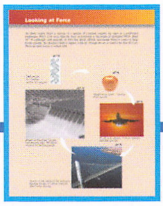
# Special Features of Physics Matters

In an effort to aid student learning and make the world of physics both accessible and exciting, several distinctive features appear frequently throughout the book. These features have two basic goals:

1. to emphasize the interconnectedness of the great ideas of physics and so help students connect key concepts into a coherent whole, and
2. to inspire students to explore the principles behind the many practical applications that fuel our world and our society.



## Special Visual Features



## Develop Your Intuition

### Selected Examples

## Connections

### Selected Examples



## Thinking More About . . .

### Selected Examples

# Physics Matters

# Physics Matters

## An Introduction to Conceptual Physics

**James Trefil**

**Robert M. Hazen**

**George Mason University**

WILEY

JOHN WILEY & SONS, INC.

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|---|---|
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| COVER PHOTO: | © Lawrence Englesberg/Image State |

This book was set in 10/12 Times Ten Roman by Matrix Publishing and printed and bound by PrintPlus. The cover was printed by PrintPlus.





Library of Congress Cataloging-in-Publication Data

Trefil, James S., 1938–
Physics matters : an introduction to conceptual physics / James Trefil, Robert M. Hazen.
p. cm.
Includes index.
ISBN 978-0-471-15058-9
1. Physics. I. Hazen, Robert M., 1948– II. Title.

QC23.2.T74 2004
530—dc22

2003065703

ISBN 978-0-471-15058-9

10 9 8 7 6

*Dedicated to our children*

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# Contents in Brief

# Contents

# Preface

## TO THE INSTRUCTOR

We all know how important all of the sciences, particularly physics, have become to modern society. All too often, however, physics is taught as if it were an isolated field of study, with no connections to other sciences, to history, or to society at large. What we have tried to do in this book is to present the traditional principles of physics in the rigor appropriate to a liberal arts course, while at the same time emphasizing how those principles are connected to the rest of human experience. We feel strongly that when students see physics as part of life, as something relevant to what they see in the news of the day, the learning process will become more meaningful.

### Organization of the Book

*Physics Matters* follows the traditional historical approach to the presentation of physics, beginning with mechanics, thermodynamics, and electromagnetism, and progressing from them to the physics of the twentieth and twenty-first centuries. This division reflects both the history of the science and a difference in focus and subject matter. Although we do not make an explicit distinction, the division between classical and modern physics is pretty clear in the text.

***Making the Connection*** It has been our experience that each of these areas—classical and modern physics—offers opportunities and difficulty as far as teaching is concerned. Classical physics is close to everyday experience, close to things our students see every day. We have stressed this aspect of the science in many ways, hoping to draw students into the subject. On the other hand, if presented unimaginatively, classical physics can also be a little dull. To see the connection between a block sliding down an inclined plane and the latest mission of space exploration, or to understand how simple experiments of rubbing glass jars to produce electric charge led to generators and power lines are the sorts of goals appropriate to classical physics.

To stress this point, we open each chapter with a section titled **Physics Around Us . . .**, which recounts common experiences and relates them to the principles of physics that will be studied in that chapter. It is our hope that these opening sections will serve to convince students that there is something worthwhile to be gained from studying the chapter.

Modern physics, particularly relativity and quantum mechanics, has an innate ability to fire the imagination, to engage the intellect. On the other hand, it is also farther from everyday experience than its classical counterpart. In this section of the book, we emphasize continually the connection of seemingly obscure laws to everyday life. A student who looks at a computer screen needs to know that she is dealing with the results of quantum mechanics, a student getting an MRI that he is benefiting from studies of the atomic nucleus. As with classical physics, *connectedness is the key.*

In some cases, we have looked at this connection explicitly. In the chapter dealing with cosmology, for example, we have gone into some detail about how the laws of physics apply to the large-scale structure and history of the universe. In other cases, we have pointed out the interconnectedness of physics with other sciences in each chapter in sections titled **Connections.** These special sections flow integrally from the text and are not presented as isolated boxes. In this way, students will not get the message that applications of physics to other sciences is somehow superfluous or added on. Instead, they will view them as central components of the idea we are trying to get across: Physics is at the basis of a logical, interconnected web of ideas and concepts that helps us understand the world around us.

***The Issues of the Day*** It is hard to imagine being a citizen in the twenty-first century without having some understanding of science, at least as it applies to the political issues of the day. Because we believe that the connection between science and important issues of the day should be stressed in any university course, at the end of every chapter in this book you will find a section titled **Thinking More About. . . .** In this section, we talk about how the topics covered in that chapter affect some important political or social issue, and invite the student to apply what he or she has just learned to an area outside of science. Science and technology do not exist by themselves in some isolated world. The student needs to learn to think critically about them, to make judgments about the myriad of science-related issues that will cross his or her horizon every day. This need was constantly in our minds as we wrote this book, and the section at the end of each chapter is only one manifestation of that concern.

***A Spirit of Investigation and Discovery*** In each chapter you will also find integrated sections titled **Physics in the Making,** which tell the fascinating story of our unfolding understanding and illustrate how the scientific method has been applied to bring us to where we are today. Often, these stories contain a good deal of human interest as well as scientific principles, and we make use of the stories to portray physics (and science) as a human endeavor, one that requires as much creativity and imagination as writing a novel or a symphony.

The process of learning about physics, like the process of learning about almost anything, is not passive. It is necessary to get into the subject, to think about what you are reading and learning. To help the student with this process, you will find short sections labeled **Develop Your Intuition** embedded throughout the text. When students get to one of these, encourage them to pause for a moment and try to think about how to answer the question being posed, given what they have just learned. When they have done this, they compare their answer to the one given in the text immediately following the question. In this way, students are encouraged to see for themselves how even the most complex of phenomena can be understood in terms of processes that are at bottom simple and understandable.

The same philosophy can be seen in our use of numerical problems at the end of the chapters. In many chapters you will find worked examples, fully explained, at the beginning of the Problem section. Again, the purpose of these **Problem-solving Examples** is to illustrate that the kind of reasoning used in mathematics can be expressed in simple language. Once this point is made, of course, the student is then given ample opportunity to apply that sort of reasoning in different situations.

**Physics in the Making** These integrated essays illustrate the scientific method by describing the way in which specific new understanding was gained, with particular emphasis on pivotal experimental and observational advances. Students have commented that inclusion of such background information helps them retain information. Examples include the development of conservation laws, Galileo's experiments with inertia, and the advance of the Copernican model of the solar system.

> **Physics in the Making**
>
> **Measuring Time Without a Watch**
>
> In our age of stop watches, digital timers, and atomic clocks, with Olympic races routinely measured to a hundredth or even a thousandth of a second, it's hard to imagine measuring time without an accurate instrument. But when Galileo set out to study accelerated motion in the 1600s, measuring time was a formidable technological challenge. Think about how you might determine small time intervals if all you had was a clock that ticked off seconds but could record no shorter times.
>
> Galileo wanted to document as accurately as possible the way falling objects accelerate, but these measurements required knowledge of both distance and time. Since objects that fall straight down moved much too fast for him to mea-

**Ongoing Process of Science** Science is a never-ending process of asking questions and seeking answers. In these features, integrated with the text as are the other recurring features, we examine some of the most exciting questions currently being addressed by physicists.

> **Ongoing Process of Science**
>
> **The Value of *G***
>
> It might surprise you to learn that the measurement of $G$ is still of great interest to scientists around the world. It turns out that most fundamental physical constants, such as the mass of an electron or the electrical force between two charged particles, are known with great precision and accuracy, to many decimal places. But $G$ is still only known, at best, to the fourth decimal place.
>
> In November 1998 a group of 45 physicists met in London to celebrate the 200th anniversary of Cavendish's original experiment and to compare notes on several new determinations of the constant. All of these workers performed meticulous experiments: they enclosed their apparatus in a vacuum, they eliminated all stray magnetic and electrical fields, they checked and rechecked every aspect of their work.

**Equations and Worked Examples** Perhaps the most difficult aspect of physics for the new student is the use of mathematics. In this book, we try to demystify the presence of mathematics in the sciences, while at the same time retaining the basic laws of physics in their familiar mathematical forms.

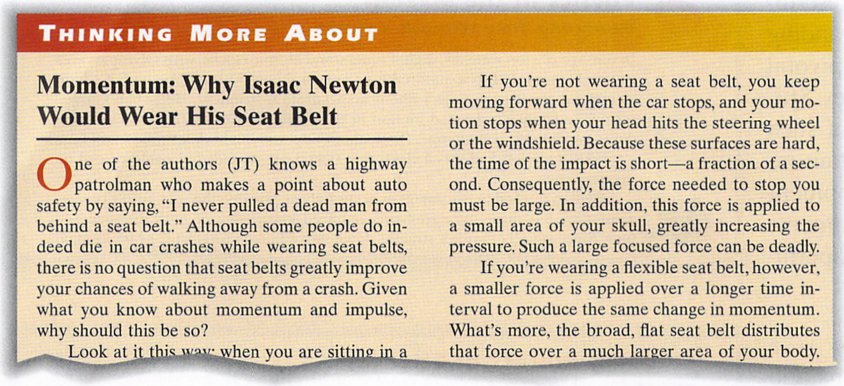
The most important concept to grasp, as we emphasize in Chapter 2, is the fact that an equation is simply a translation into the language of mathematics of an idea that can also be expressed in an ordinary English sentence. To get this idea across, each equation in the text is given in three separate forms. It is first stated as a simple sentence which contains the main idea of the relationship, then as an equation in which words are substituted for symbols, and only then in its full mathematical form. We do this to emphasize the fact that, as mysterious as mathematics may be to some students, the ideas contained in the equations are really simple.

> **Acceleration**
>
> Acceleration measures the rate of change of velocity.
>
> **1.** In words:
>
> **Acceleration** *is the change in velocity divided by the time it takes for that change to occur.*
>
> **2.** In an equation with words:
>
> $$\text{Acceleration} = \frac{\text{Final velocity} - \text{Initial velocity}}{\text{Time}}$$
>
> **3.** In an equation with symbols:
>
> $$a = \frac{\Delta v}{t}$$
>
> where $\Delta v$ indicates the change in velocity. Like velocity, acceleration requires information about the direction and is therefore a vector.

**Key Terms** Key terms appear in **bold** type within each chapter. They are highlighted in the chapter **Summary** and are also listed at the end of the chapter, along with their definitions and the number of the page on which they are first explained. Many other terms are important, although more specialized; we have highlighted these terms in italics within each chapter. Both sets of terms are defined in the **Glossary** at the end of the text.

**Looking Deeper** These sections are intended to be assigned by professors who prefer a somewhat higher-level discussion of certain topics, such as collisions in two dimensions, diet and calories, and efficiency. They are set off in screened blue boxes for easy identification and flexibility in assignment.

**Thinking More About** Each chapter ends with a section that addresses a social or philosophical issue tied to physics, such as our place in the ordered universe, what constitutes proof that something is real, and the effects of electric and magnetic fields on wildlife.



THINKING MORE ABOUT

**Momentum: Why Isaac Newton Would Wear His Seat Belt**

One of the authors (JT) knows a highway patrolman who makes a point about auto safety by saying, "I never pulled a dead man from behind a seat belt." Although some people do indeed die in car crashes while wearing seat belts, there is no question that seat belts greatly improve your chances of walking away from a crash. Given what you know about momentum and impulse, why should this be so?

Look at it this way: when you are sitting in a

If you're not wearing a seat belt, you keep moving forward when the car stops, and your motion stops when your head hits the steering wheel or the windshield. Because these surfaces are hard, the time of the impact is short—a fraction of a second. Consequently, the force needed to stop you must be large. In addition, this force is applied to a small area of your skull, greatly increasing the pressure. Such a large focused force can be deadly.

If you're wearing a flexible seat belt, however, a smaller force is applied over a longer time interval to produce the same change in momentum. What's more, the broad, flat seat belt distributes that force over a much larger area of your body.

**Questions** We feature four levels of end-of-chapter questions, giving instructors the flexibility to choose the types of questions appropriate for their classes.

- **Review** questions test important factual information covered in the text and are provided to emphasize key points.
- **Questions** are also based on chapter material but involve more exploration and analysis of physics concepts. Some questions include diagrams to help students visualize geometric relationships, whereas other questions build on the same or similar situations to test students' understanding in greater depth.
- **Problems** are quantitative questions that require students to use mathematical operations, typically those introduced in worked examples. **Problem-solving Examples,** placed directly before the start of the Problem set in some chapters, help prepare students to work the Problems.
- **Investigations** require additional research outside the classroom.

**WWW Resources** At the end of each chapter, you will find a list of relevant websites. In addition, the www icon appears in the margin throughout the book to highlight links that amplify the text. These links have been well researched and provide additional content on many fascinating topics. You can also visit the *Physics Matters* home page at **www.wiley.com/college/trefil** to explore materials developed to support and enhance the study of physics.

## SUPPLEMENTS

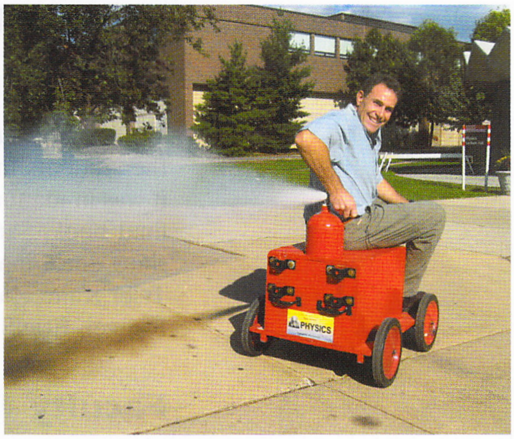
The *Lab Manual* by Robert Ehrlich and Anna Wyczalkowski of George Mason University contains enjoyable and interesting experiments that will reinforce the concepts learned during lecture. There are minimal equipment requirements for the labs so they can be implemented with ease at both small and large departments.

The *Activity Book* by Michael Tammaro of the University of Rhode Island is an excellent resource for self-study and homework assignments. Activities build skills in making hypotheses, taking measurements, and plotting data. Follow-up questions emphasize conceptual understanding.

The *Instructor's Resource and Solution Manual* by Michael Tammaro of the University of Rhode Island is an essential item that contains the solutions and answers to every end-of-chapter problem and discussion question. It also contains lecture outlines, lecture tips, additional discussion questions (with answers), and demonstration ideas. Both new and experienced instructors are sure to find this manual useful.

The *Test Bank* contains over 1500 test items. Instructors will find this a time-saver in exam preparation. Many of the questions have been specifically written to promote conceptual understanding rather than rote memorization.

The *Instructor Resource CD-ROM* includes an *Image Bank* with all of the line art from the text as well as a *Computerized Test Bank*. Use the image bank to enhance classroom presentations, create custom handouts, and add images to course websites. The computerized test bank by Brownstone allows instructors a wide range of functionality in an easy-to-use format.



Demonstrating rocket motion with a fire extinguisher cart.

The *Wiley Physics Demonstration Videos* by David Maiullo of Rutgers University consist of over 100 classic physics demonstrations that will engage and instruct your students. Filmed, edited, and produced by a professional film crew, the demonstrations include

- 55-Gallon Drum: Illustrates atmospheric pressure through the dramatic collapsing of a large metal drum.
- Bed of Nails: Shows how having more nails on a bed of nails actually makes it safer.
- Breaking Glass with Sound: Demonstrates how sound resonance can be used to break a glass.
- Penny and Feather: Illustrates that objects will fall at the same rate in the absence of atmosphere.
- Standing Waves on a String: Shows how vibrating a large rope with the right frequencies can produce standing waves on the rope.
- Light the Match (uses mirrors and a heat source): Shows that the infrared spectra may act in the same way as the visible light spectra.
- Magnet over Superconductor (Meissner Effect): Illustrates the strange properties of superconductors by floating a magnet over one.
- Polaroids with a Light Source: Shows how light can be polarized and filtered through the use of two Polaroids.

Each demonstration is labeled according to the Physics Instructional Resource Association's demonstration classification system. This system identifies the area, topic, and concept presented in each demonstration. Go to www.pira.nu for more information about the Physics Instructional Resources Association and to download a spreadsheet of the demonstration classification system.

The *Physics Matters* website offers a wealth of material for both students and instructors. You can view demonstration videos, get suggestions for group projects and quantitative skill building exercises, or take practice quizzes. To access the *Physics Matters* website go to **www.wiley.com/college/trefil.** Select *Physics Matters* from the list of titles and enter either the instructor or student website.

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# ACKNOWLEDGMENTS


## Student Involvement

We are grateful to Professor Michael Tammaro, University of Rhode Island, and the students in his Ideas of Physics class, who used some of this material while it was in manuscript form and gave us invaluable feedback that helped shape the final book: Sarah Allard, Brett Vincent Beaubien, Erin Bonsall, Carlton Bradshaw, Joe Cinaglia, Nicholas DePetrillo, Elizabeth Feuer, Abby Heredia, Letitia Tyler Kane, Zachary Karp, Katie Lidestri, Holly Osberg, Adi Pekmezovic, Steven Rangel, Eric Simpson, Andrew Stover, and Trevor Utley.

## Faculty Input

We are also grateful to Kurt Gareiss, who contributed many of the end-of-chapter questions. Besides class-testing the manuscript, Professor Michael Tammaro, University of Rhode Island, provided invaluable editorial suggestions, offered many creative end-of-chapter questions, and prepared the Activity Book and the comprehensive Instructor's Resource and Solutions Manual. We are also grateful to Prof. Dan MacIsaac, SUNY–Buffalo State College, for identifying many of the WWW Resources entries listed at the end of each chapter.

We gratefully acknowledge the significant contributions of many reviewers who commented in detail on the various drafts of this text. Their insights and teaching experience have been invaluable to us:

Elizabeth C. Behrman, *Wichita State University*
Edward R. Borchardt, *Minnesota State University, Mankato*
Arthur J. Braundmeier, *Southern Illinois University, Edwardsville*
William D. Bruton, Stephen F. *Austin State University*
Tom Carter, *College of DuPage*
Marco Ciocca, *Eastern Kentucky University*
Doug Davis, *Eastern Illinois University*
Doyle V. Davis, *New Hampshire Community Technical College*
John Farrell, *Winona State University*
Lyle Ford, *University of Wisconsin, Eau Claire*
Kyle Forinash, *Indiana University Southeast*
Mike Franklin, *Northwestern Michigan College*
Nevin D. Gibson, *Denison University*
Yuan K. Ha, *Temple University*
Robert B. Hallock, *University of Massachusetts, Amherst*
Joseph H. Hamilton, *Vanderbilt University*
Adam Johnston, *Weber State University*
Hsu-Feng Lai, *Santa Monica College*
David Lamp, *Texas Tech University*
Teresa L. Larkin, *American University*
Mary Lu Larsen, *Towson University*
Andrew J. Leonardi, *University of South Carolina, Spartanburg*
Ilan Levine, *Indiana University, South Bend*
Steve Lindaas, *Minnesota State University, Moorhead*
Michael C. LoPresto, *Henry Ford Community College*
John A. McClelland, *University of Richmond*

Allen Miller, *Syracuse University*
Peter Morse, *Santa Monica College*
Russell Palma, *Sam Houston State University*
Russ Poch, *Howard Community College*
Brian Raue, *Florida International University*
Russell A. Roy, *Santa Fe Community College*
Toni D. Sauncy, *Angelo State University*
Donald Schnitzler, *Linfield College*
Michael I. Sobel, *Brooklyn College*
Chris Sorensen, *Kansas State University*
Jimmy H. Stanton, *Cameron University*
Francis M. Tam, *Frostburg State University*
Michael J. Tammaro, *University of Rhode Island*
Frederick J. Thomas, *Sinclair Community College*
Lawrence B. Weinstein, *Old Dominion University*
Jeff Williams, *Bridgewater State College*

Iris Knell at George Mason University assisted in manuscript preparation and offered valuable suggestions for editorial improvements, while providing an atmosphere of cheerful efficiency.

## Publisher Support

We are deeply indebted to the dedicated staff of John Wiley & Sons, who first proposed this textbook and who have contributed substantially during every aspect of its development and production. *Physics Matters* would not have been possible without their extraordinary efforts. Stuart Johnson oversaw the project from its inception with vision and a commitment to excellence. Development editor Nancy Perry managed the complex coordination of text, images, special features, reviews, and more with unflagging enthusiasm and consummate professionalism. Supplements Editor Geraldine Osnato oversaw with creativity and dedication the development of the print and electronic supplements and worked with Senior New Media Editor Martin Batey to develop the *Physics Matters* website and demonstration videos. We also thank Marketing Manager Bob Smith for his continuing efforts to ensure that this book reaches a wide audience.

David Chelton played a central role in creative aspects of writing, editing, revising and illustrating the book. His major contributions are reflected on every page and are most gratefully acknowledged.

We also thank Wiley's exceptional production team. The project was skillfully managed by Production Editor Barbara Russiello, who dealt with the countless technical details associated with an introductory physics book. Many thanks to Gloria Hamilton for her careful proofreading and requests for the clearest language. We are also grateful to Illustration Editor Anna Melhorn and to Matrix Art Services, Photo Editors Hilary Newman and Sara Wight for their tireless efforts in securing the many distinctive images that amplify our text, as well as to Senior Designer Harry Nolan and design studio Circa 86 who created the book's distinctive and handsome layout.

# TO THE STUDENT

Science shapes our lives, touches things we do every day, gives us the necessities and conveniences that make our lives what they are. It is also a force that drives change in our world, that makes your life different from your parents' lives, and that will make your children's lives different from yours.

But there is another reason to study science. When you enjoy a sunset or watch the wind blow ripples across a lake, your appreciation and understanding of the experience can be deepened and enriched by understanding something about the processes that produce what you are seeing. At a deeper level, knowing something about how the universe works brings with it a sense of philosophical satisfaction, a sense of grounding, that is hard to obtain any other way.

## Why Study Physics?

Physics is the most basic of the sciences. Open any textbook on modern science—chemistry, astronomy, and even biology—and you will find the concepts you'll encounter in the pages that follow. The sorts of things that you'll study in this course, such as energy, atoms, and electricity, form the solid core on which scientists have built our modern picture of the world.

And what a picture it is! We live in a world that is both complex and simple, easy and difficult to understand. Historically, the science of physics has been concerned with finding simplicity in nature, even when that simplicity is hidden under seeming complexity.

This historic quest is intimately tied up with the development of a new way for human beings to learn about nature. We call this technique the *scientific method,* and it is so important that it is dealt with in the first chapter of this book. It represents nothing less than a new way of understanding and controlling the world around us. All of the benefits of science and technology we mentioned above have flowed from our ability to apply this method to different areas of experience, from the motion of electric charges to the strange behavior of atoms. Each new advance, each increase in our understanding, has come as the result of someone applying the scientific method in a real world situation.

It would be wrong, though, to think that the great discoveries of physics affect only the esoteric world of the professional scientist. In fact, the principles of physics are all around you, affecting everything you do every day of your life. It would also be wrong to think that what you will be studying in this book applies only in a narrow way to the science of physics. In fact, the principles you will be learning are used by all scientists, no matter what their field of expertise. For science in general, and physics in particular, has never been only a collection of unconnected facts. Science—and physics—are instead, a logical, interconnected web of ideas and concepts.

Finally, it is important to realize that the scientific process never really ends—that we never know everything. All the answers are not in, all knowledge is not to be found in books like this one. In fact, the same process that began with ancient astronomers tracking the paths of the planets through the heavens goes on today, with physicists probing ever deeper into the fundamental structure of matter, astronomers studying ever more distant galaxies, and biologists uncovering more and more of the complexity of the things we call "living systems."

All of this magnificent saga, from Greek philosophers thinking about the nature of the universe two thousand years ago to the scientists taking data from complex modern instruments as you read this, is the story of physics. When you have finished this course, you will know something about how we got to where we are and will have a picture of where we may be going in the future.

*J. T. & R. M. H.*

All of these special features, described more fully below, are designed with one goal in mind—to show our students how physics is an integral part of their lives and of their futures.

## Special Features of *Physics Matters*

In an effort to aid student learning and make the world of physics both accessible and exciting, we have incorporated several distinctive features throughout the book. These features have two basic goals:

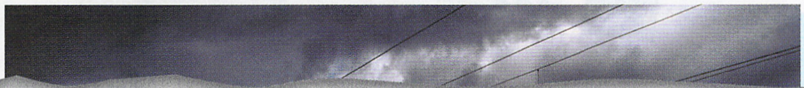
1. to emphasize the interconnectedness of the great ideas of physics and so help students connect key concepts into a coherent whole, and
2. to inspire students to explore the principles behind the many practical applications that fuel our world and our society.

**Key Ideas** Each chapter begins with a statement of a key idea in physics, so that students immediately grasp the chief concept of that chapter. These statements are not intended to be recited or memorized, but rather to provide a framework for placing the concepts students encounter in the chapter.

# 4 Isaac Newton and the Laws of Motion

**KEY IDEA**

Newton's laws of motion describe the behavior of objects on Earth and in space.



**Physics Around Us . . .** Each chapter begins with a Physics Around Us section, in which we tie the chapter's main theme to a common experience, such as riding in a train, riding a roller coaster, relaxing at the beach, going to the doctor, or using the Internet. In this way we emphasize that the great principles of physics are constantly part of our lives.

### PHYSICS AROUND US . . . Dealing with Momentum

You get in your car, put your books on the seat next to you, and drive away. A squirrel runs across the road and you jam on your brakes to avoid hitting it. As you do so, the pile of books slides onto the floor of the car.

Later that day, in the cafeteria, you watch a fellow student hurrying across the floor with her tray. Stopping suddenly, she reaches out to grab her soft-drink cup to keep it from falling over and some of the drink sloshes over on her hand.

That night, you turn on your TV to watch a hockey game. The puck comes free and two players skate for it at top speed. They collide just as they reach the puck and bounce off each other, taking themselves out of the action and leaving the puck for another player to pick up.

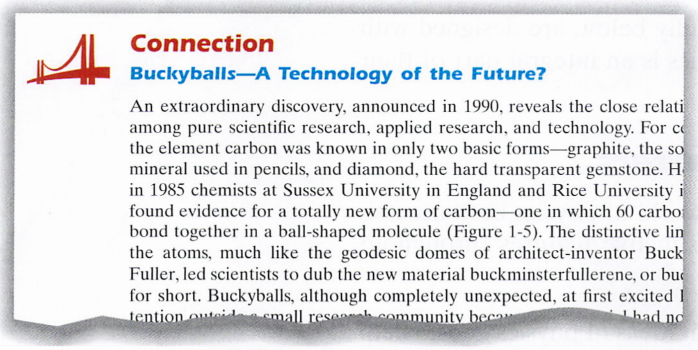
All of these occurrences (and countless more) illustrate a quantity called momentum, whose properties follow from Newton's laws of motion. And believe it or not, in addition to being involved in everyday events, momentum also governs such large-scale processes as the formation of planets and stars. As a result, momentum is one of the most important physical attributes of an object in motion.

**Develop Your Intuition** Students testing *Physics Matters* before publication commented on the helpfulness of having immediate applications of the concepts presented, pointing in particular to the Develop Your Intuition sections. In these sections, which appear throughout the book, we ask students to pause and think about the implications of what they have learned. We do this by asking them to consider questions related to their daily life, such as, "Why when you're in an elevator do you usually feel heavier when the elevator starts going up and lighter when it starts down?" or "Why is it that when you look at your face in the bathroom mirror, the image is reversed?"

### Develop Your Intuition: Flashbulbs and Baseball

You'll often see hundreds of flashbulbs go off at a stadium when a famous baseball player comes up to bat during a night game. Based on what you know about the inverse square relationship, do these flashes help the would-be photographers?

The intensity of light drops off as the inverse square of the distance, so flashbulbs are ineffective at distances greater than a few dozen feet. All the popping flashbulbs make a great sight, but they don't help photographs taken over the great distances of a stadium.


Connection
Buckyballs—A Technology of the Future?

An extraordinary discovery, announced in 1990, reveals the close relati among pure scientific research, applied research, and technology. For c the element carbon was known in only two basic forms—graphite, the so mineral used in pencils, and diamond, the hard transparent gemstone. H in 1985 chemists at Sussex University in England and Rice University i found evidence for a totally new form of carbon—one in which 60 carbo bond together in a ball-shaped molecule (Figure 1-5). The distinctive lin the atoms, much like the geodesic domes of architect-inventor Buck Fuller, led scientists to dub the new material buckminsterfullerene, or bu for short. Buckyballs, although completely unexpected, at first excited l

**Connection** Special sections highlight applications of physics concepts to other areas of science, including biology, earth science, astronomy, materials science, and critical modern technologies. These recurring discussions flow naturally from the text and are identified by a specific icon of a bridge. Topics include the clotting of blood, applications of ultrasound, television and computer screens, and inertial navigation systems.


**Special visual features** One of our goals has been to support the verbal exposition with visually exciting and pedagogically meaningful illustrations. We know that many students can be drawn into the text if inspired by compelling figures and photographs. Student reviewers have praised the way the numerous illustrations and photos supported their understanding of the text. Three kinds of illustrations in particular help students grasp physics concepts and serve as handy reviews of basic concepts:

- **Looking at . . .** figures familiarize students with the range of magnitudes common for various physical quantities, such as length, energy, temperature, and voltage.
- **Physics and Modern Technology** figures illustrate the many systems and devices generated by application of individual physics concepts, such as the atomic structure of a diamond or the orbits of satellites.
- **Physics and Daily Life** figures show how physical concepts and relations appear in the context of everyday, familiar activities, from playing volleyball to holding a coffee cup to using the telephone.