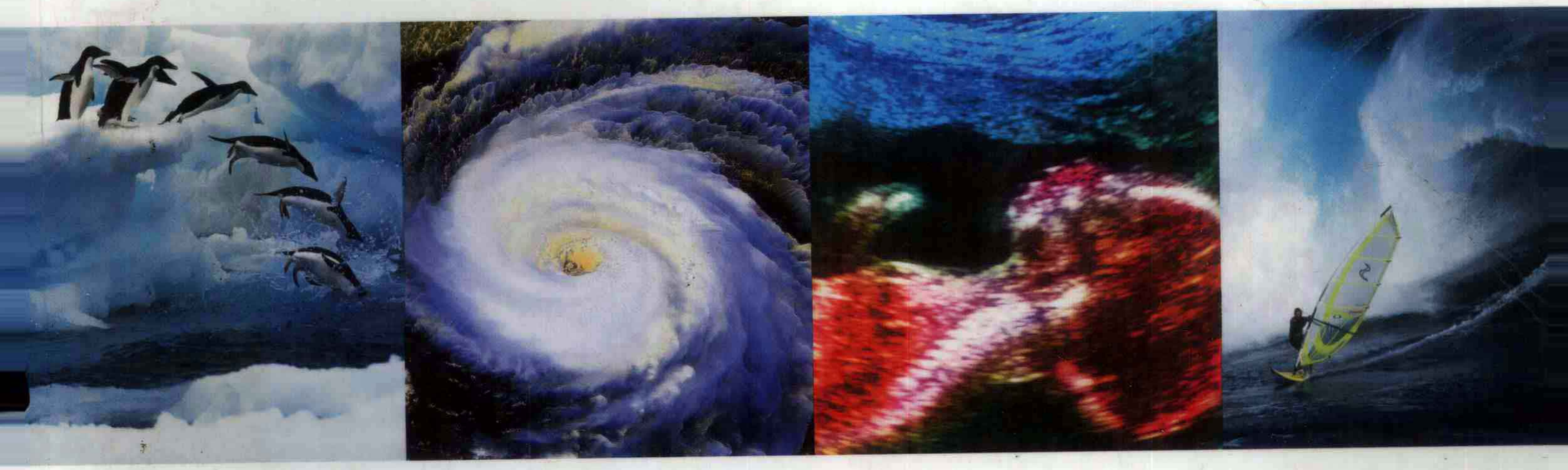
PHYSICS

Volume I



JAMES S. WALKER

Physics

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Prentice Hall

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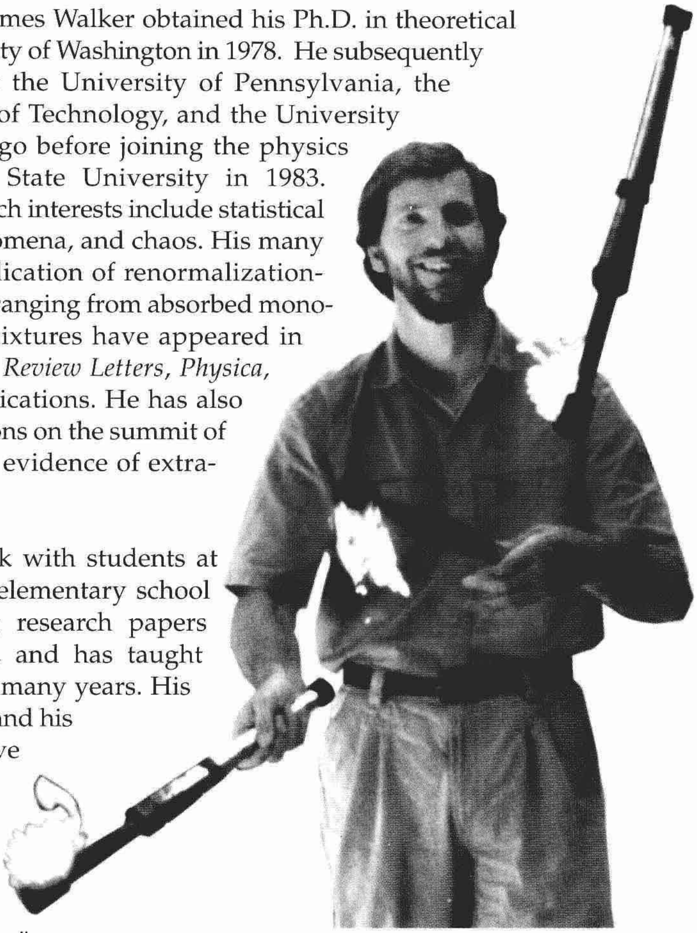

James S. Walker James Walker obtained his Ph.D. in theoretical physics from the University of Washington in 1978. He subsequently served as a post-doc at the University of Pennsylvania, the Massachusetts Institute of Technology, and the University of California at San Diego before joining the physics faculty at Washington State University in 1983. Professor Walker's research interests include statistical mechanics, critical phenomena, and chaos. His many publications on the application of renormalization-group theory to systems ranging from absorbed mono-layers to binary-fluid mixtures have appeared in *Physical Review, Physical Review Letters, Physica,* and a host of other publications. He has also participated in observations on the summit of Mauna Kea, looking for evidence of extra-solar planets.

Jim Walker likes to work with students at all levels, from judging elementary school science fairs to writing research papers with graduate students, and has taught introductory physics for many years. His enjoyment of this course and his empathy for students have earned him a reputation as an innovative, enthusiastic, and effective teacher. Jim's educational publications include "Reappearing Phases" (*Scientific American,* May 1987) as well as articles in the *American Journal of Physics* and *The Physics Teacher.* In recognition of his contributions to the teaching of physics, Jim was recently named Boeing Distinguished Professor of Science and Mathematics Education.

When he is not writing, conducting research, teaching, or developing new classroom demonstrations and pedagogical materials, Jim enjoys amateur astronomy, bird watching, photography, juggling, unicycling, boogie boarding, and kayaking. He recently spent three weeks rafting through the Grand Canyon and hiking in various side canyons. Jim is also an avid jazz pianist and organist. He has served as ballpark organist for several Class A minor league baseball teams, including minor league affiliates of the Seattle Mariners and San Francisco Giants.

This book is dedicated to my parents,
Ivan and Janet Walker.

Preface: To the Instructor

Teaching any subject can be a most challenging—and rewarding—experience. This is particularly true of the introductory algebra-based physics course, where students with a wide range of backgrounds and interests participate in a unique learning experience. With only a limited time at our disposal, we, the instructors, strive not only to convey the basic concepts and fundamental laws of physics, but also to give students an appreciation of its relevance and appeal. This is a tall order, but one that is well worth the effort.

To help with the task, this text incorporates a number of unique and innovative pedagogical features. These features, which evolved from years of teaching experience, have been tested extensively in the classroom and refined on the basis of interviews and discussions with students. The enthusiastic response I receive from students using this material has encouraged my belief that your students, like mine, will find the presentation of physics given in this text to be clear, engaging, and empowering.

Learning Tools in the Text

The goal of this text is to help students improve their conceptual understanding of physics hand in hand with the development of their problem-solving skills. One of the chief means to that end is the replacement of the traditional Examples in the text by an integrated suite of learning tools: fully worked *Examples in Two-Column Format*, *Active Examples*, *Conceptual Checkpoints*, and *Exercises*. Each of these tools performs some of the functions of an Example, but each is specialized to meet the needs of students at a particular point in the development of the chapter's content.

These needs are not always the same. Sometimes students require a detailed explanation of how to tackle a particular problem; at other times, they must be allowed to take an active role and work out the details for themselves. Sometimes it is important for them to perform calculations and concentrate on numerical precision; at other times it may be more fruitful for them to explore a key idea more fully in a non-quantitative context. Sometimes the analysis of a detailed physical context is essential; at other times, practice in using a new equation or relationship is all that is called for.

A good teacher can sense when students need a very patient exposition and when they need only minimal reinforcement; when they need to focus on concepts and when they need an opportunity to practice their quantitative skills. This text attempts to mimic the teaching style of successful instructors by providing the right tool at the right time and place.

Worked Examples in Two-Column Format

Examples provide the most complete and detailed illustration of how to solve a particular type of problem. The Examples in this text are presented in a unique two-column format that focuses on the basic strategies and thought processes involved in problem solving. The aim of this approach is to help students devise a *strategy* to be followed and then implement a clear *step-by-step solution* to the problem. The emphasis is thus on the relationship between the physical concepts and their mathematical expression. This focus on the intimate relationship between conceptual insights and problem-solving techniques encourages students to view the ability to solve problems as a logical outgrowth of conceptual understanding rather than a kind of parlor trick.

Each Example has the same basic structure:

- **Picture the Problem** The first, crucial element in this structure is *Picture the Problem*, which discusses how the physical situation can be represented visually and what such a representation can tell us about how to analyze and solve the problem. At this stage we set up a coordinate system where appropriate, label important quantities, and indicate which values are known.
- **Strategy** Closely linked with this visualization process is the formulation of a *Strategy* to be followed in solving the problem. The strategy addresses the commonly asked question, "How do I get started?" by providing a clear overview of the problem and helping students to identify the relevant physical principles. It then guides the student in using known relationships to chart a step-by-step path to the solution.
- **Solution** In the the step-by-step *Solution* of the problem, each of the steps is presented with a prose statement in the left-hand column and the corresponding mathematical implementation in the right-hand column. In effect, each step shows how to translate the idea described in words into the appropriate equations.

  When reviewing an Example, note that the left-hand column gives the flow of ideas used in the solution; the right-hand column gives the mathematical calculations that were carried out. Students often find it useful to practice problem solving by covering one column of an Example with a sheet of paper and filling in the covered steps as they refer to the other column.
- **Insight** Each example wraps up with an *Insight*—a comment regarding the solution just obtained. Some Insights deal with possible alternative solution techniques, others with new ideas suggested by the results.
- **Practice Problem** Following the Insight is a *Practice Problem*, which gives the student a chance to practice the type of calculation just presented. The Practice Problems, always accompanied by their answers, provide students with a valuable check on their understanding of the material. Finally, each Example ends with a reference to some related end-of-chapter problems to allow students to test their skills further.

Active Examples

Active Examples serve as a bridge between the fully worked Examples, in which every detail is fully discussed and every step is given, and the homework problems, where no help is given at all. In an Active Example, the solution to a problem is broken down into a series of manageable steps, with the prose on the left and the mathematical implementation on the right, but in skeleton form which the student must flesh out. Students take an active role in solving the problem by thinking through the logic of the steps described on the left and performing the calculations indicated on the right. Working through Active Examples will make students better prepared to tackle homework problems on their own.

Conceptual Checkpoints

Conceptual Checkpoints help students sharpen their insight into key physical principles. A typical Conceptual Checkpoint presents a thought-provoking question that can be answered by logical reasoning based on physical concepts rather than by numerical calculations. These questions, which can be just as challenging as any numerical problem and just as educational, are presented in multiple-choice format to help focus the student's thinking. The statement of the question is followed by a detailed discussion and analysis in the section titled *Reasoning and Discussion*, and the *Answer* is given at the end of the checkpoint for quick and easy reference.

Exercises

Exercises present brief calculations designed to illustrate the application of important new relationships, without the expenditure of time and space required by a fully worked Example. Exercises generally give students an opportunity to practice the use of a new equation, become familiar with the units of a new physical quantity, and get a feeling for typical magnitudes.

Problem Solving Notes

In addition to the in-text elements just described, each chapter includes a number of marginal *Problem Solving Notes*. These practical hints are designed to highlight useful problem-solving methods while helping students avoid common pitfalls and misconceptions.

PROBLEM SOLVING NOTE
Radians

Remember to measure angles in radians when using the relation $s = r\theta$.

End of Chapter Learning Tools

The end of chapter material in this text also includes a number of innovations, along with refinements of more familiar elements.

Chapter Summary

Each chapter concludes with a Chapter Summary presented in an easy-to-use outline style. Key concepts and equations are collected in the summary for convenient reference.

Problem-Solving Summary

A unique feature of this text is the *Problem-Solving Summary* at the end of the chapter. This is a new type of summary that addresses common sources of misconceptions in problem solving, and gives specific references to Examples and Active Examples illustrating the correct procedures. Each entry in the Problem-Solving Summary relates a specific type of calculation to the relevant physical concepts.

Conceptual Questions

The homework for each chapter begins with a section of *Conceptual Questions*. Answers to the odd-numbered questions can be found in the back of the book, so that students can check their reasoning and conclusions.

Numerical and Integrated Homework Problems

A collection of numerical and integrated problems are presented at the end of each chapter. Note that a number of problems are given for each section of the chapter. In addition, a section titled "General Problems" presents a variety of problems that use material from two or more sections within the chapter, or refer to material covered in earlier chapters.

Within each section of the homework, the problems are presented in order of difficulty. The most straightforward problems are labeled with a single bullet (•), problems involving several steps and more detailed reasoning are labeled with two bullets (••), and problems of a more challenging nature are indicated with three bullets (•••).

Problems of special biological or medical relevance are indicated with the symbol **BIO**.

Certain problems throughout the homework, labeled with the symbol **IP**, *integrate a conceptual question with a numerical problem*. Problems of this type, which stress the importance of reasoning from principles, show how conceptual insight and numerical calculation go hand in hand in physics. They afford students the opportunity to express their understanding of physics in both words and mathematics.

Scope and Organization

Table of Contents

As you will notice from the Table of Contents (pages v–x), the presentation of physics in this text follows the standard practice for introductory courses, with only a few well-motivated refinements.

First, note that Chapter 3 is devoted to vectors and their application to physics. This material could be presented in an Appendix, but my experience has been that students benefit greatly from a full discussion of vectors early in the course. Most students have seen vectors and trigonometric functions before, but rarely from the point of view of physics. Thus, including vectors in the text sends a message that this is important material, and it gives students an opportunity to brush up on their math skills.

Note also that additional time is given to some of the more fundamental aspects of physics, such as Newton's laws and energy. Presenting such material in two chapters gives the student a better opportunity to assimilate and master these crucial topics, which form the foundation for so much of what follows. Given the time constraints we all face in the classroom, the distribution of material presented in this text is designed to give time and emphasis where most appropriate. Sections considered optional are marked with an asterisk.

Real World Physics

REAL WORLD PHYSICS
Moment of inertia of the Earth

REAL WORLD PHYSICS: BIO
The microhematocrit centrifuge

Since physics applies to everything in nature, it is only reasonable to point out applications of physics that students may encounter in the real world. Each chapter presents a number of discussions focusing on "Real World Physics." Those of general interest are designated by a globe icon in the margin. Applications that pertain more specifically to biology and medicine are indicated by a CAT scan icon in the margin. The inclusion of a generous selection of such topics should help to make the course material more interesting and relevant to all students, including the many whose career orientation is toward the life sciences. A full list of the real-world applications in the text is given on pages xi–xii.

The Illustration Program

Drawings

Physics is a highly visual subject, and many physics concepts are best conveyed by graphic means. Figures do far more than illustrate a physics text—often, they bear the main burden of the exposition. Accordingly, great attention has been paid to the figures in this book so as to achieve the optimal balance of realism and stylization, with the primary emphasis always on the clarity of the analysis.

As mentioned previously, *every* Example in the text (as well as most of the Active Examples and many of the Conceptual Checkpoints) is accompanied by a figure. In addition, every Example includes a section, "Picture the Problem," that concentrates on visual representation of the physical situation described in the problem, as well as the use of that representation in devising a problem-solving strategy. Great emphasis has been placed on how to draw a free-body diagram (see pp. 110–111), and all such diagrams in Examples and end-of-chapter problems have been drawn to scale using the data given.

In addition, color has been used consistently throughout the text to reinforce concepts and make the diagrams easier for students to understand. Thus, force vectors are always red, velocity vectors always green, and so on. Similarly, wave fronts, adiabats, heat flow, work output, and many other elements have each been assigned a characteristic color. While the student has not been asked to learn the colors scheme consciously, there can be little question that such consistency is pedagogically helpful on a subliminal level.

Companion Photographs

One of the most fundamental ways in which we learn is by comparing and contrasting. This principle is exploited in the way photographs are used throughout the text. Many photos are presented in groups of two or three that contrast opposing physical principles or illustrate a single concept in a variety of contexts. Grouping carefully chosen photographs in this way helps students to see the universality of physics.

In conclusion, it is my hope that this text will engage the imagination and interest of the students who use it, and open to them a world governed by the fundamental laws and principles of physics. Those of us who devote ourselves to studying and teaching physics know that it is a subject of great beauty and power. This book strives to share some of that appreciation with others.

Supplements

For the Instructor

Instructor's Solutions Manual (Vol. I: 0-13-027065-2; Vol. II: 0-13-027066-3)
Prepared by Laurel Technical Services. Contains detailed, worked solutions to every problem in the text. Electronic versions are available on CD-ROM (WIN: 0-13-027056-3; MAC:0-13-064715-2) for instructors with Microsoft Word or Word-compatible software.

Instructor's Resource Manual (0-13-040801-8)
This instructor's manual has two parts. The first is a traditional resource manual by Kathy Whatley and Judy Beck (University of North Carolina–Asheville) with lecture outlines, notes, ideas, and resources. The second, by *Just In Time Teaching* developers Gregor Novak and Andrew Gavrin, contains an overview of the JiTT teaching method, strategies for using it in your course, and specific strategies, tips, and feedback for the JiTT material in the Study Guide and Companion Website.

Test Item File (0-13-027059-8)
Contains over 2500 multiple choice, short answer, and true/false questions, many conceptual in nature. All are referenced to the corresponding text section and ranked by level of difficulty.

Prentice Hall Custom Test (Windows: (0-13-027058-X; Mac: 0-13-027057-1)
Based on the powerful testing technology developed by Engineering Software Associates, Inc. (ESA), Prentice Hall Custom Test includes all questions from the Test Item File and allows instructors to create and tailor exams to their own needs. With the Online Testing Program, exams can also be administered on line and data can then be automatically transferred for evaluation. A comprehensive desk reference guide is included along with online assistance.

Transparency Pack (0-13-027062-8)
Includes approximately 400 full color transparencies of images from the text.

Image Viewer CD-ROM (0-13-027055-5)
This CD-ROM by Sue Willis (Northern Illinois University) contains all text illustrations, digitized segments from the Prentice Hall *Physics You Can See* videotape as well as additional lab and demonstration videos, and animations from the Prentice Hall *Interactive Journey Through Physics* CD-ROM. Instructors can preview, sequence, and playback images, as well as perform keyword searches, add lecture notes, and incorporate their own digital resources. Free to qualified adopters.

***Physics You Can See* Video** (0-205-12393-7)
Contains 11 two- to five- minute demonstrations of classical physics experiments. It includes segments such as "Coin and Feather" (acceleration due to gravity); "Monkey and Gun" (projectile motion); "Swivel Hips" (force pairs); and "Collapse a Can" (atmospheric pressure). One copy is free to qualified adopters.

For the Student

Student Study Guide with Selected Solutions (0-13-027064-4)
David Reid (Eastern Michigan University)
The print study guide provides the following for each chapter:

- Objectives
- Warm-Up Questions from the *Just in Time Teaching* method by Gregor Novak and Andrew Gavrin (Indiana University–Purdue University, Indianapolis)
- Chapter Review with two-column Examples and integrated quizzes
- Reference Tools & Resources (equation summaries, important tips, and tools)
- Practice Problems by Carl Adler (East Carolina University)
- Puzzle Questions (also from Novak & Gavrin's *JiTT* method)
- Selected Solutions for several end-of-chapter problems

An electronic, interactive, media-enhanced version of the print-based study guide, with additional modules, is available on the www at http://www.prenhall.com/Walkerphysics, and on CD-ROM (0-13-027076-8). Please see the description of our companion website below for further details.

Student Pocket Companion (0-13-027063-6)
Biman Das (SUNY Potsdam)
This easy-to-carry 5″ x 7″ paperback contains a summary of the entire text, including all key concepts and equations, as well as tips and hints. Perfect for carrying to lecture and taking notes.

Companion Website (*http://www.prenhall.com/Walkerphysics*)
The Companion Website is an electronic, media-enriched, and interactive version of the print-based Study Guide with additional modules. For each text chapter it provides the following:

- Objectives by David Reid (Eastern Michigan University)
- Warm Up Questions from the *Just in Time Teaching* method by Gregor Novak and Andrew Gavrin (Indiana University–Purdue University, Indianapolis)
- Chapter Review by David Reid, with automated integrated practice quizzes and integrated "Physlet Illustration" Java applets written by Steve Mellema and Chuck Niederriter (Gustavus Adolphus College)
- Chapter Quiz by Carl Adler (East Carolina University)
- Physlet Problems by Wolfgang Christian (Davidson College)
- Algorithmically generated Practice Problems by Carl Adler
- "What's Physics Good For?" applications, with links to related internet sites, by Gregor Novak & Andrew Gavrin
- Puzzle Questions (also from Novak & Gavrin's *JiTT* method)
- An automatically scored MCAT Study Guide by Glenn Terrell (University of Texas at Arlington)
- Selected Solutions for several end-of-chapter problems
- PDF files for *Ranking Task Exercises* by Thomas O'Kuma (Lee College), David Maloney (Indiana University–Purdue University, Fort Wayne), and Curtis Hieggelke (Joliet Junior College)
- On-line Destinations (links to related sites) by Carl Adler

All objective modules are scored by the computer; results can be automatically e-mailed to the student's professor or teaching assistant.

For students without web access, a version of the website is available on CD-ROM (0-13-027076-8). The CD contains the same modules as the website (except for the Applications and Destinations modules, which are internet dependent) and has the same interactive capabilities (except for the ability to e-mail results to the instructor).

Physics on the Internet: A Student's Guide (0-13-890153-8)
Andrew Stull and Carl Adler
The perfect tool to help students take advantage of the Walker Companion Website. This useful resource gives clear steps to access Prentice Hall's regularly updated physics resources, along with an overview of general World Wide Web navigation strategies. Available free for students when packaged with the text.

Interactive Physics Player II Workbook (Windows: (0-13-667312-0; Mac: 0-13-477670-4)
Knowledge Revolution and Cindy Schwarz (Vassar College)
This highly interactive workbook/disk package contains 40 mechanics simulation projects of varying degrees of difficulty. Can be used in conjunction with any text.

Interactive Journey Through Physics CD-ROM (Dual Platform: 0-13-254103-3)
Logal and Cindy Schwarz (Vassar College) with Bob Beichner (North Carolina State University)
This highly interactive resource covers Mechanics, Thermodynamics, Electricity & Magnetism, and Light & Optics. It contains 62 videos, 120 simulations, 39 animations, and 231 problems. Can be used in conjunction with any text.

Prentice Hall/New York Times Themes of the Times—Physics
This unique newspaper supplement brings together a collection of the latest physics-related articles from the pages of the *New York Times*. Updated twice per year and available free to students when packaged with the text.

Acknowledgments

I would like to express my gratitude to my colleagues at Washington State University, as well as others in the physics community for their contributions to this project. In addition to the reviewers and accuracy checkers listed below, I am especially grateful to Jeff Braun (University of Evansville), James Cook (Middle Tennessee State University), Biman Das (State University of New York-Potsdam), Anthony Pitucco (Pima Community College), David Raffaelle (Glendale Community College), Rex Ramsier (University of Akron), Fred Thomas (Sinclair Community College), Jack Tuszynski (University of Alberta), and Karl Vogler (Northern Kentucky University) for their help with applications and problems.

My thanks are due also to many people at Prentice Hall who encouraged and helped me through the long and sometimes arduous process of making this book a reality: Alison Reeves, who sponsored the project and nurtured it at every stage; Tim Bozik and Paul Corey, for their patient support and encouragement; Liz Kell and Christian Botting, for their work on the supplements as well as their coordination of the elaborate reviewing program; Joe Sengotta, for his countless contributions to many aspects of the book, far above and beyond the call of duty; and Dan Schiller, for his help in shaping the final product. In addition, I am grateful for the tireless work of Yvonne Gerin, our indefatigable photo researcher; Jennifer Maughan, for choreographing the production process with diligence and unfailing good cheer; J. C. Morgan, for managing a very complex and demanding art program; and Bill Fellers, for his invaluable assistance with the problem solutions. The patience, dedication, and skill of these people are much appreciated.

I owe a great debt to my students over the years. My experience with them in the classroom provided the motivation and the inspiration for this book.

Finally, I would like to thank my wife, Betsy, for her patience and support during the long years this book was in the making, as well as her expert help in checking the pages.

I would very much appreciate hearing from users of this book. I welcome comments, criticisms, and above all suggestions that might make subsequent editions of the text even more useful to teachers and students of physics.

Reviewers

We are grateful to the following instructors for their thoughtful comments on the manuscript of this text and careful checking of proofs.

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University of Houston

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Student Reviewers

We wish to thank the following students at North Carolina State University for providing helpful feedback during the development of this text. Their comments offered us valuable insight into the student experience.

Margaret Baker
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Jamie Helms
Michelle Lim
Stephanie Starnes
Monique Thomas
Timothy Nathan Witwer
Melissa Wright

Preface: To the Student

As a student preparing to take an introductory, algebra-based physics course, you are probably aware that physics applies to absolutely everything in the natural world, from raindrops and people to galaxies and atoms. Because physics is so wide-ranging and comprehensive it can sometimes seem a bit overwhelming. This text, which is based on extensive classroom experience and testing, is designed to help you deal with a large body of information and develop a working understanding of the basic concepts in physics. As you develop this understanding, you will find that you have enriched your experience of the world in which you live.

Now, I must admit that I like physics, and so I may be a bit biased in this respect. Still, the reason I teach and continue to study physics is that I enjoy the insight it gives into the physical world. I can't help but notice—and enjoy—aspects of physics all around me each and every day. I would like to share some of this enjoyment with you, and that is why I undertook the task of writing this book.

To assist you in the process of studying physics, this text incorporates a number of learning aids, including *Two-Column Examples, Active Examples*, and *Conceptual Checkpoints*. These and other elements work together in a unified way to enhance your understanding of physics on both a conceptual and a quantitative level. The pages that follow will introduce these elements to you, describe the purpose of each, and explain how they can help you.

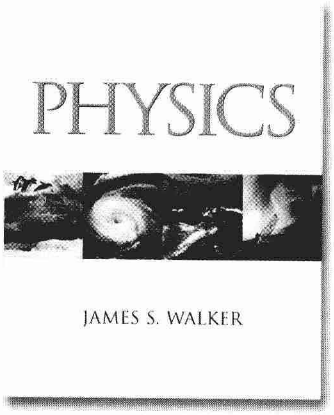
As you progress through the text, you will encounter many interesting and intriguing applications of physics drawn from the world around you. Some of these, such as magnetically levitated trains or the satellite-based Global Positioning System that enables you to determine your position anywhere on Earth to within a few feet, are primarily technological in nature. Others focus on explaining familiar or not-so-familiar phenomena, such as why the Moon has no atmosphere, how sweating cools the body, or why flying saucer-shaped clouds often hover over mountain peaks even when the sky is clear. Still others, such as countercurrent heat exchange in animals and humans or the use of sound waves to destroy kidney stones, are of particular relevance to students of biology and the other life sciences.

In many cases, you may find the applications to be a bit surprising. Did you know, for example, that you are shorter at the end of the day than when you first get up in the morning? (This is discussed in Chapter 5.) That an instrument called the ballistocardiograph can detect the presence of a person hiding in a truck, just by registering the minute recoil from the beating of the stowaway's heart? (This is discussed in Chapter 9.) That if you hum next to a spider's web at just the right pitch you can cause a resonance effect that sends the spider into a tizzy? (This is discussed in Chapter 13.) That your hearing is sensitive enough to detect sounds that displace the eardrum by as little as the diameter of an atom? (This is discussed in Chapter 14.) That powerful magnets can exploit the phenomenon of diamagnetism to levitate living creatures? (This is discussed in Chapter 22.)

Writing this textbook was a rewarding experience for me. I hope using it will prove equally rewarding to you, and that it will inspire an interest in and appreciation of physics that will last a lifetime.

James S. Walker

In-Chapter Learning Tools



The unique suite of tools in this book fosters understanding of physical principles and active involvement in the learning process. Because one-size-fits-all examples do not sufficiently address the needs of students, the text employs a variety of pedagogical elements, each used where it can contribute most to developing conceptual insight and problem-solving skills.

Worked Examples in Two-Column Format

Worked Examples show students how to apply important concepts to commonly encountered, realistic problems. The structure of the Example not only helps students to master the problem at hand but also gives them greater insight into the physical principles and concepts behind the problem.

Problem Statement

Describes the physical situation to be analyzed, what is known, and what is to be found.

Picture the Problem

Helps students sketch and visualize the processes taking place, identify and label important quantities, and set up coordinate axes.

Strategy

Here, students learn how to analyze the problem, identify the key physical principles at work, and devise a plan for obtaining the solution.

Solution

A unique, two-column format presents the logical thought processes parallel to the mathematical steps, helping students see the relationship between the physical concepts and their mathematical expression.

Insight

Often, solving a problem leads to new insights. This feature points out interesting or significant features of the problem, the solution process, or the result.

Practice Problem

Students are given an opportunity to test their skills on a problem similar to the one just worked. For immediate reinforcement, the answer is provided after the Practice Problem. Related homework problems also direct students to end-of-chapter problems that are similar to the Example.

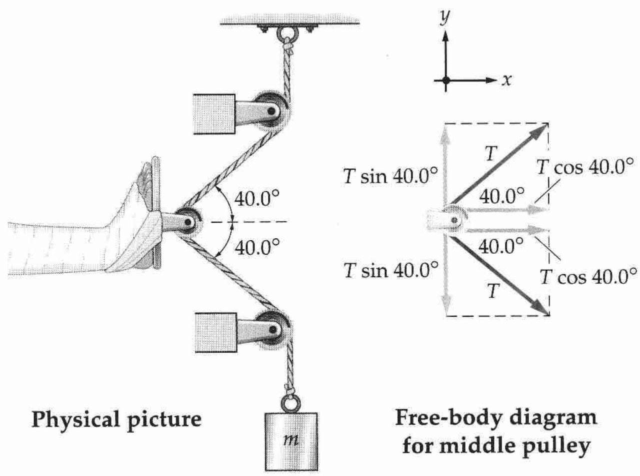
EXAMPLE 6–4 A Bad Break: Setting a Broken Leg with Traction

Real World Physics: Bio

A traction device employing three pulleys is applied to a broken leg, as shown in the sketch. The middle pulley is attached to the sole of the foot, and a mass m supplies the tension in the ropes. Find the value of the mass m if the force exerted on the sole of the foot by the middle pulley is to be 165 N.

Picture the Problem

Our sketch shows the physical picture as well as the free-body diagram for the middle pulley. Notice that the rope makes an angle of 40.0° with the horizontal on either side of the middle pulley.



Physical picture

Free-body diagram for middle pulley

Strategy

We begin by noting that the rope supports the hanging mass m. As a result, the tension in the rope, T, must be equal in magnitude to the weight of the mass; $T = mg$.

Next, the pulleys simply change the direction of the tension without changing its magnitude. Therefore, the tension in each segment of the rope is the same. The net force exerted on the sole of the foot is the sum of the tension T at 40.0° above the horizontal plus the tension T at 40.0° below the horizontal. We will calculate the net force component by component.

Once we calculate the net force acting on the foot, we set it equal to 165 N and solve for the tension T. Finally, we find the mass using the relation $T = mg$.

Solution

1. First, consider the tension that acts upward on the middle pulley. Resolve this tension into x and y components:

$$T_x = T\cos 40.0^\circ \qquad T_y = T\sin 40.0^\circ$$

2. Next, consider the tension that acts downward on the middle pulley. Resolve this tension into x and y components. Note the minus sign in the y component:

$$T_x = T\cos 40.0^\circ \qquad T_y = -T\sin 40.0^\circ$$

3. Sum the x and y components of force acting on the foot. We see that the net force acts only in the x direction, as one might expect from symmetry:

$$\sum F_x = T\cos 40.0^\circ + T\cos 40.0^\circ = 2T\cos 40.0^\circ$$
$$\sum F_y = T\sin 40.0^\circ - T\sin 40.0^\circ = 0$$

4. Step 3 shows that the net force acting on the foot is $2T\cos 40.0^\circ$. Set this force equal to 165 N and solve for T:

$$2T\cos 40.0^\circ = 165\ \text{N}$$
$$T = \frac{165\ \text{N}}{2\cos 40.0^\circ} = 108\ \text{N}$$

5. Solve for the mass, m, using $T = mg$:

$$T = mg$$
$$m = \frac{T}{g} = \frac{108\ \text{N}}{9.81\ \text{m/s}^2} = 11.0\,\text{kg}$$

Insight

Notice that this pulley arrangement "magnifies the force" in the sense that a 108 N weight attached to the rope produces a 165 N force exerted on the foot. In addition, the net force on the foot produces an opposing force in the leg that acts in the direction of the head (a cephalad force), as desired to set a broken leg.

Practice Problem

(a) Would the required mass m increase or decrease if the angles in this device were changed from 40.0° to 30.0°? **(b)** Find the mass m for an angle of 30.0°. [**Answer: (a)** The required mass m will decrease. **(b)** 9.71 kg]

Some related homework problems: Problem 16, Problem 19, Problem 29

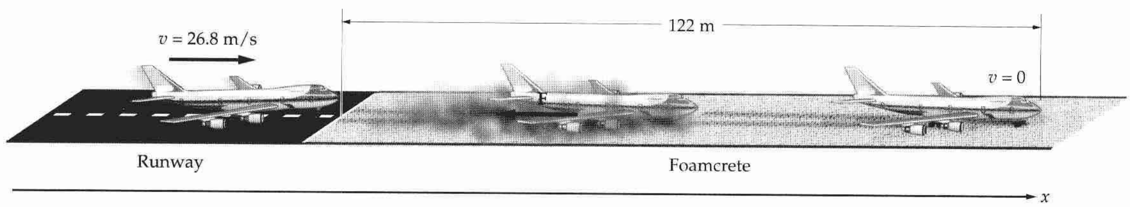
In-Chapter Learning Tools

Active Examples

Active Examples break down a problem into a series of manageable, logical steps, but require the student to play an active role in the solution. These examples act as a bridge between the worked Examples in the chapter, in which the solution process is fully spelled out, and the end-of-chapter problems, where students receive no guidance at all.

ACTIVE EXAMPLE 5–1 **Foamcrete**

Foamcrete is a substance designed to stop an airplane that has run off the end of a runway, without causing injury to passengers. It is solid enough to support a car, but crumbles under the weight of a large airplane. By crumbling, it slows the plane to a safe stop. For example, suppose a 747 jetliner with a mass of 1.75×10^5 kg and an initial speed of 26.8 m/s is slowed to a stop in 122 m. What is the magnitude of the retarding force **F** exerted by the Foamcrete on the plane?



Solution

1. Use $v^2 = v_0^2 + 2a_x\Delta x$ to find the plane's acceleration: $a_x = -2.94\ \mathrm{m/s^2}$
2. Sum the forces in the x direction. Let F represent the magnitude of the force **F**: $\Sigma F_x = -F$
3. Set the sum of forces equal to mass times acceleration: $-F = ma_x$
4. Solve for the magnitude of the force, F: $F = -ma_x = 5.15 \times 10^5\ \mathrm{N}$

Conceptual Checkpoints

Conceptual Checkpoints test students' ability to make inferences based on chapter concepts. These qualitative questions are presented in multiple-choice format to guide student response. "Reasoning and Discussion" clearly explains the physical principles behind the answer, while recognizing and addressing students' possible misconceptions.

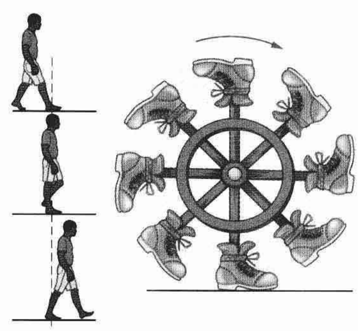
CONCEPTUAL CHECKPOINT 6–1

A car drives with its tires rolling freely. Is the friction between the tires and the road **(a)** kinetic or **(b)** static?

Reasoning and Discussion

A reasonable-sounding answer is that because the car is moving, the friction between its tires and the road must be kinetic friction—but this is not the case.

Actually, the friction is static because the bottom of the tire is in static contact with the road. To understand this, watch your feet as you walk. Even though you are moving, each foot is in static contact with the ground once you step down on it. Your foot doesn't move again until you lift it up and move it forward for the next step. A tire can be thought of as a succession of feet arranged in a circle, each of which is momentarily in static contact with the ground.



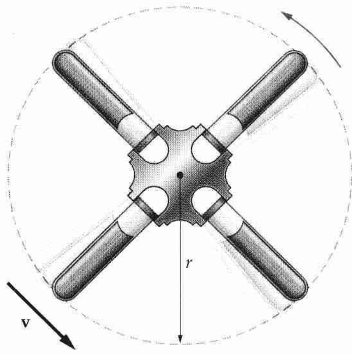
Answer:

(b) The friction between the tires and the road is static friction.

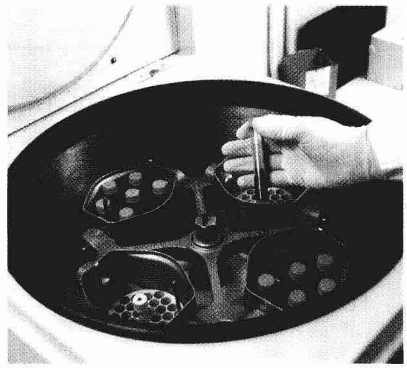
REAL WORLD PHYSICS: BIO

Centrifuges and ultracentrifuges

Finally, we determine the acceleration produced in a **centrifuge**, a common device in biological and medical laboratories that uses large centripetal accelerations to perform such tasks as separating red and white blood cells from serum. A simplified top view of a centrifuge is shown in **Figure 6–14**.



▲ **FIGURE 6–14 Simplified top view of a centrifuge in operation**



▲ A laboratory centrifuge of the kind commonly used to separate blood components.

EXERCISE 6–2

The centrifuge in Figure 6–14 rotates at a rate that gives the bottom of the test tube a linear speed of 89.3 m/s. If the bottom of the test tube is 8.50 cm from the axis of rotation, what is the centripetal acceleration experienced there?

Solution

Applying the relation $a_{cp} = v^2/r$ yields

$$a_{cp} = \frac{v^2}{r} = \frac{(89.3\ \mathrm{m/s})^2}{0.0850\ \mathrm{m}} = 93{,}800\ \mathrm{m/s^2} = 9560\,g$$

In this expression, g is the acceleration of gravity, 9.81 $\mathrm{m/s^2}$.

Exercises

When a more elaborate device is not needed, simple Exercises give students practice in using a new formula or relationships introduced in the text.