant } k = 8.98 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$$

$$\text{Universal gravitation constant } G = 6.673 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2$$

$$\text{Acceleration due to gravity } g = 32.2 \text{ ft/s}^2 = 9.8 \text{ m/s}^2 \text{ at earth's surface}$$

Contents

Preface xi

Useful Information xiv

1

The Nature of Physics 1

- 1.1 From Archeology to Zoology 3
- 1.2 Recent and Modern 3
- Special Topic: *The Urge to Unify* 6

2

Motion 7

- 2.1 Length 9
- 2.2 Time 13
- 2.3 Vectors 15
- 2.4 Speed and Velocity (A Scalar and a Vector) 22
- 2.5 Relative Velocities 23
- 2.6 Average Speed and Instantaneous Speed (Two Scalars) 27
- 2.7 Acceleration 29
- 2.8 Projectile Motion (Vectors in Two Dimensions) 38
- Special Topic: *Higher, Faster, Farther* 52

3

Forces 55

- 3.1 Newton's Laws of Motion 57
 - 3.2 The Second Law 60
 - 3.3 Mass and Weight 61
 - 3.4 Units of Force 63
 - 3.5 The Second Law in Action 65
 - 3.6 Newton's Third Law 66
 - 3.7 Applying Newton's Laws 69
 - 3.8 Friction 77
- Special Topic: Return to a Small Planet 88*

4

Universal Gravitation 89

- 4.1 Kepler's Laws of Planetary Motion 92
 - 4.2 Newton's Law of Universal Gravitation 94
 - 4.3 Moving Round Curves 99
 - 4.4 Gravitation and the Solar System 102
 - 4.5 Artificial Satellites 107
 - 4.6 When the Tide Rushes In 108
 - 4.7 That Floating Feeling 111
 - 4.8 Fleeing the Center 114
 - 4.9 Earth's Gravitational Field 114
- Special Topic: An Open and Shut Universe 121*

5

Energy 123

- 5.1 The Real Meaning of Work 125
 - 5.2 Kinetic Energy: Energy of Movement 128
 - 5.3 Potential Energy: Energy of Position 130
 - 5.4 Conservation of Energy 133
 - 5.5 Swinging the Changes 135
 - 5.6 Gravitational Potential Energy 139
 - 5.7 Power 143
- Special Topic: Producing Energy for the People 149*

6

Impulse and Momentum 153

- 6.1 Momentum 154
- 6.2 Impulse 155
- 6.3 Conservation of Momentum 158
- 6.4 Coming Together 161
- Special Topic: *The Impulsive Athlete* 171

7

Systems of Many Particles 173

- 7.1 The Two Centers 175
- 7.2 Tau is for Torque 177
- 7.3 Getting at the Center of Gravity 181
- 7.4 Moving Around 187
- 7.5 Rotational Dynamics 191
- 7.6 The Gyroscope 197
- Special Topic: *A Revolutionary Means of Staying on the Straight and Narrow* 207

8

Matter under Stress 209

- 8.1 Solids, Liquids, and Gases 211
- 8.2 Density and Relative Density 213
- 8.3 Under Pressure 216
- 8.4 Stresses and Strains 219
- 8.5 Surface Tension 226
- Special Topic: *Bone As a Building Material* 232

9

Fluids under Pressure 234

- 9.1 The Pressure of the Atmosphere 237
- 9.2 Archimedes and His Principle 243
- 9.3 Fluids in Equilibrium 249
- 9.4 The Bernoulli Effect 252
- 9.5 Viscosity: A Real Drag 256
- Special Topic: *The Circulatory System* 262

10 Thermal Energy and Thermal Properties of Matter 264

- 10.1 Taking the Temperature 266
- 10.2 Expanding on Expansion 270
- 10.3 Moving in All Directions 273
- 10.4 A Question of Calories 277
- 10.5 Hidden Heat 281
- 10.6 The Mechanical Equivalent 283
- 10.7 Heat, Temperature, Thermal Energy, and Kinetic Theory 285
- 10.8 The Transfer of Heat 286
Special Topic: *Holding Down Those Heating Bills* 294

11 Ideal Gases, and Thermodynamics 295

- 11.1 Chemical Interlude 300
- 11.2 The Gas Law 301
- 11.3 The Ideal Gas 305
- 11.4 Maxwell's Speed Distribution 309
- 11.5 Vapor Pressure—The Key to Good Breath 312
- 11.6 Relative Humidity—The Comfort Barrier 314
- 11.7 Laws of Thermodynamics 316
Special Topic: *The Cruel Air, the Cruel Sea* 328

12 Making Waves 330

- 12.1 Why Waves Wave 333
- 12.2 Simple Harmonic Motion 336
- 12.3 Wave Speed 341
- 12.4 Periodic Waves 346
- 12.5 Reflection 349
- 12.6 Standing Waves and Resonance 352
- 12.7 And the Beats Go On 362
- 12.8 Sounds—Physical Versus Subjective 363
- 12.9 The Doppler Effect 367
Special Topic: *Hear, Hear: The Inside Story of the Ear* 379

13

Electrostatics 381

- 13.1 Getting a Charge Out of Electricity 382
- 13.2 Conductors and Insulators 385
- 13.3 Introducing the Electroscope 387
- 13.4 Coulomb's Law 389
- 13.5 Electric Fields 393
- 13.6 Potential Difference and Potential Energy 398
- 13.7 Potential Difference and Potential Gradient 405
- 13.8 Equipotentials and Electric Field Lines 407
- Special Topic: *How Millikan Measured the Ultimate Electric Charge* 415

14

Current Electricity 417

- 14.1 The Reason for Resistance 421
- 14.2 Energy and Electricity 427
- 14.3 Ohm's Law in Action 430
- 14.4 Kirchoff's Laws 435
- 14.5 Measuring Methods 439
- Special Topic: *How the Nervous System Works* 450

15

Moving Charges and Magnetic Fields 451

- 15.1 The Earth's Magnetic Field 455
- 15.2 Electric Charges in Magnetic Fields 455
- 15.3 The Magnetic Field and Electric Currents 466
- 15.4 Current Loops and Magnets 473
- 15.5 Meters and Motors 476
- Special Topic: *Earth's Changing Magnetic Field* 486

16

Induced Electric Currents 487

- 16.1 Induction in the Beginning 490
- 16.2 The Contrariness of Nature 492

- 16.3 The AC Generator 497
 16.4 Stepping Up and Stepping Down 502
 Special Topic: *The Oscilloscope* 512

17

Alternating Current and Electromagnetic Waves 516

- 17.1 Changing the Character of Circuits 517
 17.2 AC Versus DC Power 525
 17.3 Capacitive and Inductive Circuits 527
 17.4 Electrical Oscillations 530
 17.5 AC to DC 533
 17.6 The Transistor and Beyond 536
 17.7 Maxwell's Equations 538
 17.8 Electromagnetic Waves 540
 Special Topic: *Is Anybody Out There?* 548

18

The Nature of Light 552

- 18.1 Huygens Sees the Light 554
 18.2 The Interference of Light 561
 18.3 Other Forms of Interference 566
 18.4 Diffraction: Interference at the Edges 572
 18.5 Polarization 577
 18.6 Holography: Photographs Without Lenses 580
 Special Topic: *The Search for c* 587

19

Geometrical Optics 589

- 19.1 Through a Glass Darkly 590
 19.2 Lenses 596
 19.3 Picturing the Image 599
 19.4 Calculating the Image 602
 19.5 The Lens-Makers' Equation 607
 19.6 Lenses in Combination 609
 19.7 Aberrations of Lenses 615
 19.8 Reflections on Mirrors 616
 Special Topic: *The Eye: The Window of the Brain* 626

20

Relativity 628

- 20.1 Relative Motion 630
- 20.2 The Special Theory of Relativity 635
- 20.3 Space and Time 637
- 20.4 The Transformations of Lorentz 643
- 20.5 Time Dilation 647
- 20.6 Velocity Transformations 652
- 20.7 Mass and Energy 655
- 20.8 The General Theory of Relativity 659
- Special Topic: *The General Theory of Relativity:
Into the Fourth Dimension* 662

21

Approaching the Atom 664

- 21.1 The Radiation Riddle 665
- 21.2 The Photoelectric Effect 669
- 21.3 The Discovery of the Nucleus 676
- 21.4 The Hydrogen Spectrum 681
- 21.5 The Atom According to Bohr 683
- 21.6 Confirming Bohr's Theory 686
- Special Topic: *The Solution Without a Problem* 697

22

Moving Into the Atom 700

- 22.1 The Compton Effect 701
- 22.2 The Schizophrenic Nature of Light and Matter 705
- 22.3 The Proof of the Duality 708
- 22.4 The Quantized Atom 711
- 22.5 The Nature of Matter Waves 714
- 22.6 The Uncertainty Principle 716
- 22.7 Quantum Numbers 721
- 22.8 Pauli and the Periodic Table 726
- Special Topic: *The Men Who Made a
Scientific Revolution* 732

23

Inside the Nucleus 734

- 23.1 Now, the Neutron 736
- 23.2 Nuclear Forces 739
- 23.3 Nuclear Binding Energy 740
- 23.4 The Stability of Nuclei 743
- 23.5 Radioactive Decay 744
- 23.6 The Decay of Radioisotopes 749
- 23.7 Nuclear Reactions 753
- 23.8 Beyond the Nucleus 761
- Special Topic: *Selected Species from the Subnuclear Zoo* 765

24

Radiation

- 24.1 The Generation of an X-Ray Beam 769
- 24.2 Radiation Detectors 774
- 24.3 How Radiation Affects Matter 779
- 24.4 Particle Radiation 783
- 24.5 Radiation Dosimetry 785
- 24.6 Radiation in Medicine 788
- Special Topic: *The Radiation Around Us* 792

Epilogue 794

Appendixes 796

- A Mathematics 796
- B Conversions 814
- C Physical Constants 816
- D Tables of Useful Data 817
- E Natural Trigonometric Functions 818
- F Table of Elements, Abundant Isotopes 820

Answers to Odd-Numbered Problems 823

Index 828

1

The Nature of Physics

1.1 FROM ARCHEOLOGY TO ZOOLOGY

1.2 RECENT AND MODERN

SHORT SUBJECT: Powers of 10

Summary

SPECIAL TOPIC: The Urge to Unify

What is physics and why is it so important? Scientists have long tended to justify their pursuit of knowledge in an expression similar to that used by the British climber George Mallory to explain why he tried to conquer Mount Everest: “Because it’s there.” Certainly few physicists, or other scientists for that matter, start out on their avocation with anything but a desire to add to humanity’s fund of knowledge, however abstruse their contribution may appear to the average person in the street, to scientists in other fields, and even to their colleagues in the next office. But the past half-decade has seen the emergence of articulate critics who argue that science in general, and often physics in particular, has caused more harm than good by creating nuclear bombs, nuclear power plants, aerosol sprays, vehicles that emit pollutants, and other devices that, in the critics’ view, are harming our environment. These critics all too often confuse science—the pursuit of new knowledge—with technology—the application of that knowledge. The message is clear: in this age of skepticism, since scientific research is largely funded by taxpayers through government grants, scientists must justify their existence in more concrete terms than the mysterious interest their fields of research hold for them personally.

For physicists, an important part of this type of justification lies in the basic nature of their subject. Physics is truly a fundamental science, encompassing a range of subject matter from atoms to galaxies and even beyond, into the miniature world of subatomic particles and the unimaginably large arena of the nature of the universe. The first people who rationally could be called scientists were the priests and sages of ancient Babylon, Egypt, and China, who plotted the movements of the stars and planets through the heavens by using the evidence of their naked eyes. The man who was first to use what we regard today as the modern scientific method of moving from observation to theory to prediction to confirmation was also a physicist—a former medical student named Galileo Galilei, whose unstinting support around the turn of the seventeenth century of the theory that the earth orbits around the sun forced an intellectual struggle with the Roman Catholic Church which echoed throughout the civilized world.

Less than 50 years (yr) after Galileo died, another physicist, Isaac Newton, reached what has been called “the greatest generalization achieved by the human mind” in his elegant yet simple laws of motion and the law of universal gravitation: the law that describes how the world goes round. Closer to our time, no scientist has ever achieved as much public adulation as physicist Albert Einstein, whose theory of

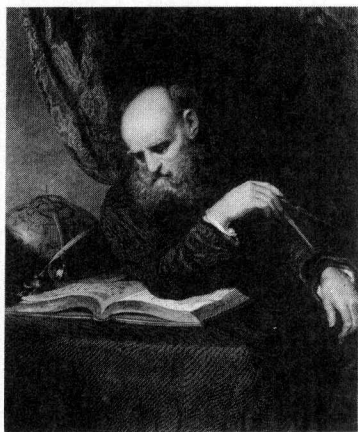


Figure 1.1 Galileo: source of an intellectual struggle. (Culver)