

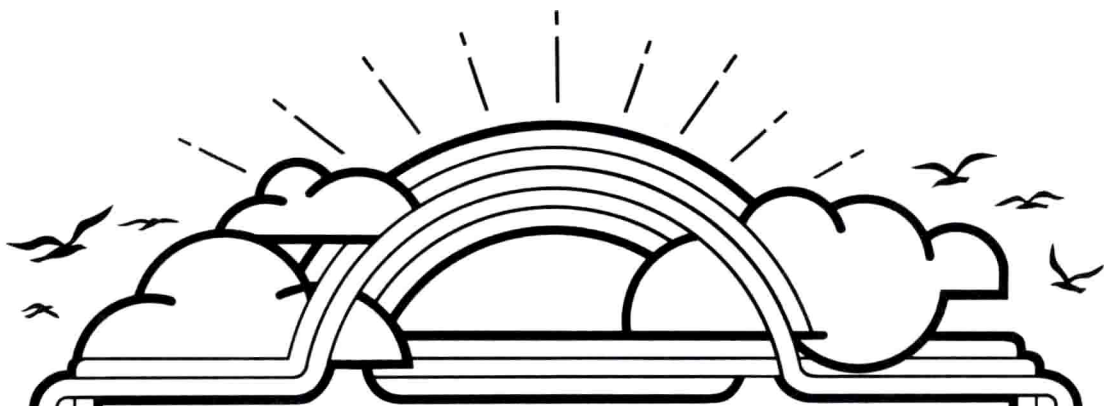


PAUL G. HEWITT

CONCEPTUAL

Physics

FIFTH EDITION



CONCEPTUAL **Physics** FIFTH EDITION

Written & Illustrated by

PAUL G. HEWITT

City College of San Francisco



Little, Brown and Company

Boston Toronto

Library of Congress Cataloging in Publication Data

Hewitt, Paul G.

Conceptual physics.

Rev. ed. of: Conceptual physics—a new introduction
to your environment. 4th ed. 1981.

Includes bibliographies and index.

I. Physics. I. Hewitt, Paul G. Conceptual physics—
a new introduction to your environment. II. Title.

QC23.H56 1985 530 84-21803

ISBN 0-316-35974-2

Copyright © 1985 by Paul G. Hewitt

All rights reserved. No part of this book may be reproduced in any form or by any
electronic or mechanical means including information storage and retrieval systems
without permission in writing from the publisher, except by a reviewer who may quote
brief passages in a review.

Library of Congress Catalog Card No. 84-21803

ISBN 0-316-35974-2

9 8 7 6 5 4 3

HAL

Published simultaneously in Canada

by Little, Brown & Company (Canada) Limited

Printed in the United States of America

Adaptation of material in Chapters 23 and 25 from R. P. Feynman, R. B. Leighton,
and M. Sands, *The Feynman Lectures on Physics*, Volumes I and II. Used by
permission of Addison-Wesley Publishing Company, Inc., Reading, MA.

Figure 6.13: Adapted from K. F. Kuhn and J. S. Faughn, *Physics in Your World*,
1980. Reprinted by permission of W. B. Saunders, Publishers.

Figure 32.19: Redrawn from "The Prospects of Fusion Power" by William C. Gough
and Bernard J. Eastlund from *Scientific American*, February 1971. Copyright © 1971
by Scientific American, Inc. All rights reserved. Reprinted by permission.

Page 173: Portions of the text in "Scaling," Chapter 10, are based on the following
sources: "On Being the Right Size," from *Possible Worlds* by J. B. S. Haldane.
Copyright 1928 by Harper & Row, Publishers, Inc. Renewed 1956 by J. B. S.
Haldane. By permission of Harper & Row, Publishers, Inc. and Chatto and Windus
Ltd. "On Magnitude," from *On Growth and Form* by Sir D'Arcy Wentworth
Thompson (New York: Cambridge University Press). Used with permission.

Produced by The Compage Company

Design: The Compage Company

Editorial production: Pearl C. Vapnek

Copyediting: Judy Chaffin

Indexing: James K. Hewitt

Composition: Holmes Typography

CONCEPTUAL **Physics**

**To Frank Oppenheimer
and those like him,
who explore the beauty
that lies in all things**

To the Student

PHYSICS CAN BE AN ENJOYABLE EXPERIENCE --- ESPECIALLY SERIOUS PHYSICS WHEN IT'S PRESENTED IN A NONMATHEMATICAL LANGUAGE AND IN A DOWN-TO-EARTH MANNER. I ENJOY PHYSICS AND HOPE TO CONVEY MY ENTHUSIASM FOR IT AS I'LL BE TALKING WITH YOU ABOUT IT IN THE FOLLOWING 35 CHAPTERS. IF YOU BEGIN BY DISCOVERING THE PHYSICS IN THIS BOOK, YOU'LL SOON FIND, I HOPE, THAT YOU'RE DISCOVERING THE PHYSICS THAT'S IN EVERYTHING YOU DO AND SEE.

SINCE THE PHYSICS IN THIS BOOK IS NOT TREATED AS APPLIED MATHEMATICS, YOU WON'T NEED A CALCULATOR. MOST END-OF-CHAPTER PROBLEMS ARE EXERCISES IN THINKING ABOUT THE MEANING AND IMPLICATIONS OF THE IDEAS OF PHYSICS—IN ENGLISH—NOT VIA ALGEBRAIC MANIPULATIONS AND COMPUTATIONS. BUT IF YOU HAVE

A CALCULATOR ANYWAY, SAVE IT. AS YOU FIND THAT PHYSICS IS FASCINATING, YOU MAY TAKE A FOLLOW-UP COURSE. THEN YOU CAN USE YOUR CALCULATOR -- WITH UNDERSTANDING.

ENJOY!



PAUL G. HEWITT

To the Instructor

Physics is the basic science; it is the foundation of chemistry, biology, and all disciplines of science. As such, the study of physics should be part of the educational mainstream, for both science students and nonscience students. Unfortunately, the mathematical language of physics often deters the average nonscience student. But when the ideas of physics are presented conceptually and when formulas are seen to be guides to thinking rather than recipes for algebraic manipulation, our discipline is accessible to all students. And for students who will continue in physics instruction, I am convinced that the ideas of physics should be first understood conceptually before they are used as a base for applied mathematics. This book seeks to build that conceptual base. It is a base for nonscience students and science students alike. For the nonscience student, it is a base from which to view nature more perceptively. For the science student, it is this and a springboard to a greater involvement in physics. A first-semester conceptual overview of Newtonian and modern physics for science majors will help to correct a missing essential in physics education: the practice of conceptualizing before calculating. For nonscience and science students alike, a conceptual way of looking at physics shapes analytical thinking.

Although the overall organization of this edition is essentially that of the previous editions insofar as the sequence from mechanics to astrophysics is concerned, considerable change and new material occur throughout. Part 1, Mechanics, has been substantially revised. It begins with linear motion in Chapter 2 and then goes immediately to projectile motion in Chapter 3. The study of projectiles leads to satellites in the same chapter. This reordering has two advantages. The first is logical progression: the kinematics of vertically falling bodies logically extends to projectiles, which in turn extends to a simple treatment of satellite motion. The second advantage is the early introduction of a topic of much current interest: the space-shuttle missions and other spacefaring activities that have captured the interest and imagination of most of your students. Newton's laws follow in Chapter 4, and logically following Newton's second and third laws is Chapter 5, on momentum. Chapter 6 on energy follows, with a spiral-approach return to satellite motion and escape velocity. Rotational motion, Chapter 7, and the law of universal gravitation, Chapter 8, complete the mechanics sequence. The fourth edition's chapter on power production and the chapter on electronics have been omitted to allow the introduction of new material without inflating the size of the book. The popular section on exponential growth, à la Al Bartlett, now appears on its own as Appendix V. A new chapter on thermodynamics

appears in Part 3, Heat. Part 6, Light, has been revamped. Fermat's principle of least time, à la Richard Feynman, now provides your students with an alternative, interesting view of reflection and refraction. Quantum physics has been considerably revised and expanded. Important to the overall flavor of this edition are the many new insights and, I hope, pleasant surprises that are sprinkled in almost every chapter.

There are a wealth of new exercises in this edition. As in the fourth edition, there are more than enough for fresh assignments each semester or quarter without overlap for several terms. Some exercises are moderately simple and are designed to prompt the application of physics to everyday situations. Others are more sophisticated and call for considerable critical thinking. Some are quantitative and involve simple, straightforward calculations that will help your students capture the idea being treated, without requiring algebraic skills. The challenge to your students will be in the conceptual reasoning and critical thinking that are called for in the exercises. Please don't overload your students and blanketly assign *all* exercises to the chapters you cover. If you favor lengthy written assignments, it is more in order to have your students write up all or most of the review questions. These are relatively straightforward and they summarize, in question form, the essentials of the chapter.

As in previous editions, units of measurement are not emphasized. When used, they are almost exclusively expressed in SI (exceptions include such units as calories, grams/cm³, and light-years). Mathematical derivations are avoided in the main body of the text and appear in footnotes or in the appendixes.

More than enough material is included for a one-semester course, which allows for a variety of course designs to fit your taste. These are suggested in the Instructor's Manual, which you'll find to be the most different of instructor's manuals. It contains many lecture ideas and topics not treated in the textbook, as well as teaching tips, suggested step-by-step lectures and demonstrations, information on overhead transparency masters and on new videotaped lectures by the author, and much more to assist you in making Conceptual Physics the most interesting, informative, and worthwhile science course available to your students.

Acknowledgments

For the many suggestions that contributed to this fifth edition, I am indebted to my friend Paul Robinson at Computech, Fresno, California; to my colleagues at City College of San Francisco (CCSF): Jim Conley, Jim Court, Frank Creese, Jerry Hosken, Frank Koehler, Dack Lee, Will Maynez, Dave Wall, and Norman Whitlatch; to Al Bartlett, University of Colorado; Clifford M. Braun, a student at CCSF; Jeffrey J. Braun, Lincoln Land Community College, Indiana; Bill Cary, Madison Memorial High School, Wisconsin; Marshall Ellenstein, Ridgewood High School, Illinois; Gabe Espinda, the Exploratorium, San Francisco; N. J. Farrier, Sinclair Community College, Ohio; Ron Hipschman, the Exploratorium; Lester Hirsch, California State University, Los Angeles; Lillian Lee (Figure 18.3); Tenny Lim (Figure 6.3), California Polytechnic State University, San Luis Obispo; Iain MacInnes, Jordanhill College of Education, Scotland; Tony French, MIT; Mary Beth Todd Monroe, Southwest Texas Junior College; Mel Mayfield, Austin Peay State University, Tennessee; Frank Oppenheimer, the Exploratorium; Ken Ozawa, California Polytechnic State University, San Luis Obispo; Bob Plumb, California State University, Chico; Ray Sachs, University of California, Berkeley; Richard Stepp, Humboldt State University, California; John Taube and Roger Werner, San Francisco Chapter of Technocracy; Jearl Walker, Cleveland State University; Brian Watson, St. Lawrence University, New York; and Yoshihisa Yoshida, Sagami Women's University, Japan. I am most grateful to the many students, both at CCSF and at the world's most wonderful place to teach physics, the Exploratorium; their feedback was paramount in developing this book, which is in large part a reflection of their participation.

I thank the reviewers of the manuscript: Art Cary, California Polytechnic State University, San Luis Obispo; Horace Coburn, New Mexico State University; Frank Crawford, University of California, Berkeley; Paul Doherty, Oakland University; Neil Fleishon, Southern Oregon State College; Barry Gilbert, Rhode Island College; Roger Hanson, University of Northern Iowa; Sherwood Harrington, CCSF and Astronomical Society of the Pacific; Joseph Klarmann, Washington University; Dack Lee, CCSF; Robert Luke, Boise State University; Joseph Klarmann, Washington University; and Thomas L. Rokoske, Appalachian State University.

I am grateful to those whose own books initially served as principal influences and references: Theodore Ashford, *From Atoms to Stars*; Albert Baez, *The New College Physics—A Spiral Approach*; John N. Cooper and Alpheus W. Smith, *Elements of Physics*; Richard P. Feynman, *The Feynman Lectures on Physics*, Volumes I and II; Kenneth Ford, *Basic*

Physics; Eric Rogers, *Physics for the Inquiring Mind*; Alexander Taffel, *Physics: Its Methods and Meanings*; UNESCO, *700 Science Experiments for Everyone*; and Harvey E. White, *Descriptive College Physics*.

I am especially grateful to John Hubisz, College of the Mainland, Texas, for reviewing the end-of-chapter exercises and answers, as well as making contributions to the test bank. Special thanks also to my friend and CCSF colleague Annette Rappleyea for improving the test-bank questions and for writing the computer program for the test bank. I thank my photographer-type friends Craig Dawson, Lila Lee, and Dave Vasquez (Figure 5.14) for their many photos that add a nice touch to this edition. A note of appreciation is due my friend Gary Zukav for many discussions on both our similar and our different points of view, the outcome of which is an expanded treatment of quantum physics. Thanks go to my lifelong friend Ernie Brown for designing the new physics logo. For Zip-a-tone shading the new drawings and for compiling the index, I thank my son James and, for helping with the index, Lisa Rodriguez. For helping me through all the stages from manuscript through production, I thank most of all Helen Yan (Figures 5.13 and 14.10).

A special note of appreciation is due editor Ron Pullins of Little, Brown, for his very professional concern and assistance. Thanks also to his assistant Pat Bellanca for excellent editorial advice. I am especially indebted to Ken Burke and Pearl C. Vapnek, who produced the book.

San Francisco

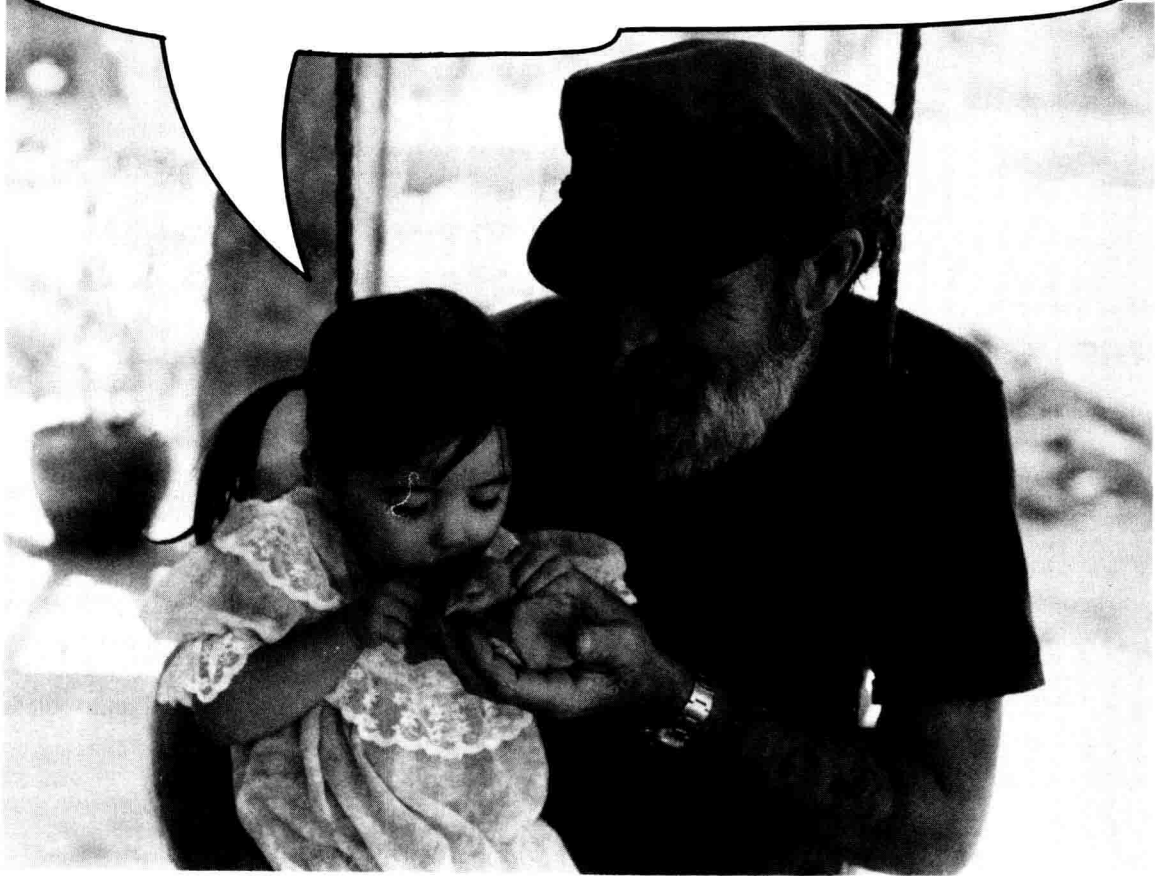
Paul G. Hewitt

CONCEPTUAL Physics

By trying to understand the natural world around us, we gain confidence in our ability to determine whom to trust and what to believe about other matters as well. Without this confidence, our decisions about social, political, and economic matters are inevitably based entirely on the most appealing lie that someone else dishes out to us. Our appreciation of the noticings and discoveries of both scientists and artists therefore serves, not only to delight us, but also to help us make more satisfactory and valid decisions and to find better solutions for our individual and societal problems.

Frank Oppenheimer

GOLLY GEE, UNCLE BEN - BEFORE THIS CHICKIE EXHAUSTED THE LAST OF ITS INNER-SPACE RESOURCES AND POKED ITS WAY OUT OF ITS SHELL, IT MUST HAVE THOUGHT IT WAS AT ITS LAST MOMENTS. BUT WHAT SEEMED LIKE ITS END WAS ONLY ITS BEGINNING. ARE WE LIKE CHICKIES, READY TO POKE THROUGH TO SOME WHOLE NEW ENVIRONMENT---LIKE HUMANIZING OUTER SPACE, MAYBE ?



Contents in Brief

Contents in Detail	x
To the Student	xvi
To the Instructor	xvii
Acknowledgments	xix

1 About Science	1
------------------------	----------

Part 1 Mechanics 9

2 The Study of Motion	10
3 Projectile and Satellite Motion	27
4 Newton's Laws of Motion	45
5 Momentum	65
6 Energy	80
7 Rotational Motion	101
8 Gravitation	125

Part 2 Properties of Matter 147

9 The Atomic Nature of Matter	149
10 Solids	165
11 Liquids	181
12 Gases and Plasmas	198

Part 3 Heat 219

13 Temperature, Heat, and Expansion	220
14 Heat Transfer	233
15 Change of State	250
16 Thermodynamics	263

Part 4 Sound 279

17 Vibrations and Waves	280
18 Sound	294
19 Musical Sounds	307

Part 5 Electricity and Magnetism 321

20 Electrostatics	322
21 Electric Current	338
22 Magnetism	355
23 Electromagnetic Interactions	367
24 Electromagnetic Radiation	382

Part 6 Light 393

25 Reflection and Refraction	394
26 Color	418
27 Light Waves	435
28 Light Emission	459
29 Light Quanta	477

Part 7 Atomic and Nuclear Physics 495

30 The Atom and the Quantum	496
31 The Atomic Nucleus and Radioactivity	507
32 Nuclear Fission and Fusion	529

Part 8 Relativity and Astrophysics 547

33 Special Theory of Relativity	550
34 General Theory of Relativity	577
35 Astrophysics	591

Epilogue 609

Appendix I Systems of Measurement 610

Appendix II More About Motion 615

Appendix III Vectors 617

Appendix IV The Universal Gravitational Constant, G 623

Appendix V Exponential Growth and Doubling Time 625

Glossary 632

Index of Names 643

Index of Topics 644

Contents in Detail

1 About Science	1	6 Energy	80
The Scientific Attitude 2		Work 80	
Science and the Arts 5		Power 81	
Science and Technology 5		Mechanical Energy 82	
Physics—The Basic Science 6		Potential Energy 82	
In Perspective 7		Kinetic Energy 83	
Part 1 Mechanics	9	Conservation of Energy 85	
2 The Study of Motion	10	<i>Energy Conservation in Satellite Motion</i> 86	
Aristotle on Motion 10		<i>Escape Velocity</i> 88	
Copernicus and the Moving Earth 11		<i>Machines—An Application of Energy Conservation</i> 89	
Galileo and the Leaning Tower 12		Efficiency 90	
Galileo's Inclined Planes 12		Comparison of Kinetic Energy and Momentum 92	
Description of Motion 14		Energy for Life 95	
<i>Speed</i> 14		7 Rotational Motion	101
<i>Velocity</i> 16		Rotational Inertia 101	
<i>Acceleration</i> 17		Torque 104	
Falling Bodies 18		Center of Mass and Center of Gravity 105	
<i>Velocity and Acceleration</i> 18		<i>Locating the Center of Gravity</i> 106	
3 Projectile and Satellite Motion	27	<i>Stability</i> 107	
Projectile Motion 27		Centripetal and Centrifugal Force 110	
Earth Satellites 32		Centrifugal Force in a Rotating Frame 113	
Elliptical Orbits 34		Simulated Gravity 114	
Escape Velocity 37		Angular Momentum 117	
4 Newton's Laws of Motion	45	Conservation of Angular Momentum 117	
Newton's First Law of Motion 45		8 Gravitation	125
Newton's Second Law of Motion 48		Kepler's Laws 125	
<i>Net Force</i> 50		Newton's Development of the Law of Gravitation 127	
<i>Friction</i> 50		<i>Newton's Law of Universal Gravitation</i> 128	
Newton's Laws and Falling Bodies 52		Weight and Weightlessness 131	
<i>Case 1: Free Fall</i> 52		Tides 133	
<i>Case 2: Nonfree Fall—Air Resistance</i> 53		Gravitational Field 136	
Newton's Third Law of Motion 55		Einstein's Theory of Gravitation 139	
Summary of Newton's Three Laws 61		Black Holes 139	
5 Momentum	65	Universal Gravitation 141	
Impulse and Momentum 65			
Conservation of Momentum 70			
Collisions 72			
<i>Bouncing</i> 74			
<i>Vector Addition for Momentum</i> 74			

Part 2 Properties of Matter	147	Part 3 Heat	219
9 The Atomic Nature of Matter	149	13 Temperature, Heat, and Expansion	220
Atoms 149		Temperature 220	
Molecules 153		<i>Measuring Temperature</i> 221	
Molecular and Atomic Masses 155		Heat 222	
Elements, Compounds, and Mixtures 156		<i>Quantity of Heat</i> 223	
Atomic Structure 157		<i>Specific Heat</i> 224	
Antimatter 159		Expansion 225	
States of Matter 160		<i>Expansion of Water</i> 227	
10 Solids	165	14 Heat Transfer	233
How Atoms Are Ordered in a Solid 165		Conduction 233	
How Atoms Are Held Together in a Solid 167		Convection 234	
Liquid Crystals 169		<i>Why Warm Air Rises</i> 234	
Alloys 169		<i>Why Expanding Air Cools</i> 235	
Density 170		Radiation 237	
Elasticity 171		<i>Temperature Dependence of Radiation</i> 238	
Scaling 173		<i>Emission, Absorption, and Reflection of Radiation</i> 239	
11 Liquids	181	<i>Cooling at Night by Radiation</i> 241	
Pressure in a Liquid 181		<i>Greenhouse Effect</i> 242	
Buoyancy 184		Newton's Law of Cooling 242	
Pascal's Principle 190		Solar Power 243	
Surface Tension 191		Excess Heat Problem 246	
Capillarity 193		15 Change of State	250
12 Gases and Plasmas	198	Evaporation and Condensation 250	
The Atmosphere 198		Boiling 251	
Atmospheric Pressure 199		<i>Geysers</i> 252	
<i>Barometers</i> 201		<i>Boiling Is a Cooling Process</i> 253	
Boyle's Law 204		<i>Boiling and Freezing at the Same Time</i> 253	
Buoyancy of Air 205		Melting and Freezing 254	
Bernoulli's Principle 206		<i>Regelation</i> 254	
<i>Applications of Bernoulli's Principle</i> 208		<i>Freezing Point of Solutions</i> 254	
Plasma 211		Energy of Changes of State 255	
<i>Plasma in the Everyday World</i> 212		Humidity 257	
<i>Plasma Power</i> 212		Fog and Clouds 259	
		16 Thermodynamics	263
		Absolute Zero 263	
		Internal Energy 264	
		First Law of Thermodynamics 265	
		<i>Adiabatic Processes</i> 267	
		<i>Meteorology and the First Law</i> 268	
		Second Law of Thermodynamics 271	
		Entropy 275	

Part 4 Sound	279	Part 5 Electricity and Magnetism	321
17 Vibrations and Waves	280	20 Electrostatics	322
Pendulums 280		Electrical Forces 322	
Some Technical Terms 281		Coulomb's Law 323	
Wave Motion 282		Electrical Shielding 324	
<i>Wave Velocity</i> 283		Conductors and Insulators 324	
Transverse Waves 284		Semiconductors 326	
Longitudinal Waves 284		Charging 327	
Interference 285		<i>Charging by Friction</i> 327	
<i>Standing Waves</i> 286		<i>Charging by Contact</i> 328	
Doppler Effect 287		<i>Charging by Induction</i> 328	
Wave Barriers 289		Electric Field 330	
Bow Waves 289		Electric Potential 333	
Shock Waves 290		<i>Van de Graaff Generators</i> 334	
18 Sound	294	21 Electric Current	338
Origin of Sound 294		Flow of Charge 338	
Nature of Sound in Air 294		Electromotive Force and Current 339	
Media That Transmit Sound 296		Electrical Resistance 340	
Speed of Sound 296		Ohm's Law 340	
Refraction of Sound 297		<i>Electric Shock and Ohm's Law</i> 341	
Reflection of Sound 298		Direct Current	
Energy in Sound Waves 298		and Alternating Current 343	
Forced Vibrations 299		Speed and Source of Electrons	
Resonance 299		in a Circuit 343	
Interference 300		Electric Power 345	
<i>Beats</i> 302		Electrical Circuits 346	
19 Musical Sounds	307	<i>Series Circuits</i> 346	
Noises and Musical Sounds 307		<i>Parallel Circuits</i> 348	
Pitch 307		22 Magnetism	355
Loudness 308		Magnetic Forces 355	
Quality 309		Nature of the Magnetic Field 355	
Musical Instruments 311		Magnetic Domains 356	
Musical Scales 312		Magnetic Poles 358	
Fourier Analysis 314		Earth's Magnetic Field 359	
Laser Discs 316		Magnetic Forces	
		on Moving Charged Particles 360	
		Magnetism and Evolution 362	
		Biomagnetism 363	

23 Electromagnetic Interactions	367	26 Color	418
Magnetic Force		Selective Reflection	418
on a Current-Carrying Wire	368	Selective Transmission	420
Electromagnetic Induction	370	Color Mixing	421
Transformers	374	<i>Rules for Color Mixing</i>	425
Self-Induction	375	Why the Sky Is Blue	426
Power Production	376	Why Sunsets Are Red	427
<i>Turbogenerator Power</i>	376	Color Vision	428
<i>MHD Power</i>	377		
Power Transmission	378	27 Light Waves	435
Field Induction	379	Huygens' Principle	435
In Perspective	379	Diffraction	437
		Interference	439
24 Electromagnetic Radiation	382	Interference Colors by Reflection	
Electromagnetic Wave Velocity	382	from Thin Films	444
Electromagnetic Spectrum	383	Polarization	446
Production of Electromagnetic Waves	384	<i>Three-Dimensional Viewing</i>	450
Electromagnetic Waves		Colors by Transmission	
Are Everywhere	388	Through Polarizing Materials	451
		Holography	453
Part 6 Light	393	28 Light Emission	459
25 Reflection and Refraction	394	Excitation	459
Reflection	394	<i>Emission Spectra</i>	462
Principle of Least Time	395	Incandescence	463
Law of Reflection	396	<i>Absorption Spectra</i>	465
<i>Plane Mirrors</i>	397	Fluorescence	466
<i>Diffuse Reflection</i>	398	<i>Fluorescent Lamps</i>	468
Refraction	399	Phosphorescence	469
Velocity of Light		Lasers	469
in a Transparent Medium	403		
Cause of Refraction	405	29 Light Quanta	477
<i>Dispersion in a Prism</i>	407	Birth of the Quantum Theory	477
<i>Rainbows</i>	407	Quantization and Planck's Constant	478
Lenses	409	Photoelectric Effect	479
Total Internal Reflection	412	Wave-Particle Duality	482
		Double-Slit Experiment	483
		Particles as Waves:	
		Electron Diffraction	484
		Uncertainty Principle	487
		Complementarity	491