



SEARS AND ZEMANSKY'S

UNIVERSITY PHYSICS

WITH MODERN PHYSICS

14TH EDITION

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The Leonardo Bridge Project is a project to build functional interpretations of Leonardo da Vinci's Golden Horn Bridge design, conceived and built first in Norway by artist Vebjørn Sand as a global public art project, linking people and cultures in communities in every continent.

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BRIEF CONTENTS

MECHANICS

1	Units, Physical Quantities, and Vectors	1
2	Motion Along a Straight Line	34
3	Motion in Two or Three Dimensions	67
4	Newton's Laws of Motion	101
5	Applying Newton's Laws	130
6	Work and Kinetic Energy	172
7	Potential Energy and Energy Conservation	203
8	Momentum, Impulse, and Collisions	237
9	Rotation of Rigid Bodies	273
10	Dynamics of Rotational Motion	303
11	Equilibrium and Elasticity	339
12	Fluid Mechanics	369
13	Gravitation	398
14	Periodic Motion	433

WAVES/ACOUSTICS

15	Mechanical Waves	468
16	Sound and Hearing	505

THERMODYNAMICS

17	Temperature and Heat	545
18	Thermal Properties of Matter	584
19	The First Law of Thermodynamics	618
20	The Second Law of Thermodynamics	647

ELECTROMAGNETISM

21	Electric Charge and Electric Field	683
22	Gauss's Law	722
23	Electric Potential	752
24	Capacitance and Dielectrics	785
25	Current, Resistance, and Electromotive Force	816

26	Direct-Current Circuits	848
27	Magnetic Field and Magnetic Forces	881
28	Sources of Magnetic Field	921
29	Electromagnetic Induction	955
30	Inductance	990
31	Alternating Current	1020
32	Electromagnetic Waves	1050

OPTICS

33	The Nature and Propagation of Light	1078
34	Geometric Optics	1111
35	Interference	1160
36	Diffraction	1186

MODERN PHYSICS

37	Relativity	1218
38	Photons: Light Waves Behaving as Particles	1254
39	Particles Behaving as Waves	1279
40	Quantum Mechanics I: Wave Functions	1321
41	Quantum Mechanics II: Atomic Structure	1360
42	Molecules and Condensed Matter	1407
43	Nuclear Physics	1440
44	Particle Physics and Cosmology	1481

APPENDICES

A	The International System of Units	A-1
B	Useful Mathematical Relations	A-3
C	The Greek Alphabet	A-4
D	Periodic Table of the Elements	A-5
E	Unit Conversion Factors	A-6
F	Numerical Constants	A-7
	Answers to Odd-Numbered Problems	A-9
	Credits	C-1
	Index	I-1

VOLUME 1: Chapters 1–20 • VOLUME 2: Chapters 21–37 • VOLUME 3: Chapters 37–44



THE BENCHMARK FOR CLARITY AND RIGOR

Since its first edition, *University Physics* has been renowned for its emphasis on fundamental principles and how to apply them. This text is known for its clear and thorough narrative and for its uniquely broad, deep, and thoughtful set of worked examples—key tools for developing both conceptual understanding and problem-solving skills.

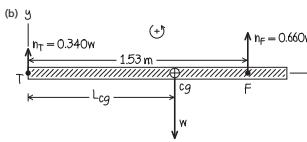
The **Fourteenth Edition** improves the defining features of the text while adding new features influenced by physics education research. A focus on visual learning, new problem types, and pedagogy informed by MasteringPhysics metadata headline the improvements designed to create the best learning resource for today's physics students.

A FOCUS ON PROBLEM SOLVING

EXAMPLE 11.2 LOCATING YOUR CENTER OF GRAVITY WHILE YOU WORK OUT

The *plank* (Fig. 11.8a) is a great way to strengthen abdominal, back, and shoulder muscles. You can also use this exercise position to locate your center of gravity. Holding plank position with a scale under his toes and another under his forearms, one athlete measured that 66.0% of his weight was supported by his forearms and 34.0% by his toes. (That is, the total normal forces on his forearms and toes were 0.660 w and 0.340 w , respectively, where w is the athlete's weight.) He is 1.80 m tall, and in plank position

11.8 An athlete in plank position.



the distance from his toes to the middle of his forearms is 1.53 m. How far from his toes is his center of gravity?

SOLUTION

IDENTIFY and SET UP: We can use the two conditions for equilibrium, Eqs. (11.6), for an athlete at rest. So both the net force and net torque on the athlete are zero. Figure 11.8b shows a free-body diagram, including x - and y -axes and our convention that counterclockwise torques are positive. The weight w acts at the center of gravity, which is between the two supports (as it must be; see Section 11.2). Our target variable is the distance L_{cg} , the lever arm of the weight with respect to the toes T , so it is wise to take torques with respect to T . The torque due to the weight is negative (it tends to cause a clockwise rotation around T), an upward normal force at the forearms F is a counterclockwise rotation around T .

EXECUTE: The first condition for equilibrium $\sum F_x = 0$ because there are no x -components. Because $0.340w + 0.660w + (-w) = 0$, we can ignore the weight and solve for L_{cg} :

$$\sum \tau_T = 0.340w(0) - wL_{cg} + 0.660w \\ L_{cg} = 1.01 \text{ m}$$

EVALUATE: The center of gravity is slight naval (as it is for most people) and closer to his toes, which is why his forearms support more of his weight. You can check our result by writing the total normal force at the forearms F . You'll find that his center of gravity is at $(1.53 \text{ m}) - (0.52 \text{ m}) = 1.01 \text{ m}$ from the toes.

◀ A research-based **PROBLEM-SOLVING APPROACH—IDENTIFY, SET UP, EXECUTE, EVALUATE**—is used in every Example and throughout the Student's and Instructor's Solutions Manuals and the Study Guide. This consistent approach teaches students to tackle problems thoughtfully rather than cutting straight to the math.

PROBLEM-SOLVING STRATEGY 3.1 PROJECTILE MOTION

NOTE: The strategies we used in Sections 2.4 and 2.5 for straight-line, constant-acceleration problems are also useful here.

IDENTIFY the relevant concepts: The key concept is that through-out projectile motion, the acceleration is downward and has a constant magnitude g . Projectile-motion equations don't apply to throwing a ball, because during the throw the ball is acted on by both the thrower's hand and gravity. These equations apply only after the ball leaves the thrower's hand.

SET UP the problem

- Define your coordinate system and make a sketch showing your axes. It's almost always best to make the x -axis horizontal and the y -axis vertical, and to choose the origin to be where the body first becomes a projectile (for example, where a ball leaves the thrower's hand). Then the components of acceleration are $a_x = 0$ and $a_y = -g$, as in Eq. (3.13); the initial position is $x_0 = y_0 = 0$; and you can use Eqs. (3.19) through (3.22). (If you choose a different origin or axes, you'll have to modify these equations.)

- List the unknown and known quantities, and decide which unknowns are your target variables. For example, you might be given the initial velocity (either the components or the magnitude and direction) and asked to find the coordinates and velocity components at some later time. Make sure that

you have many equations as there are target variables to be found. In addition to Eqs. (3.19) through (3.22), Eqs. (3.23) through (3.26) may be useful.

- State the problem in words and then translate those words into symbols. For example, "When does the particle arrive at a certain point?" (That is, at what value of t ?) Where is the particle when its velocity has a certain value? That is, what are the values of x and y when v_x or v_y has the specified value? Since $v_x = 0$ at the highest point in a trajectory, the question "When does the projectile reach its highest point?" translates into "What is the value of t when $v_y = 0$?" Similarly, "When does the projectile return to its initial elevation?" translates into "What is the value of t when $y = y_0$?"

EXECUTE the solution: Find the target variables using the equations you chose. Resist the temptation to break the trajectory into segments and analyze each segment separately. You don't have to start all over when the projectile reaches its highest point! It's almost always easier to use the same axes and time scale throughout the problem. If you need numerical values, use $g = 9.80 \text{ m/s}^2$. Remember that g is positive!

EVALUATE your answer: Do your results make sense? Do the numerical values seem reasonable?

PROBLEM-SOLVING STRATEGIES ▶

coach students in how to approach specific types of problems.

BRIDGING PROBLEM HOW LONG TO DRAIN?

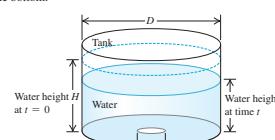
A large cylindrical tank with diameter D is open to the air at the top. The tank contains water to a height H . A small circular hole with diameter d , where $d \ll D$, is then opened at the bottom of the tank (Fig. 12.32). Ignore any effects of viscosity. (a) Find y , the height of water in the tank a time t after the hole is opened, as a function of t . (b) How long does it take to drain the tank completely? (c) If you double height H , by what factor does the time to drain the tank increase?

SOLUTION GUIDE

IDENTIFY and SET UP

- Draw a sketch of the situation that shows all of the relevant dimensions.
- List the unknown quantities, and decide which of these are the target variables.
- At what speed does water flow out of the bottom of the tank? How is this related to the volume flow rate of water out of the tank? How is the volume flow rate related to the rate of change of y ?
- Use your results from step 3 to write an equation for dy/dt . Your result from step 4 is a relatively simple differential equation. With your knowledge of calculus, you can integrate it to find y as a function of t . (Hint: Once you've done the integration, you'll still have to do a little algebra.)

12.32 A water tank that is open at the top and has a hole at the bottom.



- Use your result from step 5 to find the time when the tank is empty. How does your result depend on the initial height H ?

EVALUATE

- Check whether your answers are reasonable. A good check is to draw a graph of y versus t . According to your graph, what is the algebraic sign of dy/dt at different times? Does this make sense?

◀ BRIDGING PROBLEMS

, which help students move from single-concept worked examples to multi-concept problems at the end of the chapter, have been revised, based on reviewer feedback, ensuring that they are effective and at the appropriate difficulty level.



INFLUENCED BY THE LATEST IN EDUCATION RESEARCH

PEDAGOGY INFORMED BY DATA AND RESEARCH

DATA SPEAKS

Gravitation

When students were given a problem about superposition of gravitational forces, more than 60% gave an incorrect response. Common errors:

- Assuming that equal-mass objects A and B must exert equally strong gravitational attraction on an object C (which is not true when A and B are different distances from C).
- Neglecting to account for the vector nature of force. (To add two forces that point in different directions, you can't just add the force magnitudes.)

DATA SPEAKS SIDEBARS

, based on MasteringPhysics metadata, alert students to the statistically most common mistakes made in solving problems on a given topic.

$$x = (v_0 \cos \alpha_0)t \quad (3.19)$$

Coordinates at time t of a projectile (positive y-direction is upward, and $x = y = 0$ at $t = 0$)

$$y = (v_0 \sin \alpha_0)t - \frac{1}{2}gt^2 \quad (3.20)$$

Speed at $t = 0$ at $t = 0$ Time

$$v_x = v_0 \cos \alpha_0 \quad (3.21)$$

Velocity components at time t of a projectile (positive y-direction is upward)

$$v_y = v_0 \sin \alpha_0 - gt \quad (3.22)$$

Speed at $t = 0$ Direction at $t = 0$ Acceleration due to gravity: Note $g > 0$ Time

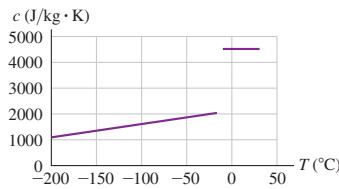
PASSAGE PROBLEMS

BIO PRESERVING CELLS AT COLD TEMPERATURES. In cryopreservation, biological materials are cooled to a very low temperature to slow down chemical reactions that might damage the cells or tissues. It is important to prevent the materials from forming ice crystals during freezing. One method for preventing ice formation is to place the material in a protective solution called a *cryoprotectant*. Stated values of the thermal properties of one cryoprotectant are listed here:

Melting point	-20°C
Latent heat of fusion	$2.80 \times 10^5 \text{ J/kg}$
Specific heat (liquid)	$4.5 \times 10^3 \text{ J/kg} \cdot \text{K}$

17.117 Careful measurements show that the specific heat of the solid phase depends on temperature (Fig. P17.117). How will the actual time needed for this cryoprotectant to come to equilibrium with the cold plate compare with the time predicted by using the values in the table? Assume that all values other than the specific heat (solid) are correct. The actual time (a) will be shorter; (b) will be longer; (c) will be the same; (d) depends on the density of the cryoprotectant.

Figure P17.117



- ▲ Each chapter includes three to five **PASSAGE PROBLEMS**, which follow the format used in the MCATs. These problems require students to investigate multiple aspects of a real-life physical situation, typically biological in nature, as described in a reading passage.

- ▲ All **KEY EQUATIONS ARE NOW ANNOTATED** to help students make a connection between a conceptual and a mathematical understanding of physics.

DATA PROBLEMS appear in each chapter. These data-based reasoning problems, many of which are context rich, require students to use experimental evidence, presented in a tabular or graphical format, to formulate conclusions. ▼

9.89 **DATA** You are rebuilding a 1965 Chevrolet. To decide whether to replace the flywheel with a newer, lighter-weight one, you want to determine the moment of inertia of the original, 35.6-cm-diameter flywheel. It is not a uniform disk, so you can't use $I = \frac{1}{2}MR^2$ to calculate the moment of inertia. You remove the flywheel from the car and use low-friction bearings to mount it on a horizontal, stationary rod that passes through the center of the flywheel, which can then rotate freely (about 2 m above the ground). After gluing one end of a long piece of flexible fishing line to the rim of the flywheel, you wrap the line a number of turns around the rim and suspend a 5.60-kg metal block from the free end of the line. When you release the block from rest, it descends as the flywheel rotates. With high-speed photography you measure the distance d the block has moved downward as a function of the time since it was released. The equation for the graph shown in Fig. P9.89 that gives a good fit to the data points is $d = (165 \text{ cm/s}^2)t^2$. (a) Based on the graph, does the block fall with constant acceleration? Explain. (b) Use the graph to calculate the speed of the block when it has descended 1.50 m. (c) Apply conservation of mechanical energy to the system of flywheel and block to calculate the moment of inertia of the flywheel. (d) You are relieved that the fishing line doesn't break. Apply Newton's second law to the block to find the tension in the line as the block descended.



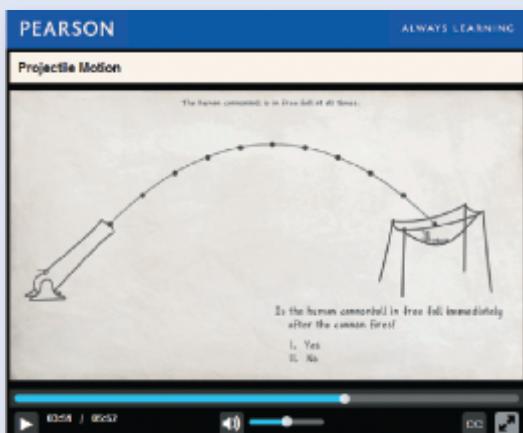
PERSONALIZE LEARNING WITH MASTERINGPHYSICS

MasteringPhysics® from Pearson is the leading online homework, tutorial, and assessment system, designed to improve results by engaging students before, during, and after class with powerful content. Instructors can now ensure that students arrive ready to learn by assigning educationally effective content before class, and encourage critical thinking and retention with in-class resources such as Learning Catalytics. Students can further master concepts after class through traditional and adaptive homework assignments that provide hints and answer-specific feedback. The Mastering gradebook records scores for all automatically graded assignments in one place, while diagnostic tools give instructors access to rich data to assess student understanding and misconceptions.

Mastering brings learning full circle by continuously adapting to each student and making learning more personal than ever—before, during, and after class.

BEFORE CLASS

INTERACTIVE PRE-LECTURE VIDEOS address the rapidly growing movement toward pre-lecture teaching and flipped classrooms. These videos provide a conceptual introduction to key topics. Embedded assessment helps students to prepare before lecture and instructors to identify student misconceptions.

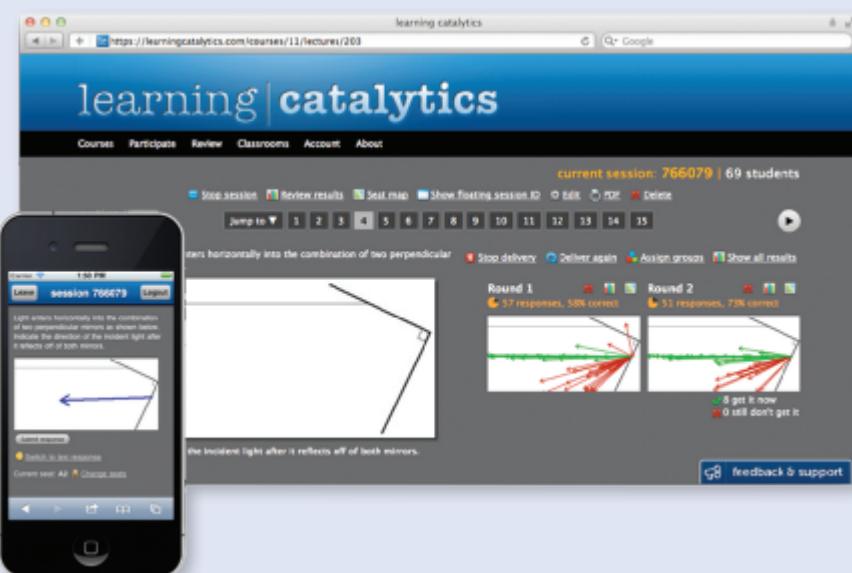


PRE-LECTURE CONCEPT QUESTIONS check familiarity with key concepts, prompting students to do their assigned reading prior to coming to class. These quizzes keep students on track, keep them more engaged in lecture, and help you spot the concepts with which they have the most difficulty. Open-ended essay questions help students identify what they find most difficult about a concept, better informing you and assisting with “just-in-time” teaching.

DURING CLASS

LEARNING CATALYTICS™ is a “bring your own device” student engagement, assessment, and classroom intelligence system. With Learning Catalytics you can:

- Assess students in real time, using open-ended tasks to probe student understanding.
- Understand immediately where students are and adjust your lecture accordingly.
- Improve your students’ critical-thinking skills.
- Access rich analytics to understand student performance.
- Add your own questions to make Learning Catalytics fit your course exactly.
- Manage student interactions with intelligent grouping and timing.



BEFORE, DURING, AND AFTER CLASS

AFTER CLASS

TUTORIALS featuring specific wrong-answer feedback, hints, and a wide variety of educationally effective content guide your students through the toughest topics in physics. The hallmark Hints and Feedback offer instruction similar to what students would experience in an office hour, allowing them to learn from their mistakes without being given the answer.

The screenshot shows a 'MasteringPhysics*' window titled 'Banked Frictionless Curve, and Flat Curve with Friction'. It includes a 'Work an Example' section with a table for unit conversion (1 m = 1000 mm), a diagram of a car on a banked curve, and a question asking if the car can turn. Below is a 'Rethink' section with a question about uniform circular motion and a 'Try Again' button.

ADAPTIVE FOLLOW-UPS are personalized assignments that pair Mastering's powerful content with Knewton's adaptive learning engine to provide personalized help to students. These assignments address common student misconceptions and topics students struggled with on assigned homework, including core prerequisite topics. ▼

The screenshot shows the 'Create/Edit Assignment: Chapter 7' interface. It includes tabs for 'Edit', 'Select Content', 'Organize Content', 'Specify Outcomes', and 'Assign and Add Follow-up'. A 'Continuous Adaptive Learning' section is highlighted, showing how it integrates with the adaptive learning engine. Assignment details like title, length, credit, due date, and test out options are visible.

The screenshot shows a worked example titled 'Example 5.11 Toboggan ride with friction III'. It includes a free-body diagram of a toboggan on a slope, equations for force components, and a solution for acceleration. The equations shown are:

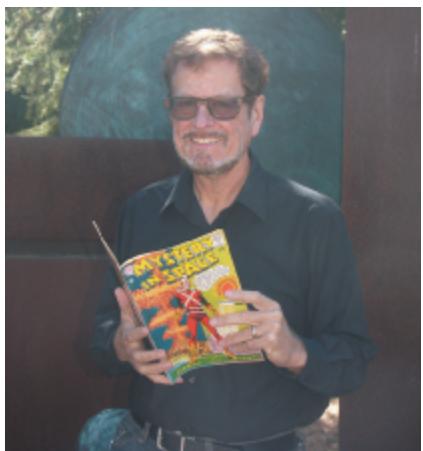
$$\sum F_x = mg \sin \alpha + (-f_k) = ma_x$$
$$\sum F_y = n + (-mg \cos \alpha) = 0$$
$$n = mg \cos \alpha$$
$$f_k = \mu_k n = \mu_k mg \cos \alpha$$
$$mg \sin \alpha + (-\mu_k mg \cos \alpha) = ma_x$$

VIDEO TUTOR DEMONSTRATIONS, available in the Study Area and in the Item Library and accessible by QR code in the textbook, feature "pause-and-predict" demonstrations of key physics concepts as assessment to engage students actively in understanding key concepts. New VTDs build on the existing collection, adding new topics for a more robust set of demonstrations. ▼



◀ **VIDEO TUTOR SOLUTIONS** are tied to each worked example and Bridging Problem in the textbook and can be accessed through MasteringPhysics or from QR codes in the textbook. They walk students through the problem-solving process, providing a virtual teaching assistant on a round-the-clock basis.

ABOUT THE AUTHORS



Roger A. Freedman is a Lecturer in Physics at the University of California, Santa Barbara. He was an undergraduate at the University of California campuses in San Diego and Los Angeles and did his doctoral research in nuclear theory at Stanford University under the direction of Professor J. Dirk Walecka. Dr. Freedman came to UCSB in 1981 after three years of teaching and doing research at the University of Washington.

At UCSB, Dr. Freedman has taught in both the Department of Physics and the College of Creative Studies, a branch of the university intended for highly gifted and motivated undergraduates. He has published research in nuclear physics, elementary particle physics, and laser physics. In recent years, he has worked to make physics lectures a more interactive experience through the use of classroom response systems and pre-lecture videos.

In the 1970s Dr. Freedman worked as a comic book letterer and helped organize the San Diego Comic-Con (now the world's largest popular culture convention) during its first few years. Today, when not in the classroom or slaving over a computer, Dr. Freedman can be found either flying (he holds a commercial pilot's license) or with his wife, Caroline, cheering on the rowers of UCSB Men's and Women's Crew.



IN MEMORIAM: HUGH YOUNG (1930–2013)

Hugh D. Young was Emeritus Professor of Physics at Carnegie Mellon University. He earned both his undergraduate and graduate degrees from that university. He earned his Ph.D. in fundamental particle theory under the direction of the late Richard Cutkosky. Dr. Young joined the faculty of Carnegie Mellon in 1956 and retired in 2004. He also had two visiting professorships at the University of California, Berkeley.

Dr. Young's career was centered entirely on undergraduate education. He wrote several undergraduate-level textbooks, and in 1973 he became a coauthor with Francis Sears and Mark Zemansky for their well-known introductory textbooks. In addition to his role on Sears and Zemansky's *University Physics*, he was the author of Sears and Zemansky's *College Physics*.

Dr. Young earned a bachelor's degree in organ performance from Carnegie Mellon in 1972 and spent several years as Associate Organist at St. Paul's Cathedral in Pittsburgh. He often ventured into the wilderness to hike, climb, or go caving with students in Carnegie Mellon's Explorers Club, which he founded as a graduate student and later advised. Dr. Young and his wife, Alice, hosted up to 50 students each year for Thanksgiving dinners in their home.

Always gracious, Dr. Young expressed his appreciation earnestly: "I want to extend my heartfelt thanks to my colleagues at Carnegie Mellon, especially Professors Robert Kraemer, Bruce Sherwood, Ruth Chabay, Helmut Vogel, and Brian Quinn, for many stimulating discussions about physics pedagogy and for their support and encouragement during the writing of several successive editions of this book. I am equally indebted to the many generations of Carnegie Mellon students who have helped me learn what good teaching and good writing are, by showing me what works and what doesn't. It is always a joy and a privilege to express my gratitude to my wife, Alice, and our children, Gretchen and Rebecca, for their love, support, and emotional sustenance during the writing of several successive editions of this book. May all men and women be blessed with love such as theirs." We at Pearson appreciated his professionalism, good nature, and collaboration. He will be missed.

A. Lewis Ford is Professor of Physics at Texas A&M University. He received a B.A. from Rice University in 1968 and a Ph.D. in chemical physics from the University of Texas at Austin in 1972. After a one-year postdoc at Harvard University, he joined the Texas A&M physics faculty in 1973 and has been there ever since. Professor Ford has specialized in theoretical atomic physics—in particular, atomic collisions. At Texas A&M he has taught a variety of undergraduate and graduate courses, but primarily introductory physics.

TO THE STUDENT

HOW TO SUCCEED IN PHYSICS BY REALLY TRYING

Mark Hollabaugh, Normandale Community College, Emeritus

Physics encompasses the large and the small, the old and the new. From the atom to galaxies, from electrical circuitry to aerodynamics, physics is very much a part of the world around us. You probably are taking this introductory course in calculus-based physics because it is required for subsequent courses that you plan to take in preparation for a career in science or engineering. Your professor wants you to learn physics and to enjoy the experience. He or she is very interested in helping you learn this fascinating subject. That is part of the reason your professor chose this textbook for your course. That is also the reason Drs. Young and Freedman asked me to write this introductory section. We want you to succeed!

The purpose of this section of *University Physics* is to give you some ideas that will assist your learning. Specific suggestions on how to use the textbook will follow a brief discussion of general study habits and strategies.

PREPARATION FOR THIS COURSE

If you had high school physics, you will probably learn concepts faster than those who have not because you will be familiar with the language of physics. If English is a second language for you, keep a glossary of new terms that you encounter and make sure you understand how they are used in physics. Likewise, if you are further along in your mathematics courses, you will pick up the mathematical aspects of physics faster. Even if your mathematics is adequate, you may find a book such as Arnold D. Pickar's *Preparing for General Physics: Math Skill Drills and Other Useful Help (Calculus Version)* to be useful. Your professor may assign sections of this math review to assist your learning.

LEARNING TO LEARN

Each of us has a different learning style and a preferred means of learning. Understanding your own learning style will help you to focus on aspects of physics that may give you difficulty and to use those components of your course that will help you overcome the difficulty. Obviously you will want to spend more time on those aspects that give you the most trouble. If you learn by hearing, lectures will be very important. If you learn by explaining, then working with other students will be useful to you. If solving problems is difficult for you, spend more time learning how to solve problems. Also, it is important to understand and develop good study habits. Perhaps the most important thing you can do for yourself is set aside adequate, regularly scheduled study time in a distraction-free environment.

Answer the following questions for yourself:

- Am I able to use fundamental mathematical concepts from algebra, geometry, and trigonometry? (If not, plan a program of review with help from your professor.)
- In similar courses, what activity has given me the most trouble? (Spend more time on this.) What has been the easiest for me? (Do this first; it will build your confidence.)
- Do I understand the material better if I read the book before or after the lecture? (You may learn best by skimming the material, going to lecture, and then undertaking an in-depth reading.)

- Do I spend adequate time studying physics? (A rule of thumb for a class like this is to devote, on average, 2.5 hours out of class for each hour in class. For a course that meets 5 hours each week, that means you should spend about 10 to 15 hours per week studying physics.)
- Do I study physics every day? (Spread that 10 to 15 hours out over an entire week!) At what time of the day am I at my best for studying physics? (Pick a specific time of the day and stick to it.)
- Do I work in a quiet place where I can maintain my focus? (Distractions will break your routine and cause you to miss important points.)

WORKING WITH OTHERS

Scientists or engineers seldom work in isolation from one another but rather work cooperatively. You will learn more physics and have more fun doing it if you work with other students. Some professors may formalize the use of cooperative learning or facilitate the formation of study groups. You may wish to form your own informal study group with members of your class. Use e-mail to keep in touch with one another. Your study group is an excellent resource when you review for exams.

LECTURES AND TAKING NOTES

An important component of any college course is the lecture. In physics this is especially important, because your professor will frequently do demonstrations of physical principles, run computer simulations, or show video clips. All of these are learning activities that will help you understand the basic principles of physics. Don't miss lectures. If for some reason you do, ask a friend or member of your study group to provide you with notes and let you know what happened.

Take your class notes in outline form, and fill in the details later. It can be very difficult to take word-for-word notes, so just write down key ideas. Your professor may use a diagram from the textbook. Leave a space in your notes and add the diagram later. After class, edit your notes, filling in any gaps or omissions and noting things that you need to study further. Make references to the textbook by page, equation number, or section number.

Ask questions in class, or see your professor during office hours. Remember that the only "dumb" question is the one that is not asked. Your college may have teaching assistants or peer tutors who are available to help you with any difficulties.

EXAMINATIONS

Taking an examination is stressful. But if you feel adequately prepared and are well rested, your stress will be lessened. Preparing for an exam is a continuous process; it begins the moment the previous exam is over. You should immediately go over the exam to understand any mistakes you made. If you worked a problem and made substantial errors, try this: Take a piece of paper and divide it down the middle with a line from top to bottom. In one column, write the proper solution to the problem. In the other column, write what you did and why, if you know, and why your solution was incorrect. If you are uncertain why you made your mistake or how to avoid making it again, talk with your professor. Physics constantly builds on fundamental ideas, and it is important to correct any misunderstandings immediately. *Warning:* Although cramming at the last minute may get you through the present exam, you will not adequately retain the concepts for use on the next exam.

TO THE INSTRUCTOR

PREFACE

This book is the product of six and a half decades of leadership and innovation in physics education. When the first edition of *University Physics* by Francis W. Sears and Mark W. Zemansky was published in 1949, it was revolutionary among calculus-based physics textbooks in its emphasis on the fundamental principles of physics and how to apply them. The success of *University Physics* with generations of several million students and educators around the world is a testament to the merits of this approach and to the many innovations it has introduced subsequently.

In preparing this new Fourteenth Edition, we have further augmented and developed *University Physics* to assimilate the best ideas from education research with enhanced problem-solving instruction, pioneering visual and conceptual pedagogy, all-new categories of end-of-chapter problems, and the most pedagogically proven and widely used online homework and tutorial system in the world.

NEW TO THIS EDITION

- All key equations now include annotations that describe the equation and explain the meanings of the symbols in the equation. These annotations help promote in-depth processing of information and greater recall.
- DATA SPEAKS sidebars in each chapter, based on data captured from thousands of students, alert students to the statistically most common mistakes students make when working problems on related topics in MasteringPhysics.
- Updated modern physics content includes sections on quantum measurement (Chapter 40) and quantum entanglement (Chapter 41), as well as recent data on the Higgs boson and cosmic background radiation (Chapter 44).
- Additional bioscience applications appear throughout the text, mostly in the form of marginal photos with explanatory captions, to help students see how physics is connected to many breakthroughs and discoveries in the biosciences.
- The text has been streamlined with tighter and more focused language.
- Based on data from MasteringPhysics, changes to the end-of-chapter content include the following:
 - 25%–30% of problems are new or revised.
 - Most chapters include six to ten biosciences-related problems.
 - The number of context-rich problems is increased to facilitate the greater learning gains that they can offer.
- Three new DATA problems appear in each chapter. These typically context-rich, data-based reasoning problems require students to use experimental evidence, presented in a tabular or graphical format, to formulate conclusions.
- Each chapter now includes three to five new Passage Problems, which follow the format that is used in the MCATs. These problems require students to investigate multiple aspects of a real-life physical situation, typically biological in nature, that is described in a reading passage.
- Looking back at ... essential past concepts are listed at the beginning of each chapter, so that students know what they need to have mastered before digging into the current chapter.

Standard, Extended, and Three-Volume Editions

With MasteringPhysics:

- Standard Edition: Chapters 1–37
(ISBN 978-0-13-409650-6)
- Extended Edition: Chapters 1–44
(ISBN 978-0-321-98258-2)

Without MasteringPhysics:

- Standard Edition: Chapters 1–37
(ISBN 978-0-13-396929-0)
- Extended Edition: Chapters 1–44
(ISBN 978-0-321-97361-0)
- Volume 1: Chapters 1–20
(ISBN 978-0-13-397804-9)
- Volume 2: Chapters 21–37
(ISBN 978-0-13-397800-1)
- Volume 3: Chapters 37–44
(ISBN 978-0-13-397802-5)

KEY FEATURES OF UNIVERSITY PHYSICS



DEMO

- More than 620 **QR codes** throughout the book allow students to use a mobile phone to watch an interactive video of a physics instructor giving a relevant physics demonstration (Video Tutor Demonstration) or showing a narrated and animated worked Example (Video Tutor Solution). All of these videos also play directly through links within the Pearson eText as well as the Study Area within MasteringPhysics.
- End-of-chapter **Bridging Problems**, many revised, provide a transition between the single-concept Examples and the more challenging end-of-chapter problems. Each Bridging Problem poses a difficult, multiconcept problem that typically incorporates physics from earlier chapters. A skeleton **Solution Guide**, consisting of questions and hints, helps train students to approach and solve challenging problems with confidence.
- Deep and extensive **problem sets** cover a wide range of difficulty (with blue dots to indicate relative difficulty level) and exercise both physical understanding and problem-solving expertise. Many problems are based on complex real-life situations.
- This textbook offers more **Examples** and **Conceptual Examples** than most other leading calculus-based textbooks, allowing students to explore problem-solving challenges that are not addressed in other textbooks.
- A research-based **problem-solving approach (Identify, Set Up, Execute, Evaluate)** is used in every Example as well as in the Problem-Solving Strategies, in the Bridging Problems, and throughout the Instructor's Solutions Manual and the Study Guide. This consistent approach teaches students to tackle problems thoughtfully rather than cutting straight to the math.
- Problem-Solving Strategies** coach students in how to approach specific types of problems.
- The **figures** use a simplified graphical style to focus on the physics of a situation, and they incorporate more **explanatory annotations** than in the previous edition. Both techniques have been demonstrated to have a strong positive effect on learning.
- Many figures that illustrate Example solutions take the form of black-and-white **pencil sketches**, which directly represent what a student should draw in solving such problems themselves.
- The popular **Caution paragraphs** focus on typical misconceptions and student problem areas.
- End-of-section **Test Your Understanding** questions let students check their grasp of the material and use a multiple-choice or ranking-task format to probe for common misconceptions.
- Visual Summaries** at the end of each chapter present the key ideas in words, equations, and thumbnail pictures, helping students review more effectively.
- Approximately 70 PhET simulations** are linked to the Pearson eText and provided in the Study Area of the MasteringPhysics website (with icons in the printed book). These powerful simulations allow students to interact productively with the physics concepts they are learning. PhET clicker questions are also included on the Instructor's Resource DVD.

INSTRUCTOR'S SUPPLEMENTS

Note: For convenience, all of the following instructor's supplements (except for the Instructor's Resource DVD) can be downloaded from the Instructor Resources Area accessed via MasteringPhysics (www.masteringphysics.com).

The **Instructor's Solutions Manual**, prepared by A. Lewis Ford (Texas A&M University) and Wayne Anderson, contains complete and detailed solutions to all end-of-chapter problems. All solutions follow consistently the same Identify/Set Up/Execute/Evaluate problem-solving framework used in the textbook. Download

only from the MasteringPhysics Instructor Area or from the Instructor Resource Center (www.pearsonhighered.com/irc).

The cross-platform **Instructor's Resource DVD** (978-0-13-398364-7) provides a comprehensive library of approximately 350 applets from ActivPhysics OnLine as well as all art and photos from the textbook in JPEG and PowerPoint formats. In addition, all of the key equations, problem-solving strategies, tables, and chapter summaries are provided in JPEGs and editable Word format, and all of the new Data Speaks boxes are offered in JPEGs. In-class weekly multiple-choice questions for use with various Classroom Response Systems (CRS) are also provided, based on the Test Your Understanding questions and chapter-opening questions in the text. Written by Roger Freedman, many new CRS questions that increase in difficulty level have been added. Lecture outlines and PhET clicker questions, both in PowerPoint format, are also included along with about 70 PhET simulations and the Video Tutor Demonstrations (interactive video demonstrations) that are linked to QR codes throughout the textbook.

MasteringPhysics® (www.masteringphysics.com) from Pearson is the leading online teaching and learning system designed to improve results by engaging students before, during, and after class with powerful content. Ensure that students arrive ready to learn by assigning educationally effective content before class, and encourage critical thinking and retention with in-class resources such as Learning Catalytics. Students can further master concepts after class through traditional homework assignments that provide hints and answer-specific feedback. The Mastering gradebook records scores for all automatically graded assignments, while diagnostic tools give instructors access to rich data to assess student understanding and misconceptions.

Mastering brings learning full circle by continuously adapting to each student and making learning more personal than ever—before, during, and after class.

- **NEW! The Mastering Instructor Resources Area** contains all of the contents of the Instructor's Resource DVD—lecture outlines; Classroom Response System questions; images, tables, key equations, problem-solving strategies, Data Speaks boxes, and chapter summaries from the textbook; access to the Instructor's Solutions Manual, Test Bank, ActivPhysics Online—and much more.
- **NEW! Pre-lecture Videos** are assignable interactive videos that introduce students to key topics before they come to class. Each one includes assessment that feeds to the gradebook and alerts the instructor to potential trouble spots for students.
- **Pre-lecture Concept Questions** check students' familiarity with key concepts, prompting students to do their assigned reading before they come to class. These quizzes keep students on track, keep them more engaged in lecture, and help you spot the concepts that students find the most difficult.
- **NEW! Learning Catalytics** is a “bring your own device” student engagement, assessment, and classroom intelligence system that allows you to assess students in real time, understand immediately where they are and adjust your lecture accordingly, improve their critical-thinking skills, access rich analytics to understand student performance, add your own questions to fit your course exactly, and manage student interactions with intelligent grouping and timing. Learning Catalytics can be used both during and after class.
- **NEW! Adaptive Follow-Ups** allow Mastering to adapt continuously to each student, making learning more personal than ever. These assignments pair Mastering's powerful content with Knewton's adaptive learning engine to provide personalized help to students before misconceptions take hold. They are based on each student's performance on homework assignments and on all work in the course to date, including core prerequisite topics.

- **Video Tutor Demonstrations**, linked to QR codes in the textbook, feature “Pause and predict” videos of key physics concepts that ask students to submit a prediction before they see the outcome. These interactive videos are available in the Study Area of Mastering and in the Pearson eText.
- **Video Tutor Solutions** are linked to QR codes in the textbook. In these videos, which are available in the Study Area of Mastering and in the Pearson eText, an instructor explains and solves each worked example and Bridging Problem.
- **NEW! An Alternative Problem Set** in the Item Library of Mastering includes hundreds of new end-of-chapter questions and problems to offer instructors a wealth of options.
- **NEW! Physics/Biology Tutorials for MasteringPhysics** are assignable, multipart tutorials that emphasize biological processes and structures but also teach the physics principles that underlie them. They contain assessment questions that are based on the core competencies outlined in the 2015 MCAT.
- **PhET Simulations** (from the PhET project at the University of Colorado) are interactive, research-based simulations of physical phenomena. These tutorials, correlated to specific topics in the textbook, are available in the Pearson eText and in the Study Area within www.masteringphysics.com.
- **ActivPhysics OnLine™** (which is accessed through the Study Area and Instructor Resources within www.masteringphysics.com) provides a comprehensive library of approximately 350 tried and tested ActivPhysics applets updated for web delivery.
- Mastering’s **powerful gradebook** records all scores for automatically graded assignments. Struggling students and challenging assignments are highlighted in red, giving you an at-a-glance view of potential hurdles in the course. With a single click, charts summarize the most difficult problems, identify vulnerable students, and show the grade distribution, allowing for just-in-time teaching to address student misconceptions.
- **Learning Management System (LMS) Integration** gives seamless access to modified Mastering. Having all of your course materials and communications in one place makes life less complicated for you and your students. We’ve made it easier to link from within your LMS to modified Mastering and provide solutions, regardless of your LMS platform. With seamless, single sign-on your students will gain access to the personalized learning resources that make studying more efficient and more effective. You can access modified Mastering assignments, rosters, and resources and synchronize grades from modified Mastering with LMS.
- The **Test Bank** contains more than 2000 high-quality problems, with a range of multiple-choice, true/false, short-answer, and regular homework-type questions. Test files are provided both in TestGen (an easy-to-use, fully networkable program for creating and editing quizzes and exams) and in Word format. Download only from the MasteringPhysics Instructor Resources Area or from the Instructor Resources Center (www.pearsonhighered.com/irc).

MasteringPhysics enables instructors to:

- Quickly build homework assignments that combine regular end-of-chapter problems and tutoring (through additional multistep tutorial problems that offer wrong-answer feedback and simpler problems upon request).
- Expand homework to include the widest range of automatically graded activities available—from numerical problems with randomized values, through algebraic answers, to free-hand drawing.
- Choose from a wide range of nationally pre-tested problems that provide accurate estimates of time to complete and difficulty.
- After an assignment is completed, quickly identify not only the problems that were the trickiest for students but also the individual problem types with which students had trouble.

- Compare class results against the system's worldwide average for each problem assigned, to identify issues to be addressed with just-in-time teaching.
- Check the work of an individual student in detail, including the time spent on each problem, what wrong answers were submitted at each step, how much help was asked for, and how many practice problems were worked.

STUDENT'S SUPPLEMENTS

The **Student's Study Guide** by Laird Kramer reinforces the textbook's emphasis on problem-solving strategies and student misconceptions. The *Study Guide for Volume 1* (978-0-13-398361-6) covers Chapters 1–20, and the *Study Guide for Volumes 2 and 3* (978-0-13-398360-9) covers Chapters 21–44.

The **Student's Solutions Manual** by A. Lewis Ford (Texas A&M University) and Wayne Anderson contains detailed, step-by-step solutions to more than half of the odd-numbered end-of-chapter problems from the textbook. All solutions follow consistently the same Identify/Set Up/Execute/Evaluate problem-solving framework used in the textbook. The *Student's Solutions Manual for Volume 1* (978-0-13-398171-1) covers Chapters 1–20, and the *Student's Solutions Manual for Volumes 2 and 3* (978-0-13-396928-3) covers Chapters 21–44.

MasteringPhysics® (www.masteringphysics.com) is a homework, tutorial, and assessment system based on years of research into how students work physics problems and precisely where they need help. Studies show that students who use MasteringPhysics compared to handwritten homework significantly increase their scores. MasteringPhysics achieves this improvement by providing students with instantaneous feedback specific to their wrong answers, simpler sub-problems upon request when they get stuck, and partial credit for their method(s). This individualized, 24/7 Socratic tutoring is recommended by nine out of ten students to their peers as the most effective and time-efficient way to study.



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TIPERs (Tasks Inspired by Physics Education Research) are workbooks that give students the practice they need to develop reasoning about physics and that promote a conceptual understanding of problem solving:

- **NEW! TIPERs: Sensemaking Tasks for Introductory Physics** (978-0-13-285458-0) by Curtis Hieggelke, Stephen Kanim, David Maloney, and Thomas O'Kuma
- **Newtonian Tasks Inspired by Physics Education Research: nTIPERs** (978-0-321-75375-5) by Curtis Hieggelke, David Maloney, and Stephen Kanim
- **E&M TIPERs: Electricity & Magnetism Tasks** (978-0-13-185499-4) by Curtis Hieggelke, David Maloney, Thomas O'Kuma, and Stephen Kanim

Tutorials in Introductory Physics (978-0-13-097069-5) by Lillian C. McDermott and Peter S. Schaffer presents a series of physics tutorials designed by a leading physics education research group. Emphasizing the development of concepts and scientific reasoning skills, the tutorials focus on the specific conceptual and reasoning difficulties that students tend to encounter.

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PLEASE TELL ME WHAT YOU THINK!

I welcome communications from students and professors, especially concerning errors or deficiencies that you find in this edition. The late Hugh Young and I have devoted a lot of time and effort to writing the best book we know how to write, and I hope it will help as you teach and learn physics. In turn, you can help me by letting me know what still needs to be improved! Please feel free to contact me either electronically or by ordinary mail. Your comments will be greatly appreciated.

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DETAILED CONTENTS

MECHANICS

1	UNITS, PHYSICAL QUANTITIES, AND VECTORS	1
1.1	The Nature of Physics	2
1.2	Solving Physics Problems	2
1.3	Standards and Units	4
1.4	Using and Converting Units	6
1.5	Uncertainty and Significant Figures	8
1.6	Estimates and Orders of Magnitude	10
1.7	Vectors and Vector Addition	10
1.8	Components of Vectors	14
1.9	Unit Vectors	18
1.10	Products of Vectors	19
	Summary	25
	Questions/Exercises/Problems	27
2	MOTION ALONG A STRAIGHT LINE	34
2.1	Displacement, Time, and Average Velocity	34
2.2	Instantaneous Velocity	37
2.3	Average and Instantaneous Acceleration	40
2.4	Motion with Constant Acceleration	45
2.5	Freely Falling Bodies	50
2.6	Velocity and Position by Integration	53
	Summary	56
	Questions/Exercises/Problems	57
3	MOTION IN TWO OR THREE DIMENSIONS	67
3.1	Position and Velocity Vectors	67
3.2	The Acceleration Vector	70
3.3	Projectile Motion	75
3.4	Motion in a Circle	82
3.5	Relative Velocity	86
	Summary	91
	Questions/Exercises/Problems	92
4	NEWTON'S LAWS OF MOTION	101
4.1	Force and Interactions	102
4.2	Newton's First Law	105
4.3	Newton's Second Law	108
4.4	Mass and Weight	114
4.5	Newton's Third Law	116
4.6	Free-Body Diagrams	120
	Summary	121
	Questions/Exercises/Problems	123
5	APPLYING NEWTON'S LAWS	130
5.1	Using Newton's First Law: Particles in Equilibrium	130
5.2	Using Newton's Second Law: Dynamics of Particles	135
5.3	Friction Forces	142
5.4	Dynamics of Circular Motion	150
5.5	The Fundamental Forces of Nature	155
	Summary	157
	Questions/Exercises/Problems	159
6	WORK AND KINETIC ENERGY	172
6.1	Work	173
6.2	Kinetic Energy and the Work–Energy Theorem	177
6.3	Work and Energy with Varying Forces	183
6.4	Power	189
	Summary	192
	Questions/Exercises/Problems	193
7	POTENTIAL ENERGY AND ENERGY CONSERVATION	203
7.1	Gravitational Potential Energy	203
7.2	Elastic Potential Energy	212
7.3	Conservative and Nonconservative Forces	217
7.4	Force and Potential Energy	221
7.5	Energy Diagrams	224
	Summary	226
	Questions/Exercises/Problems	227
8	MOMENTUM, IMPULSE, AND COLLISIONS	237
8.1	Momentum and Impulse	238
8.2	Conservation of Momentum	243





8.3	Momentum Conservation and Collisions	247	12	FLUID MECHANICS	369
8.4	Elastic Collisions	251	12.1	Gases, Liquids, and Density	369
8.5	Center of Mass	254	12.2	Pressure in a Fluid	371
8.6	Rocket Propulsion	258	12.3	Buoyancy	376
	Summary	261	12.4	Fluid Flow	379
	Questions/Exercises/Problems	262	12.5	Bernoulli's Equation	381
			12.6	Viscosity and Turbulence	385
				Summary	388
				Questions/Exercises/Problems	389
9	ROTATION OF RIGID BODIES	273	13	GRAVITATION	398
9.1	Angular Velocity and Acceleration	273	13.1	Newton's Law of Gravitation	398
9.2	Rotation with Constant Angular Acceleration	278	13.2	Weight	402
9.3	Relating Linear and Angular Kinematics	280	13.3	Gravitational Potential Energy	405
9.4	Energy in Rotational Motion	283	13.4	The Motion of Satellites	407
9.5	Parallel-Axis Theorem	288	13.5	Kepler's Laws and the Motion of Planets	410
9.6	Moment-of-Inertia Calculations	289	13.6	Spherical Mass Distributions	414
	Summary	292	13.7	Apparent Weight and the Earth's Rotation	417
	Questions/Exercises/Problems	293	13.8	Black Holes	419
				Summary	423
				Questions/Exercises/Problems	424
10	DYNAMICS OF ROTATIONAL MOTION	303	14	PERIODIC MOTION	433
10.1	Torque	303	14.1	Describing Oscillation	433
10.2	Torque and Angular Acceleration for a Rigid Body	306	14.2	Simple Harmonic Motion	435
10.3	Rigid-Body Rotation About a Moving Axis	309	14.3	Energy in Simple Harmonic Motion	442
10.4	Work and Power in Rotational Motion	315	14.4	Applications of Simple Harmonic Motion	446
10.5	Angular Momentum	317	14.5	The Simple Pendulum	450
10.6	Conservation of Angular Momentum	320	14.6	The Physical Pendulum	451
10.7	Gyroscopes and Precession	322	14.7	Damped Oscillations	453
	Summary	326	14.8	Forced Oscillations and Resonance	455
	Questions/Exercises/Problems	327		Summary	457
				Questions/Exercises/Problems	459
11	EQUILIBRIUM AND ELASTICITY	339	WAVES/ACOUSTICS		
11.1	Conditions for Equilibrium	340	15	MECHANICAL WAVES	468
11.2	Center of Gravity	340	15.1	Types of Mechanical Waves	468
11.3	Solving Rigid-Body Equilibrium Problems	343	15.2	Periodic Waves	470
11.4	Stress, Strain, and Elastic Moduli	347	15.3	Mathematical Description of a Wave	473
11.5	Elasticity and Plasticity	353	15.4	Speed of a Transverse Wave	478
	Summary	354	15.5	Energy in Wave Motion	482
	Questions/Exercises/Problems	356	15.6	Wave Interference, Boundary Conditions, and Superposition	485
			15.7	Standing Waves on a String	487
			15.8	Normal Modes of a String	491
				Summary	495
				Questions/Exercises/Problems	496
16	SOUND AND HEARING	505	16	SOUND AND HEARING	505
			16.1	Sound Waves	505
			16.2	Speed of Sound Waves	510

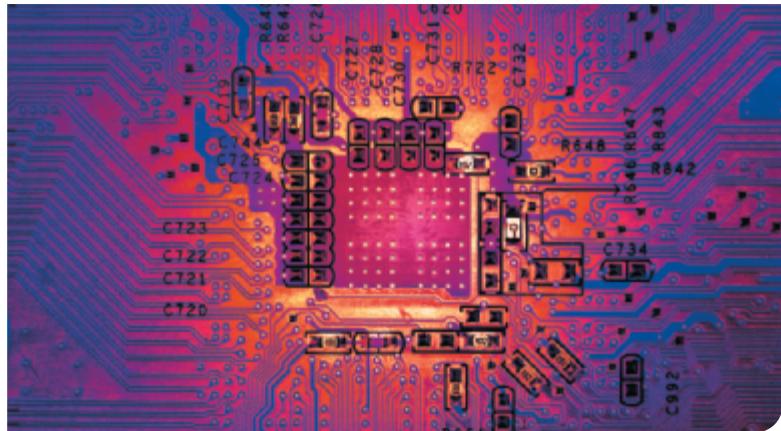
16.3	Sound Intensity	514
16.4	Standing Sound Waves and Normal Modes	518
16.5	Resonance and Sound	522
16.6	Interference of Waves	524
16.7	Beats	526
16.8	The Doppler Effect	528
16.9	Shock Waves	533
	Summary	535
	Questions/Exercises/Problems	537



THERMODYNAMICS

17	TEMPERATURE AND HEAT	545
17.1	Temperature and Thermal Equilibrium	545
17.2	Thermometers and Temperature Scales	547
17.3	Gas Thermometers and the Kelvin Scale	548
17.4	Thermal Expansion	551
17.5	Quantity of Heat	556
17.6	Calorimetry and Phase Changes	559
17.7	Mechanisms of Heat Transfer	565
	Summary	572
	Questions/Exercises/Problems	573
18	THERMAL PROPERTIES OF MATTER	584
18.1	Equations of State	585
18.2	Molecular Properties of Matter	590
18.3	Kinetic-Molecular Model of an Ideal Gas	593
18.4	Heat Capacities	599
18.5	Molecular Speeds	602
18.6	Phases of Matter	604
	Summary	607
	Questions/Exercises/Problems	609
19	THE FIRST LAW OF THERMODYNAMICS	618
19.1	Thermodynamic Systems	618
19.2	Work Done During Volume Changes	620
19.3	Paths Between Thermodynamic States	622
19.4	Internal Energy and the First Law of Thermodynamics	623
19.5	Kinds of Thermodynamic Processes	628
19.6	Internal Energy of an Ideal Gas	630
19.7	Heat Capacities of an Ideal Gas	631
19.8	Adiabatic Processes for an Ideal Gas	634
	Summary	637
	Questions/Exercises/Problems	638
20	THE SECOND LAW OF THERMODYNAMICS	647
20.1	Directions of Thermodynamic Processes	647
20.2	Heat Engines	649
20.3	Internal-Combustion Engines	652
21	ELECTRIC CHARGE AND ELECTRIC FIELD	683
21.1	Electric Charge	684
21.2	Conductors, Insulators, and Induced Charges	687
21.3	Coulomb's Law	690
21.4	Electric Field and Electric Forces	695
21.5	Electric-Field Calculations	699
21.6	Electric Field Lines	705
21.7	Electric Dipoles	706
	Summary	711
	Questions/Exercises/Problems	712
22	GAUSS'S LAW	722
22.1	Charge and Electric Flux	722
22.2	Calculating Electric Flux	725
22.3	Gauss's Law	729
22.4	Applications of Gauss's Law	733
22.5	Charges on Conductors	738
	Summary	743
	Questions/Exercises/Problems	744
23	ELECTRIC POTENTIAL	752
23.1	Electric Potential Energy	752
23.2	Electric Potential	759
23.3	Calculating Electric Potential	765
23.4	Equipotential Surfaces	769
23.5	Potential Gradient	771
	Summary	775
	Questions/Exercises/Problems	776

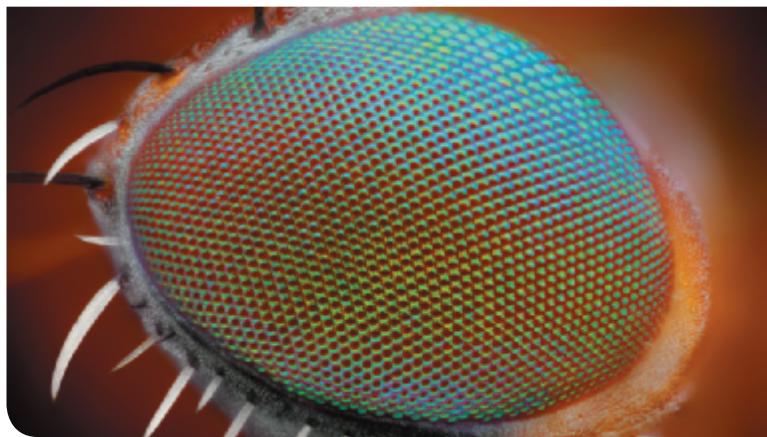
24	CAPACITANCE AND DIELECTRICS	785	27.5	Applications of Motion of Charged Particles	894
24.1	Capacitors and Capacitance	786	27.6	Magnetic Force on a Current-Carrying Conductor	896
24.2	Capacitors in Series and Parallel	790	27.7	Force and Torque on a Current Loop	900
24.3	Energy Storage in Capacitors and Electric-Field Energy	794	27.8	The Direct-Current Motor	905
24.4	Dielectrics	797	27.9	The Hall Effect	907
24.5	Molecular Model of Induced Charge	803		Summary	909
24.6	Gauss's Law in Dielectrics	805		Questions/Exercises/Problems	911
	Summary	806			
	Questions/Exercises/Problems	808			
25	CURRENT, RESISTANCE, AND ELECTROMOTIVE FORCE	816	28	SOURCES OF MAGNETIC FIELD	921
25.1	Current	817	28.1	Magnetic Field of a Moving Charge	921
25.2	Resistivity	820	28.2	Magnetic Field of a Current Element	924
25.3	Resistance	823	28.3	Magnetic Field of a Straight Current-Carrying Conductor	926
25.4	Electromotive Force and Circuits	826	28.4	Force Between Parallel Conductors	929
25.5	Energy and Power in Electric Circuits	832	28.5	Magnetic Field of a Circular Current Loop	930
25.6	Theory of Metallic Conduction	836	28.6	Ampere's Law	933
	Summary	839	28.7	Applications of Ampere's Law	936
	Questions/Exercises/Problems	840	28.8	Magnetic Materials	939
				Summary	945
				Questions/Exercises/Problems	947
26	DIRECT-CURRENT CIRCUITS	848	29	ELECTROMAGNETIC INDUCTION	955
26.1	Resistors in Series and Parallel	848	29.1	Induction Experiments	956
26.2	Kirchhoff's Rules	853	29.2	Faraday's Law	957
26.3	Electrical Measuring Instruments	858	29.3	Lenz's Law	965
26.4	R-C Circuits	862	29.4	Motional Electromotive Force	967
26.5	Power Distribution Systems	867	29.5	Induced Electric Fields	969
	Summary	871	29.6	Eddy Currents	972
	Questions/Exercises/Problems	872	29.7	Displacement Current and Maxwell's Equations	973
27	MAGNETIC FIELD AND MAGNETIC FORCES	881	29.8	Superconductivity	977
27.1	Magnetism	881		Summary	979
27.2	Magnetic Field	883		Questions/Exercises/Problems	980
27.3	Magnetic Field Lines and Magnetic Flux	887	30	INDUCTANCE	990
27.4	Motion of Charged Particles in a Magnetic Field	890	30.1	Mutual Inductance	990
			30.2	Self-Inductance and Inductors	994
			30.3	Magnetic-Field Energy	997
			30.4	The R-L Circuit	1000
			30.5	The L-C Circuit	1004
			30.6	The L-R-C Series Circuit	1008
				Summary	1011
				Questions/Exercises/Problems	1012
31	ALTERNATING CURRENT	1020			
31.1	Phasors and Alternating Currents	1020			
31.2	Resistance and Reactance	1023			
31.3	The L-R-C Series Circuit	1028			
31.4	Power in Alternating-Current Circuits	1033			



31.5	Resonance in Alternating-Current Circuits	1036
31.6	Transformers	1038
	Summary	1042
	Questions/Exercises/Problems	1043
32	ELECTROMAGNETIC WAVES	1050
32.1	Maxwell's Equations and Electromagnetic Waves	1051
32.2	Plane Electromagnetic Waves and the Speed of Light	1054
32.3	Sinusoidal Electromagnetic Waves	1059
32.4	Energy and Momentum in Electromagnetic Waves	1063
32.5	Standing Electromagnetic Waves	1068
	Summary	1071
	Questions/Exercises/Problems	1072

OPTICS

33	THE NATURE AND PROPAGATION OF LIGHT	1078
33.1	The Nature of Light	1078
33.2	Reflection and Refraction	1080
33.3	Total Internal Reflection	1086
33.4	Dispersion	1089
33.5	Polarization	1091
33.6	Scattering of Light	1099
33.7	Huygens's Principle	1100
	Summary	1102
	Questions/Exercises/Problems	1104
34	GEOMETRIC OPTICS	1111
34.1	Reflection and Refraction at a Plane Surface	1111
34.2	Reflection at a Spherical Surface	1115
34.3	Refraction at a Spherical Surface	1123
34.4	Thin Lenses	1128
34.5	Cameras	1136
34.6	The Eye	1139
34.7	The Magnifier	1143
34.8	Microscopes and Telescopes	1144
	Summary	1149
	Questions/Exercises/Problems	1151
35	INTERFERENCE	1160
35.1	Interference and Coherent Sources	1160
35.2	Two-Source Interference of Light	1164
35.3	Intensity in Interference Patterns	1167
35.4	Interference in Thin Films	1171
35.5	The Michelson Interferometer	1176
	Summary	1178
	Questions/Exercises/Problems	1179

**36 DIFFRACTION** 1186

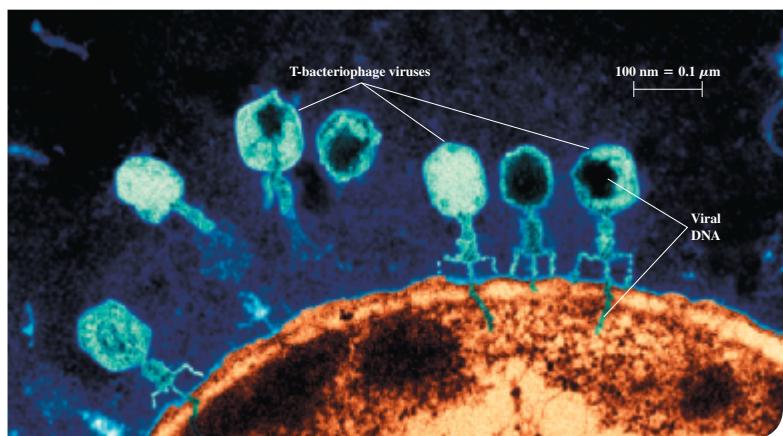
36.1	Fresnel and Fraunhofer Diffraction	1186
36.2	Diffraction from a Single Slit	1188
36.3	Intensity in the Single-Slit Pattern	1191
36.4	Multiple Slits	1195
36.5	The Diffraction Grating	1197
36.6	X-Ray Diffraction	1201
36.7	Circular Apertures and Resolving Power	1204
36.8	Holography	1207
	Summary	1209
	Questions/Exercises/Problems	1210

MODERN PHYSICS

37	RELATIVITY	1218
37.1	Invariance of Physical Laws	1218
37.2	Relativity of Simultaneity	1221
37.3	Relativity of Time Intervals	1223
37.4	Relativity of Length	1228
37.5	The Lorentz Transformations	1232
37.6	The Doppler Effect for Electromagnetic Waves	1236
37.7	Relativistic Momentum	1238
37.8	Relativistic Work and Energy	1240
37.9	Newtonian Mechanics and Relativity	1244
	Summary	1245
	Questions/Exercises/Problems	1247

38 PHOTONS: LIGHT WAVES BEHAVING AS PARTICLES 1254

38.1	Light Absorbed as Photons: The Photoelectric Effect	1254
38.2	Light Emitted as Photons: X-Ray Production	1260
38.3	Light Scattered as Photons: Compton Scattering and Pair Production	1263
38.4	Wave-Particle Duality, Probability, and Uncertainty	1266
	Summary	1273
	Questions/Exercises/Problems	1274



39	PARTICLES BEHAVING AS WAVES	1279	42	MOLECULES AND CONDENSED MATTER	1407																																																																																																																																																			
39.1	Electron Waves	1279	42.1	Types of Molecular Bonds	1407																																																																																																																																																			
39.2	The Nuclear Atom and Atomic Spectra	1285	42.2	Molecular Spectra	1410																																																																																																																																																			
39.3	Energy Levels and the Bohr Model of the Atom	1290	42.3	Structure of Solids	1414																																																																																																																																																			
39.4	The Laser	1300	42.4	Energy Bands	1418																																																																																																																																																			
39.5	Continuous Spectra	1303	42.5	Free-Electron Model of Metals	1420																																																																																																																																																			
39.6	The Uncertainty Principle Revisited	1308	42.6	Semiconductors	1424																																																																																																																																																			
	Summary	1311	42.7	Semiconductor Devices	1427																																																																																																																																																			
	Questions/Exercises/Problems	1313				42.8	Superconductivity	1432					Summary	1432					Questions/Exercises/Problems	1434	40	QUANTUM MECHANICS I: WAVE FUNCTIONS	1321	43	NUCLEAR PHYSICS	1440	40.1	Wave Functions and the One-Dimensional Schrödinger Equation	1321	43.1	Properties of Nuclei	1440	40.2	Particle in a Box	1331	43.2	Nuclear Binding and Nuclear Structure	1446	40.3	Potential Wells	1336	43.3	Nuclear Stability and Radioactivity	1450	40.4	Potential Barriers and Tunneling	1340	43.4	Activities and Half-Lives	1457	40.5	The Harmonic Oscillator	1343	43.5	Biological Effects of Radiation	1461	40.6	Measurement in Quantum Mechanics	1348	43.6	Nuclear Reactions	1464		Summary	1351	43.7	Nuclear Fission	1466		Questions/Exercises/Problems	1353				43.8	Nuclear Fusion	1470					Summary	1473					Questions/Exercises/Problems	1474	41	QUANTUM MECHANICS II: ATOMIC STRUCTURE	1360	44	PARTICLE PHYSICS AND COSMOLOGY	1481	41.1	The Schrödinger Equation in Three Dimensions	1360	44.1	Fundamental Particles—A History	1481	41.2	Particle in a Three-Dimensional Box	1362	44.2	Particle Accelerators and Detectors	1486	41.3	The Hydrogen Atom	1367	44.3	Particles and Interactions	1490	41.4	The Zeeman Effect	1375	44.4	Quarks and Gluons	1496	41.5	Electron Spin	1378	44.5	The Standard Model and Beyond	1500	41.6	Many-Electron Atoms and the Exclusion Principle	1385	44.6	The Expanding Universe	1502	41.7	X-Ray Spectra	1392	44.7	The Beginning of Time	1509	41.8	Quantum Entanglement	1395		Summary	1399		Summary	1517		Questions/Exercises/Problems	1401		Questions/Exercises/Problems	1519
			42.8	Superconductivity	1432																																																																																																																																																			
				Summary	1432																																																																																																																																																			
				Questions/Exercises/Problems	1434																																																																																																																																																			
40	QUANTUM MECHANICS I: WAVE FUNCTIONS	1321	43	NUCLEAR PHYSICS	1440																																																																																																																																																			
40.1	Wave Functions and the One-Dimensional Schrödinger Equation	1321	43.1	Properties of Nuclei	1440																																																																																																																																																			
40.2	Particle in a Box	1331	43.2	Nuclear Binding and Nuclear Structure	1446																																																																																																																																																			
40.3	Potential Wells	1336	43.3	Nuclear Stability and Radioactivity	1450																																																																																																																																																			
40.4	Potential Barriers and Tunneling	1340	43.4	Activities and Half-Lives	1457																																																																																																																																																			
40.5	The Harmonic Oscillator	1343	43.5	Biological Effects of Radiation	1461																																																																																																																																																			
40.6	Measurement in Quantum Mechanics	1348	43.6	Nuclear Reactions	1464																																																																																																																																																			
	Summary	1351	43.7	Nuclear Fission	1466																																																																																																																																																			
	Questions/Exercises/Problems	1353				43.8	Nuclear Fusion	1470					Summary	1473					Questions/Exercises/Problems	1474	41	QUANTUM MECHANICS II: ATOMIC STRUCTURE	1360	44	PARTICLE PHYSICS AND COSMOLOGY	1481	41.1	The Schrödinger Equation in Three Dimensions	1360	44.1	Fundamental Particles—A History	1481	41.2	Particle in a Three-Dimensional Box	1362	44.2	Particle Accelerators and Detectors	1486	41.3	The Hydrogen Atom	1367	44.3	Particles and Interactions	1490	41.4	The Zeeman Effect	1375	44.4	Quarks and Gluons	1496	41.5	Electron Spin	1378	44.5	The Standard Model and Beyond	1500	41.6	Many-Electron Atoms and the Exclusion Principle	1385	44.6	The Expanding Universe	1502	41.7	X-Ray Spectra	1392	44.7	The Beginning of Time	1509	41.8	Quantum Entanglement	1395		Summary	1399		Summary	1517		Questions/Exercises/Problems	1401		Questions/Exercises/Problems	1519																																																																					
			43.8	Nuclear Fusion	1470																																																																																																																																																			
				Summary	1473																																																																																																																																																			
				Questions/Exercises/Problems	1474																																																																																																																																																			
41	QUANTUM MECHANICS II: ATOMIC STRUCTURE	1360	44	PARTICLE PHYSICS AND COSMOLOGY	1481																																																																																																																																																			
41.1	The Schrödinger Equation in Three Dimensions	1360	44.1	Fundamental Particles—A History	1481																																																																																																																																																			
41.2	Particle in a Three-Dimensional Box	1362	44.2	Particle Accelerators and Detectors	1486																																																																																																																																																			
41.3	The Hydrogen Atom	1367	44.3	Particles and Interactions	1490																																																																																																																																																			
41.4	The Zeeman Effect	1375	44.4	Quarks and Gluons	1496																																																																																																																																																			
41.5	Electron Spin	1378	44.5	The Standard Model and Beyond	1500																																																																																																																																																			
41.6	Many-Electron Atoms and the Exclusion Principle	1385	44.6	The Expanding Universe	1502																																																																																																																																																			
41.7	X-Ray Spectra	1392	44.7	The Beginning of Time	1509																																																																																																																																																			
41.8	Quantum Entanglement	1395		Summary	1399		Summary	1517		Questions/Exercises/Problems	1401		Questions/Exercises/Problems	1519																																																																																																																																										
	Summary	1399		Summary	1517																																																																																																																																																			
	Questions/Exercises/Problems	1401		Questions/Exercises/Problems	1519																																																																																																																																																			

APPENDICES

A	The International System of Units	A-1
B	Useful Mathematical Relations	A-3
C	The Greek Alphabet	A-4
D	Periodic Table of the Elements	A-5
E	Unit Conversion Factors	A-6
F	Numerical Constants	A-7
	Answers to Odd-Numbered Problems	A-9
	Credits	C-1
	Index	I-1