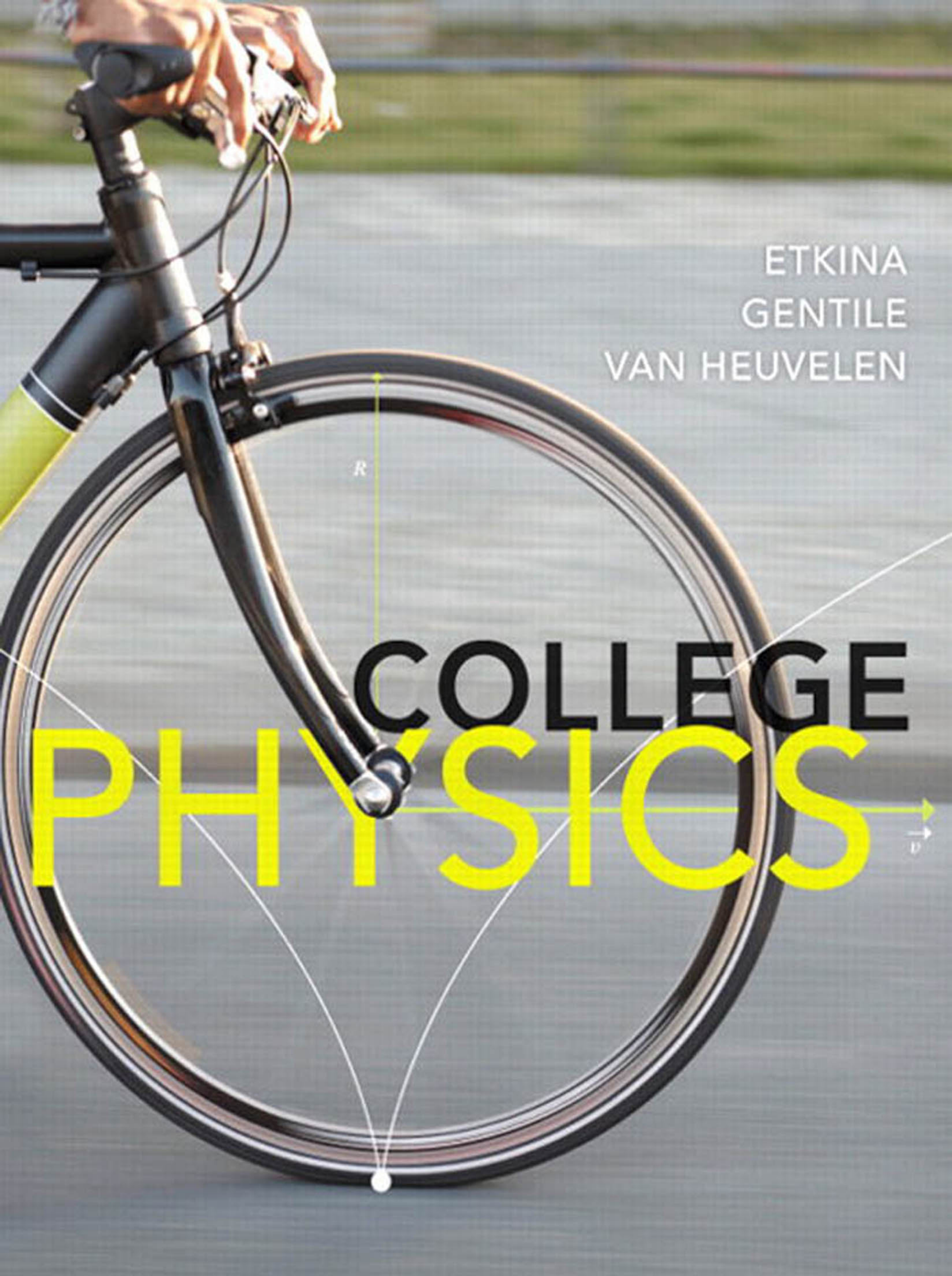
ETKINA
GENTILE
VAN HEUVELEN

COLLEGE PHYSICS



COLLEGE PHYSICS

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Brief Contents

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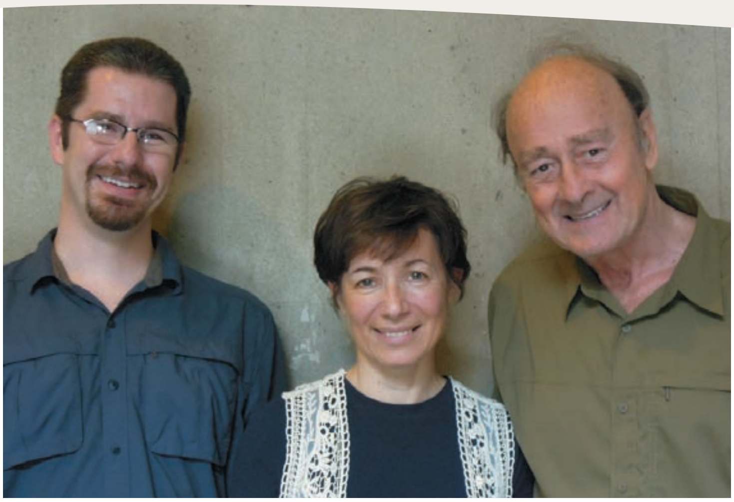
About the Authors



Eugenia Etkina holds a PhD in physics education from Moscow State Pedagogical University and has more than 30 years experience teaching physics. She currently teaches at Rutgers University, where she received the highest teaching award in 2010 and the New Jersey Distinguished Faculty award in 2012. Professor Etkina designed and now coordinates one of the largest programs in physics teacher preparation in the United States, conducts professional development for high school and university physics instructors, and participates in reforms to the undergraduate physics courses. In 1993 she developed a system in which students learn physics using processes that mirror scientific practice. That system serves as the basis for this textbook. Since 2000, Professors Etkina and Van Heuvelen have conducted over 60 workshops for physics instructors and co-authored *The Physics Active Learning Guide* (a companion edition to *College Physics* is now available). Professor Etkina is a dedicated teacher and an active researcher who has published over 40 peer-refereed articles.

Michael Gentile is an Instructor of Physics at Rutgers University. He has a masters degree in physics from Rutgers University, where he studied under Eugenia Etkina and Alan Van Heuvelen, and has also completed postgraduate work in education, high energy physics, and cosmology. He has been inspiring undergraduates to learn and enjoy physics for more than 15 years. Since 2006 Professor Gentile has taught and coordinated a large-enrollment introductory physics course at Rutgers where the approach used in this book is fully implemented. He also assists in the mentoring of future physics teachers by using his course as a nurturing environment for their first teaching experiences. Since 2007 his physics course for the New Jersey Governor's School of Engineering and Technology has been highly popular and has brought the wonders of modern physics to more than 100 gifted high school students each summer.

Alan Van Heuvelen holds a PhD in physics from the University of Colorado. He has been a pioneer in physics education research for several decades. He taught physics for 28 years at New Mexico State University where he developed active learning materials including the *Active Learning Problem Sheets (*the *ALPS Kits)* and the *ActivPhysics* multimedia product. Materials such as these have improved student achievement on standardized qualitative and problem-solving tests. In 1993 he joined Ohio State University to help develop a physics education research group. He moved to Rutgers University in 2000 and retired in 2008. For his contributions to national physics education reform, he won the 1999 AAPT Millikan Medal and was selected a fellow of the American Physical Society. Over the span of his career he has led over 100 workshops on physics education reform. In the last ten years, he has worked with Professor Etkina in the development of the Investigative Science Learning Environment (*ISLE*), which integrates the results of physics education research into a learning system that places considerable emphasis on helping students develop science process abilities while learning physics.

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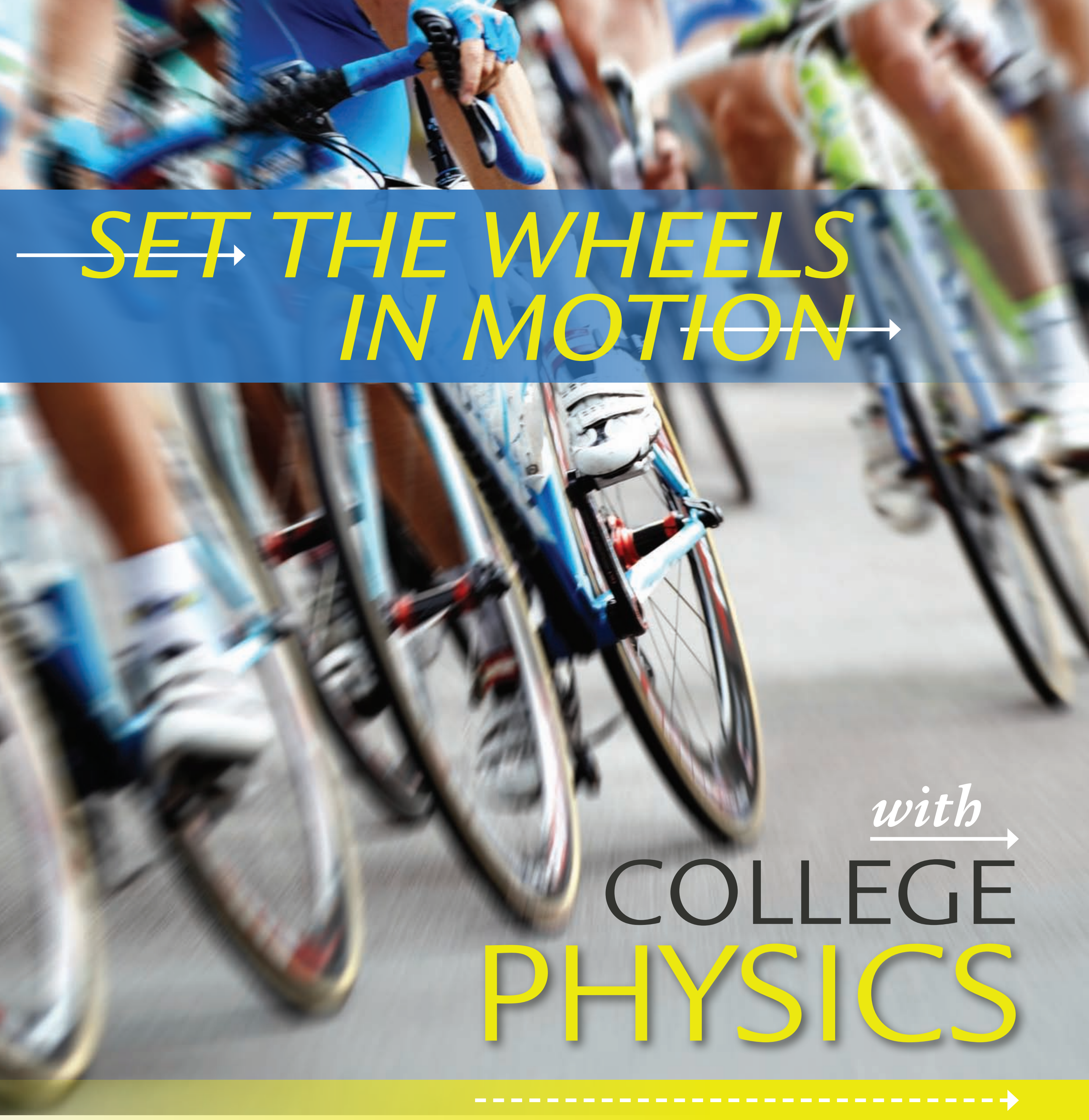


"This is an excellent way to teach physics. The approach is so logical that students will feel they are a) discovering physics themselves, and b) reaching the best conclusions... The style is approachable, consistent, systematic, engaging. I think [this textbook] teaches more than physics—it also gets at the core of the scientific process and that will be just as valuable for the students as any of the physics content."

—Andy Richter, *Valparaiso University*

BUILD A DEEP UNDERSTANDING OF PHYSICS AND THE SCIENTIFIC PROCESS

An active learning approach encourages students to construct an understanding of physics concepts and laws in the same ways that scientists acquire knowledge. Students learn physics by doing physics.

OBSERVATIONAL EXPERIMENT TABLES

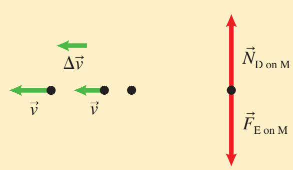
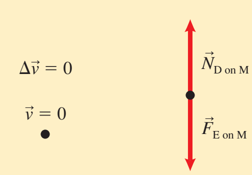
Observational Experiment Tables engage students through active discovery. Students make observations, analyze data, and identify patterns.

Scan this QR code with your smartphone to view the video that accompanies this table.

OBSERVATIONAL EXPERIMENT TABLE

2.3 Two observers watch the same coffee mug.

VIDEO 2.3

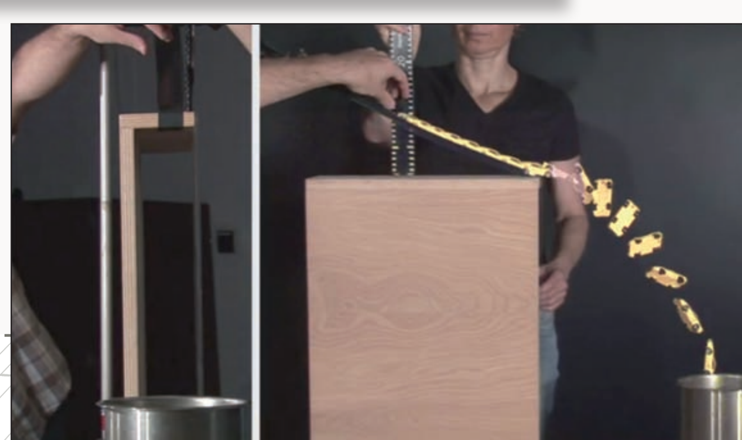
Observational experiment	Analysis done by each observer
Experiment 1. Observer 1 is slouched down in the passenger seat of a car and cannot see outside the car. Suddenly he observes a coffee mug sliding toward him from the dashboard.	Observer 1 creates a motion diagram and a force diagram for the mug as he observes it. On the motion diagram, increasingly longer $\vec{v}$ arrows indicate that the mug's speed changes from zero to nonzero as seen by observer 1 even though no external object is exerting a force on it in that direction. 
Experiment 2. Observer 2 stands on the ground beside the car. She observes that the car starts moving forward at increasing speed and that the mug remains stationary with respect to her.	Observer 2 creates a motion diagram and force diagram for the mug as she observes it. There are no $\vec{v}$ or $\Delta\vec{v}$ arrows on the diagram and the mug is at rest relative to her. 

Pattern

Observer 1: The forces exerted on the mug by Earth and by the dashboard surface add to zero. But the velocity of the mug increases as it slides off the dashboard. This is inconsistent with the rule relating the sum of the forces and the change in velocity.
Observer 2: The forces exerted on the mug by Earth and by the dashboard surface add to zero. Thus the velocity of the mug should not change, and it does not. This is consistent with the rule relating the sum of the forces and the change in velocity.

VIDEOS

Physics demonstration videos, accessed by QR codes in the text or through the MasteringPhysics® Study Area, accompany most of the Observational and Testing Experiment Tables. Students can observe the exact experiment described in the table.



TESTING EXPERIMENT TABLES

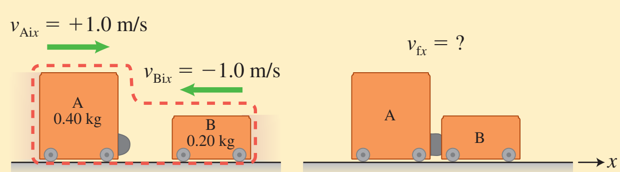
Each testing experiment evaluates a hypothesis arising from the observational experiment, and includes the experimental setup, one or more predictions, and the outcome of the experiment. A conclusion summarizes the result of the experimental process.

Scan this QR code with your smartphone to view the video shown below.

TESTING EXPERIMENT TABLE

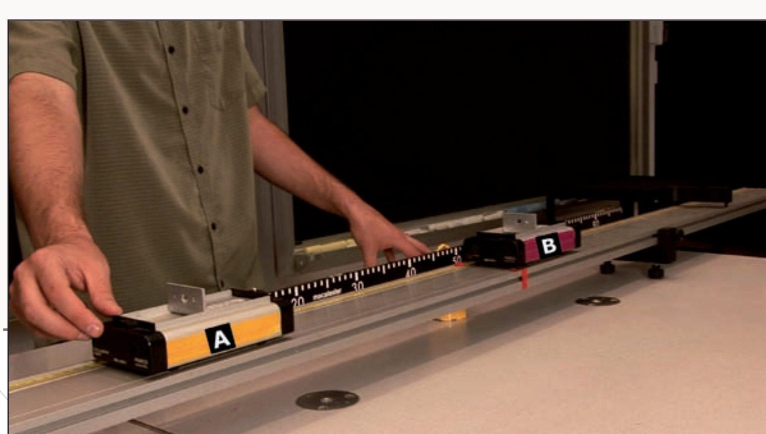
5.2 **Testing the idea that $\Sigma m\vec{v}$ in an isolated system remains constant (all velocities are with respect to the track).**

VIDEO 5.2

Testing experiment	Prediction	Outcome
Cart A (0.40 kg) has a piece of modeling clay attached to its front and is moving right at 1.0 m/s. Cart B (0.20 kg) is moving left at 1.0 m/s. The carts collide and stick together. Predict the velocity of the carts after the collision.	 The system consists of the two carts. The direction of velocity is noted with a plus or minus sign of the velocity component: $$(0.40\text{ kg})(+1.0\text{ m/s}) + (0.20\text{ kg})(-1.0\text{ m/s}) = (0.40\text{ kg} + 0.20\text{ kg})v_{fx}$$ or $$v_{fx} = (+0.20\text{ kg}\cdot\text{m/s})/(0.60\text{ kg}) = +0.33\text{ m/s}$$ After the collision, the two carts should move right at a speed of about 0.33 m/s.	After the collision, the carts move together toward the right at close to the predicted speed.

Conclusion

Our prediction matched the outcome. This result gives us increased confidence that this new quantity $m\vec{v}$ might be the quantity whose sum is constant in an isolated system.

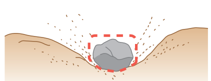


DEVELOP ADVANCED PROBLEM-SOLVING SKILLS

Students learn to represent physical phenomena in multiple ways using words, figures, and equations, including qualitative diagrams and innovative bar charts that create a foundation for quantitative reasoning and problem solving.

REASONING SKILL Constructing a force diagram

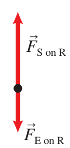
1. Sketch the situation (a rock sinking into sand).



2. Circle the system (the rock).

3. Identify external interactions:
- The sand pushes up on the rock.
- Earth pulls down on the rock.
- We assume that the air force that the air exerts on the rock is small in comparison and can be ignored.

4. Place a dot at the side of the sketch, representing the system object.



5. Draw force arrows to represent the external interactions.

6. Label the forces with a subscript with two elements.

Notice that the upward-pointing arrow representing the force exerted by the sand on the rock is longer than the downward-pointing arrow representing the force exerted by Earth on the rock. The difference in lengths reflects the difference in the magnitudes of the forces. Later in the chapter we will learn why they have different lengths. For now, we just need to include arrows for all external forces exerted on the system object (the rock).

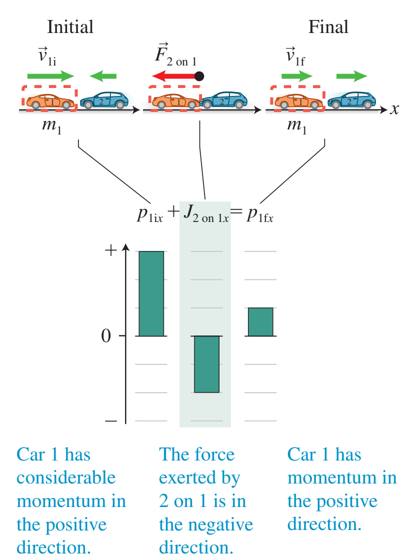
REASONING SKILL BOXES

These boxes reinforce a particular skill, such as drawing a motion diagram, force diagram, or work-energy bar chart.

BAR CHARTS

Innovative bar charts help to create a foundation for quantitative reasoning and problem solving.

Figure 5.7 A bar chart analysis of the collision of car 2 with car 1.



PROBLEM-SOLVING STRATEGY

The Problem-Solving Strategy boxes walk students step-by-step through the process of solving a worked example, applying concepts covered in the text.

PROBLEM-SOLVING STRATEGY Applying Static Equilibrium Conditions

EXAMPLE 7.6 Use the biceps muscle to lift

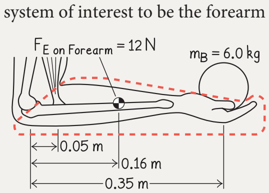
Imagine that you hold a 6.0-kg lead ball in your hand with your arm bent. The ball is 0.35 m from the elbow joint. The biceps muscle attaches to the forearm 0.050 m from the elbow joint and exerts a force on the forearm that allows it to support the ball. The center of mass of the 12-N forearm is 0.16 m from the elbow joint. Estimate the magnitude of (a) the force that the biceps muscle exerts on the forearm and (b) the force that the upper arm exerts on the forearm at the elbow.

Sketch and translate

- Construct a labeled sketch of the situation. Include coordinate axes and choose an axis of rotation.
- Choose a system for analysis.

We choose the axis of rotation to be where the upper arm bone (the humerus) presses on the forearm at the elbow joint. This will eliminate from the torque equilibrium equation the unknown force that the upper arm exerts on the forearm.

We choose the system of interest to be the forearm and hand.



(continued)

INSPIRE HIGHER-LEVEL REASONING

Innovative, widely praised examples, exercises, and problems engage students, assess learning, and promote higher-level reasoning.

* **Equation Jeopardy 1** The equation below describes a rotational dynamics situation. Draw a sketch of a situation that is consistent with the equation and construct a word problem for which the equation might be a solution. There are many possibilities.

$$-(2.2\ \text{N})(0.12\ \text{m}) = [(1.0\ \text{kg})(0.12\ \text{m})^2]\alpha$$

* **Equation Jeopardy 2** The equation below describes a rotational dynamics situation. Draw a sketch of a situation that is consistent with the equation and construct a word problem for which the equation might be a solution. There are many possibilities.

$$-(2.0\ \text{N})(0.12\ \text{m}) + (6.0\ \text{N})(0.06\ \text{m}) = [(1.0\ \text{kg})(0.12\ \text{m})^2]\alpha$$

JEOPARDY-STYLE END-OF-CHAPTER PROBLEMS

Unique, Jeopardy-style end-of-chapter problems ask students to work backwards from an equation to craft a problem statement. Chapters also include "what if" problems, estimating problems, and qualitative/quantitative multi-part problems.

REVIEW QUESTIONS

Questions at the end of each section of the chapter encourage critical thinking and synthesis rather than recall.

Review Question 1.5 Why is the following statement true? "Displacement is equal to the area between a velocity-versus-time graph line and the time axis with a positive or negative sign."

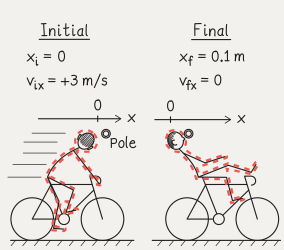
ESTIMATION PROBLEMS

Estimation problems ask students to make reasonable assumptions and estimates in problem solving as a scientist would do.

EXAMPLE 5.6 Bone fracture estimation[1]

A bicyclist is watching for traffic from the left while turning toward the right. A street sign hit by an earlier car accident is bent over the side of the road. The cyclist's head hits the pole holding the sign. Is there a significant chance that his skull will fracture?

Sketch and translate The process is sketched at the right. The initial state is at the instant that the head initially contacts the pole; the final state is when the head and body have stopped. The person is the system. We have been given little information, so we'll have to make some reasonable estimates of various quantities in order to make a decision about a possible skull fracture.



Simplify and diagram The bar chart illustrates the momentum change of the system and the impulse exerted by the pole that caused the change. The person was initially moving in the horizontal x-direction with respect to Earth, and not moving after the collision. The pole exerted an impulse in the negative x-direction on the cyclist. We'll need to estimate the following quantities: the mass and speed of the cyclist in this situation, the stopping time interval, and the area of contact. Let's assume that this is a 70-kg cyclist moving at about 3 m/s. The person's body keeps moving forward for a short distance after the bone makes contact with the pole. The skin indents some during the collision. Because of these two factors, we assume

[1]This is a true story—it happened to one of the book's authors, Alan Van Heuvelen.

MOTIVATE WITH REAL-WORLD APPLICATIONS

Real-world applications relate physics concepts and laws to everyday experiences and apply them to problems in diverse fields such as biology, medicine, and astronomy.

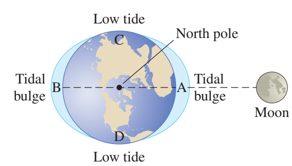
8.7 Rotational motion: Putting it all together

We can use our knowledge of rotational motion to analyze a variety of phenomena that are part of our world. In this section, we consider two examples—the effect of the tides on the period of Earth's rotation (the time interval for 1 day) and the motion of bowling (also called pitching) in the sport of cricket.

Tides and Earth's day

The level of the ocean rises and falls by an average of 1 m twice each day, a phenomenon known as the tides. Many scientists, including Galileo, tried to explain this phenomenon and suspected that the Moon was a part of the answer. Isaac Newton was the first to explain how the motion of the Moon actually creates tides. He noted that at any moment, different parts of Earth's surface are at different distances from the Moon and that the distance from a given location on Earth to the Moon varied as Earth rotated. As illustrated in **Figure 8.18**, point A is closer to the Moon than the center of Earth or point B are, and therefore the gravitational force exerted by the Moon on point A is greater than the gravitational force exerted on point B. Due to the difference

Figure 8.18 The ocean bulges on both sides of Earth along a line toward the Moon.



PUTTING IT ALL TOGETHER

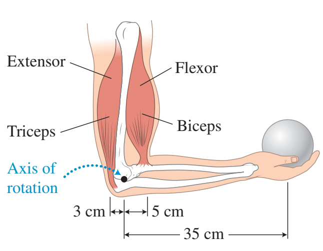
These sections help students synthesize chapter content within real-world applications such as avoiding "the bends" in scuba diving (Chapter 10), making automobiles more efficient (Chapter 13), and building liquid crystal displays (Chapter 24).

Reading Passage Problems

BIO Muscles work in pairs Skeletal muscles produce movements by pulling on tendons, which in turn pull on bones. Usually, a muscle is attached to two bones via a tendon on each end of the muscle. When the muscle contracts, it moves one bone toward the other. The other bone remains in nearly the original position. The point where a muscle tendon is attached to the stationary bone is called the *origin*. The point where the other muscle tendon is attached to the movable bone is called the *insertion*. The origin is like the part of a door spring that is attached to the doorframe. The insertion is similar to the part of the spring that is attached to the movable door.

During movement, bones act as levers and joints act as axes of rotation for these levers. Most movements require several skeletal muscles working in groups, because a muscle can only exert a pull and not a push. In addition, most skeletal muscles are arranged in opposing pairs at joints. Muscles that bring two limbs together are called flexor muscles (such as the biceps muscle in the upper arm in **Figure 7.26**). Those that cause the limb to extend outward are called extensor muscles (such as the triceps muscle in the upper arm). The flexor muscle is used when you hold a heavy object in your hand; the extensor muscle can be used, for example, to extend your arm when you throw a ball.

Figure 7.26 Muscles often come in flexor-extensor pairs.



MCAT-STYLE READING PASSAGE PROBLEMS

Help students prepare for the MCAT exam. Because so many students who take this course are planning to study medicine, each chapter includes MCAT-style reading passages and related multiple-choice questions to help prepare students for this important test.

BIOLOGICAL AND MEDICAL EXAMPLES

Examples throughout the text provide relevance for life science majors and include topics such as understanding the effect of radon on the lungs (Chapter 5), controlling body temperature (Chapter 12), and measuring the speed of blood flow (Chapter 20).

Reading Passage Problems

BIO Head injuries in sports A research group at Dartmouth College has developed a Head Impact Telemetry (HIT) System that can be used to collect data about head accelerations during impacts on the playing field. The researchers observed 249,613 impacts from 423 football players at nine colleges and high schools and collected collision data from participants in other sports. The accelerations during most head impacts ($>89\%$) in helmeted sports caused head accelerations less than a magnitude of 400 m/s^2. However, a total of 11 concussions were diagnosed in players whose impacts caused accelerations between 600 and 1800 m/s^2, with most of the 11 over 1000 m/s^2.

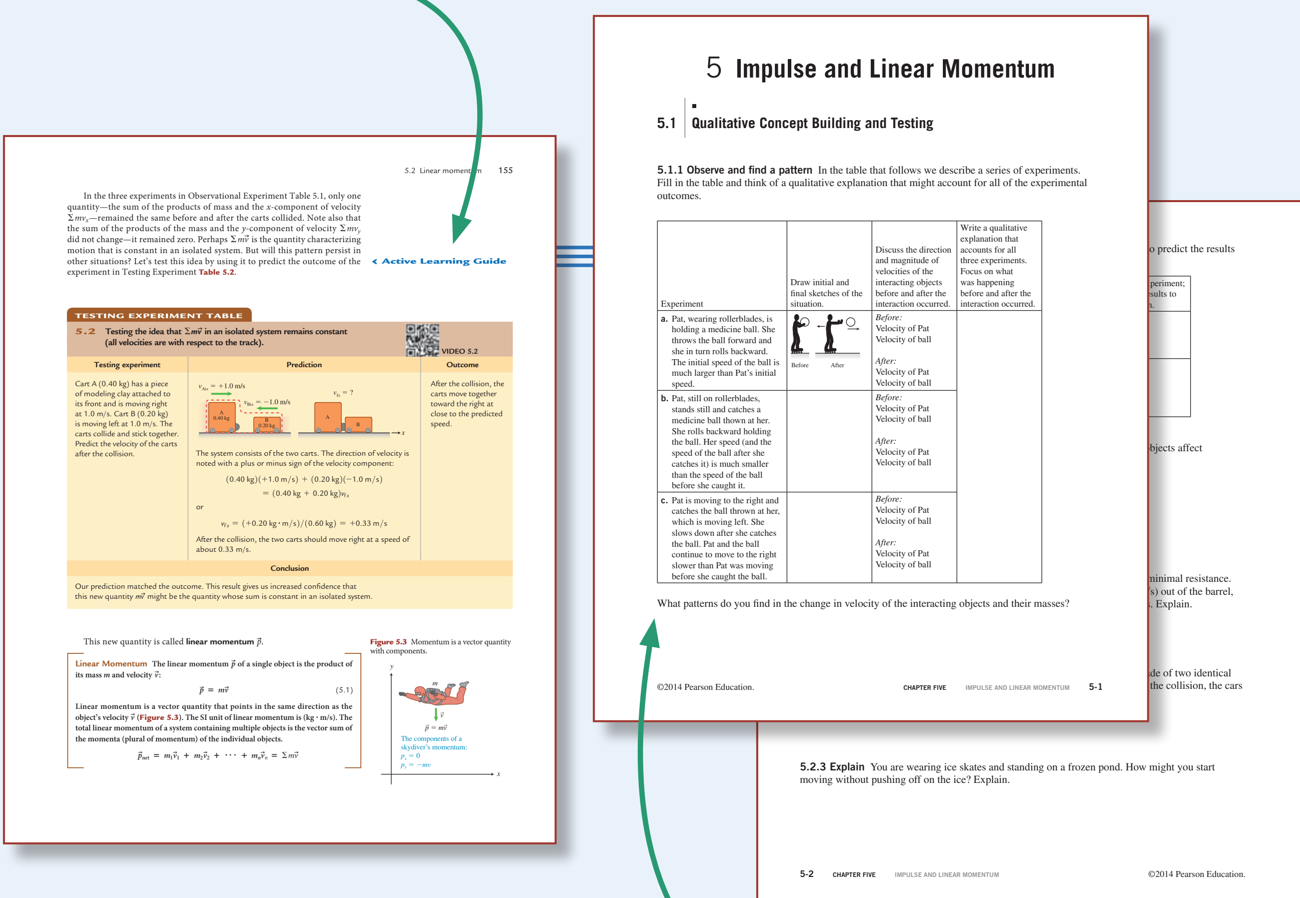
REINFORCE SCIENTIFIC THINKING

Active Learning Guide for College Physics

by Eugenia Etkina, Michael Gentile, and Alan Van Heuvelen
© 2014 • Paper • 400 pages
978-0-321-86445-1 • 0-321-86445-X

Discovery-based activities supplement the knowledge-building approach of the textbook. This workbook is organized in parallel with the textbook's chapters.

Blue labels, located in the text's margins, link the discovery-based activities in the *Active Learning Guide* to concepts covered in *College Physics*.



These activities provide an opportunity for further observation, testing, sketching, and analysis.

MAKE A DIFFERENCE WITH MasteringPhysics®

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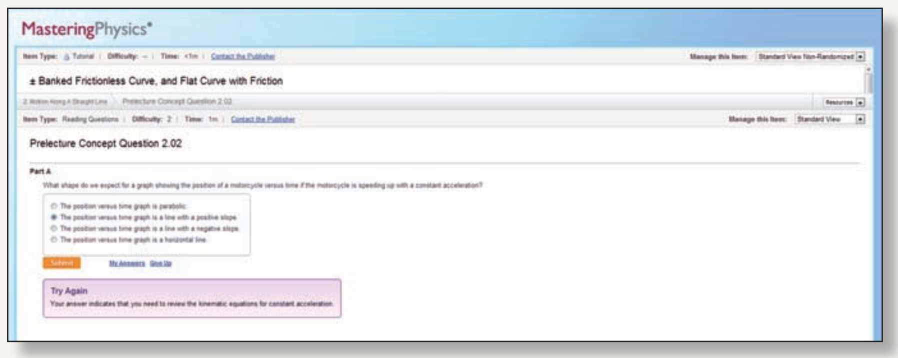
Prelecture Concept Questions

Assignable Prelecture Concept Questions encourage students to read the textbook prior to lecture so they're more engaged in class.



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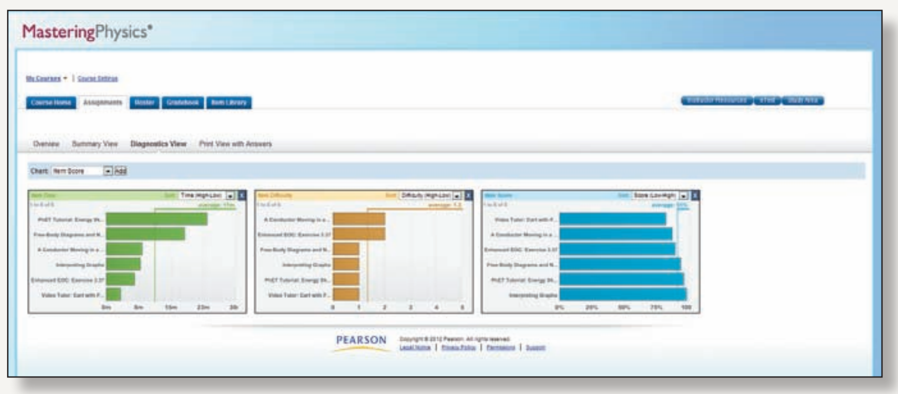
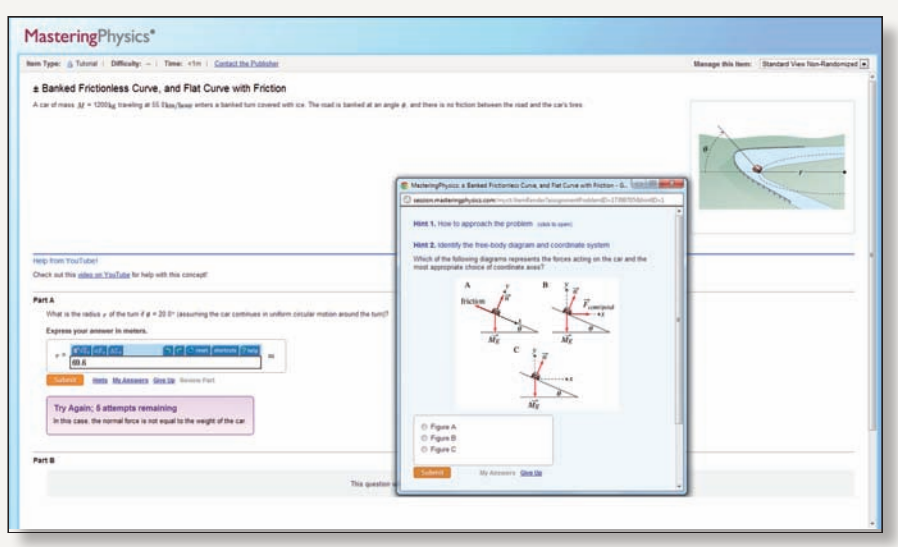
The Gradebook Diagnostics screen provides your favorite weekly diagnostics. With a single click, charts summarize the most difficult problems, vulnerable students, and grade distribution.



Tutorials with Hints and Feedback

Easily assign tutorials that provide individualized coaching.

- Mastering's hallmark Hints and Feedback offer "scaffolded" instruction similar to what students would experience in an office hour.
- Hints (declarative and Socratic) can provide problem-solving strategies or break the main problem into simpler exercises.
- Wrong-answer-specific feedback gives students exactly the help they need by addressing their particular mistake without giving away the answer.



Preface

To the student

College Physics is more than just a book. It's a learning *companion*. As a companion, the book won't just tell you about physics; it will act as a guide to help you build physics ideas using methods similar to those that practicing scientists use to construct knowledge. The ideas that you build will be *yours*, not just a copy of someone else's ideas. As a result, the ideas of physics will be much easier for you to use when you need them: to succeed in your physics course, to obtain a good score on exams such as the MCAT, and to apply to everyday life.

Although few, if any, textbooks can honestly claim to be a pleasure to read, *College Physics* is designed to make the process interesting and engaging. The physics you learn in this book will help you understand many real-world phenomena, from why giant cruise ships are able to float to how telescopes work.

A great deal of research has been done over the past few decades on how students learn. We, as teachers and researchers, have been active participants in investigating the challenges students face in learning physics. We've developed unique strategies that have proven effective in helping students think like physicists. These strategies are grounded in *active learning*, deliberate, purposeful action on your part to learn something new. It's not passively memorizing so that you can repeat it later. When you learn actively you engage with the material. You relate it to what you already know. You think about it in as many different ways as you can. You ask yourself questions such as "Why does this make sense?" and "Under what circumstances does this not apply?"

This book (your learning companion) includes many tools to support the active learning process: each problem-solving strategies tool, worked example, observational experiment, testing experiment, review question, and end-of-chapter question and problem is designed to help you build your understanding of physics. To get the most out of these tools and the course, stay actively engaged in the process of developing ideas and applying them. When things get challenging, don't give up.

At this point you should turn to the chapter Introducing Physics and begin reading. That's where you'll learn the details of the approach that the book uses, what physics is, and how to be successful in the physics course you are taking.

To the instructor

In writing *College Physics,* our main goal was to produce an effective learning companion for students that incorporates results from the last few decades of physics education research. This research has shown that there is a dramatic difference between how physicists construct new ideas and how students traditionally learn physics. Students often leave their physics course thinking of physics as a disconnected set of facts that has little to do with the real world, rather than as a framework for understanding it.

To address this problem we have based this book on a framework known as ISLE (Investigative Science Learning Environment) developed by authors Etkina and Van Heuvelen. In ISLE, the construction of new ideas begins with observational experiments. Students are explicitly presented with simple experiments from which they discern patterns using available tools (diagrams, graphs, bar charts, etc.). To explain the patterns, students devise explanations (hypotheses) for their observations. They then use these explanations in testing experiments to make predictions about the outcomes of these new experiments. If the prediction does not match the outcome of the experiment, the explanation needs to be reevaluated. Explanations that survive this testing process are the physics ideas in which we then have more confidence.

The goal of this approach is to help students understand physics as a process by which knowledge of the natural world is constructed, rather than as a body of given laws and facts. This approach also helps students reason using the tools that physicists and physics educators have developed for the analysis of phenomena—for example, motion and force diagrams, kinematics and thermodynamics graphs, energy and momentum bar charts, and many other visual representations. Using these tools helps students bridge the gap between words and mathematical equations. Along the way, they develop independent and critical thinking skills that will allow them to build their own understanding of physics principles.

All aspects of *College Physics* are grounded in ISLE and physics education research. As a result, all of the features of the text have been designed to encourage students to investigate, test ideas, and apply scientific reasoning.

Key learning principles

To achieve these goals we adhere to five key learning principles:

1. **Concept first, name second:** The names we use for physics concepts have everyday-life meanings that may differ from the meanings they have when used in physics. For example, in physics *flux* refers to the amount to which a directed quantity (such as the magnetic field) points through a surface, but in everyday-life *flux* refers to continuous change. Confusion over the meaning of terms can get in the way of learning. We address this difficulty by developing the concept first and only then assigning a name to it.

2. **Careful language**: The vernacular physicists use is rooted in history and tradition. While physicists have an internal "dictionary" that lets them understand the meaning of specific terms, students do not. We are extremely careful to use language that promotes understanding. For example: physicists would say that "heat flows from a hot object to a cool object." Heat isn't a substance that objects possess; heat is the *flow of energy*. In this book we only use the word *heat* to refer to the process of energy transfer.
3. **Bridging words and mathematics**: Words and mathematics are very abstract representations of physical phenomena. We help students translate between these abstractions by using concrete representations such as force diagrams and energy bar charts as intermediate steps.
4. **Making sense of mathematics**: We explicitly teach students how to evaluate the results of their quantitative reasoning so they can have confidence in that reasoning. We do this by building qualitative understanding first and then explicitly teaching students how to use that understanding to check for quantitative consistency. We also guide students to use limiting cases to evaluate their results.
5. **Moving away from plug-and-chug problem solving approaches**: In this book you will find many non-traditional examples and end-of-chapter problems that require students to use higher-level reasoning skills and not just plug numbers into equations that have little meaning for them. Jeopardy problems (where a solution is given and students must invent a problem that leads to it), "tell-all" problems (where students must determine everything possible), and estimation problems (where students do not have quantities given to them) are all designed to encourage higher reasoning and problem solving skills.

These key principles are described in greater detail in the Introduction to the *Instructor's Guide* that accompanies *College Physics*—please read that introduction. It elaborates on the implementation of the methodology that we use in this book and provides guidance on how to integrate the approach into your course.

While our philosophy informs *College Physics*, you need not fully subscribe to it to use this textbook. We've organized the book to fit the structure of most algebra-based physics courses: We begin with kinematics and Newton's laws, then move on to conserved quantities, statics, gases, fluids, thermodynamics, electricity and magnetism, vibrations and waves, optics, and finally modern physics. The structure of each chapter will work with any method of instruction. You can assign all of the innovative experimental tables and end-of-chapter problems, or only a few. The text provides thorough treatment of fundamental principles, supplementing this coverage with experimental evidence, new representations, an effective approach to problem solving, and interesting and motivating examples.

Real-world applications

To effectively teach physics, especially to the non-physics student, a textbook must actively engage the student's interest. To that effect, *College Physics* includes a wealth of real-world applications. Each chapter begins with a brief vignette designed to intrigue the reader. For example, Chapter 11 opens with a description of plaque build-up in arteries that can lead to stroke. Chapters also open with a set of motivating questions that are answered as students read subsequent sections. In each chapter, worked examples and exercises cover such topics as what keeps a car on the road when spinning around a circular track (Chapter 4), why air bags are so effective (Chapter 5), and why your ears pop when you change altitude (Chapter 10). A Putting it all together section applies concepts from the chapter to complex phenomena such as collisions (Chapter 6), lightning (Chapter 15), and the Doppler Effect (Chapter 20). Many applications are grounded in biology or medicine. Approximately eight percent of end-of-chapter problems are on biomedical topics. A complete list of applications appears on pages xxiv–xxvi.

Chapter features

Chapter-opening features engage the student in the chapter topic.

Each chapter opens with a bridge from the concepts and skills that students will have learned in previous chapters. This bridge takes the form of **"Be sure you know how to"** statements with cross-references to the relevant material in previous chapters.

Each chapter also includes a set of **Motivating questions** to capture student interest. These questions are answered within the chapter content. Two examples are, "Why do people snore?" and "How does a refrigerator stay cold inside?"

A brief **vignette** opens each chapter with a real-world story related to one of the motivating questions.

In-chapter features encourage the active construction of knowledge about physics and support students as they read and review the material.

Experimental tables help students explore science as a process of inquiry (e.g., making observations, analyzing data, identifying patterns, testing hypotheses, etc.) and develop reasoning skills they can use to solve physics problems.

- **Observational experiment tables** engage students in an active discovery process as they learn about key physics ideas. By analyzing and finding patterns for the experiments, students learn the process of science.

- **Testing experiment tables** allow students to test hypotheses by predicting an outcome, conducting the experiment, and forming a conclusion that compares the prediction to the outcome and summarizes the results.

Many of these tables are accompanied by videos of the experiments. Students can view them through a QR code on the table using their smartphone, or online in the MasteringPhysics study area.

- **Section review questions** encourage critical thinking and synthesis rather than recall. Answers to review questions are given at the end of each chapter.

Three types of worked examples guide students through the problem-solving process.

Examples are complete problems that utilize the four-step problem-solving strategy.

- **Sketch and Translate:** This step teaches students to translate the problem statement into the language of physics. Students read the problem, sketch the situation and include known values, and identify the unknown(s).
- **Simplify and Diagram:** Students simplify the physics problem with an appropriate physical representation, a force diagram or other representation that reflects the situation in the problem and helps them construct a mathematical equation to solve it.
- **Represent Mathematically:** In this step, students apply the relevant mathematical equations. For example, they use the force diagram to apply Newton's second law in component form.
- **Solve and Evaluate:** In the last step, students rearrange equations and insert known values to solve for the unknown(s).

Conceptual exercises focus on developing students' conceptual understanding. These exercises utilize two of the problem-solving steps: *Sketch and Translate,* and *Simplify and Diagram*.

Quantitative exercises develop students' ability to solve unknowns quantitatively. These exercises utilize the problem-solving steps *Represent Mathematically* and *Solve and Evaluate*.

Each worked example ends with a **Try It Yourself** question, an additional exercise that builds on the worked example and asks students to solve a similar problem without the scaffolding.

The text also includes additional support for problem solving.

Problem-solving strategy boxes work through an example, explaining as well as applying the four-step strategy.

Reasoning skill boxes summarize the use of a particular skill, such as drawing a motion diagram, a force diagram, or a work-energy bar chart.

Tips within the text encourage the use of particular strategies or caution the reader about common misconceptions.

Key equations and **definitions boxes** highlight important laws or principles that govern the physics concepts developed in the chapters.

The Putting it all together section (found in most chapters) focuses on two to four real-world applications of the physics learned in the chapter.

Putting it all together contains conceptual explanations and capstone worked examples that will often draw on more than one principle. The goal of this section is to help students synthesize what they have learned and broaden their understanding of the phenomena they are exploring.

End-of-chapter features

The **chapter summary** reviews key concepts presented in the chapter. The summary utilizes the multiple representation approach, displaying the concepts in words, figures, and equations.

Each chapter includes the authors' widely-lauded and highly creative problem sets, including their famous Jeopardy-style problems, "tell-all" problems, and estimating problems. The authors have written every end-of-chapter item themselves. Each question and problem is thoroughly grounded in their deep understanding of how students learn physics.

Questions: The question section includes both multiple choice and conceptual short answer questions, to help build students' fluency in the words, symbols, pictures, and graphs used in physics. Most of the questions are qualitative.

Problems: Chapters include an average of 60 section-specific problems. Approximately eight percent of the problems are drawn from biology or medicine; other problems relate to astronomy, geology, and everyday life.

General Problems: These challenging problems often involve multiple parts and require students to apply conceptual knowledge learned in previous chapters. As much as possible, the problems have a real-world context to enhance the connection between physics and students' daily lives.

MCAT reading passage and related multiple choice questions and problems: Because so many students who take this course are planning to study medicine, each chapter includes MCAT-style reading passages with related multiple-choice questions to help prepare students for their MCAT exam.

Instructor supplements

The ***Instructor's Guide***, written by Eugenia Etkina, Alan Van Heuvelen, and highly respected physics education researcher David Brookes, walks you through the innovative approaches they take to teaching physics. Each chapter of the *Instructor's Guide* contains a roadmap to assigning chapter content, *Active Learning Guide* assignments, homework, and videos of the demonstration experiments. In addition, the authors call out common pitfalls to mastering physics concepts and describe techniques that will help your students identify and overcome their misconceptions. Tips include how to manage the complex vocabulary of physics, when to use classroom-response tools, and how to organize lab, lecture, and small group learning time. Drawing from their extensive experience as teachers and researchers, the authors give you the support you need to make *College Physics* work for you.

The cross-platform **Instructor Resource DVD** (ISBN 0-321-88897-9) provides invaluable and easy-to-use resources for your class, organized by textbook chapter. The contents include a comprehensive library of more than 220 applets from **ActivPhysics OnLine™,** as well as all figures, photos, tables, and summaries from the textbook in JPEG and PowerPoint formats. A set of editable **Lecture Outlines** and **Classroom Response System "Clicker" Questions** on PowerPoint will engage your students in class.

MasteringPhysics® (www.masteringphysics.com) is a powerful, yet simple, online homework, tutorial, and assessment system designed to improve student learning and results. Students benefit from wrong-answer specific feedback, hints, and a huge variety of educationally effective content while unrivalled gradebook diagnostics allow an instructor to pinpoint the weaknesses and misconceptions of their class.

NSF-sponsored published research (and subsequent studies) show that MasteringPhysics has dramatic educational results. MasteringPhysics allows instructors to build wide-ranging homework assignments of just the right difficulty and length and provides them with efficient tools to analyze in unprecedented detail both class trends and the work of any student.

In addition to the textbook's end-of-chapter problems, MasteringPhysics for *College Physics* also includes tutorials, prelecture concept questions, and Test Bank questions for each chapter. MasteringPhysics also now has the following learning functionalities:

- **Prebuilt Assignments:** These offer instructors a mix of end-of-chapter problems and tutorials for each chapter.
- **Learning Outcomes:** In addition to being able to create their own learning outcomes to associate with questions in an assignment, professors can now select content that is tagged to a large number of publisher-provided learning outcomes. They can also print or export student results based on learning outcomes for their own use or to incorporate into reports for their administration.
- **Quizzing and Testing Enhancements:** These include options to hide item titles, add password protection, limit access to completed assignments, and randomize question order in an assignment.
- **Math Remediation:** Found within selected tutorials, special links provide just-in-time math help and allow students to brush up on the most important mathematical concepts needed to successfully complete assignments. This new feature links students directly to math review and practice, helping students make the connection between math and physics.

The **Test Bank** contains more than 2,000 high-quality problems, with a range of multiple-choice, true/false, short-answer, and regular homework-type questions. Test files are provided in both TestGen® (an easy-to-use, fully networkable program for creating and editing quizzes and exams) and Word format, and can be downloaded from www.pearsonhighered.com/educator.

Student supplements

The ***Active Learning Guide*** workbook by Eugenia Etkina, Michael Gentile, and Alan Van Heuvelen consists of carefully-crafted activities that provide an opportunity for further observation, sketching, analysis, and testing. Marginal "Active Learning Guide" icons throughout *College Physics* indicate content for which a workbook activity is available. Whether the activities are assigned or not, students can always use this workbook to reinforce the concepts they have read about in the text, to practice applying the concepts to real-world scenarios, or to work with sketches, diagrams, and graphs that help them visualize the physics.

Physics demonstration videos, accessed with a smartphone through QR codes in the text or online in the MasteringPhysics study area, accompany most of the Observational and Testing Experiment Tables. Students can observe the exact experiment described in the table.

MasteringPhysics® (www.masteringphysics.com) is a powerful, yet simple, online homework, tutorial, and assessment system designed to improve student learning and results. Students benefit from wrong-answer specific feedback, hints, and a huge variety of educationally effective content while unrivalled gradebook diagnostics allow an instructor to pinpoint the weaknesses and misconceptions of their class. The individualized, 24/7 Socratic tutoring is recommended by 9 out of 10 students to their peers as the most effective and time-efficient way to study.

Pearson eText is available through MasteringPhysics, either automatically when MasteringPhysics is packaged with new books, or available as a purchased upgrade online. Allowing students access to the text wherever they have access to the Internet, Pearson eText comprises the full text, including figures that can be enlarged for better viewing. Within eText, students are also able to pop up definitions and terms to help with vocabulary and the reading of the material. Students can also take notes in eText using the annotation feature at the top of each page.

Pearson Tutor Services (www.pearsontutorservices.com) Each student's subscription to MasteringPhysics also contains complimentary access to Pearson Tutor services, powered by Smarthinking, Inc. By logging in with their MasteringPhysics ID and password, they will be connected to highly qualified e-instructors™ who provide additional, interactive online tutoring on the major concepts of physics. Some restrictions apply; offer subject to change.

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—Eugenia Etkina and Alan Van Heuvelen

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—Mike Gentile

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Real-World Applications

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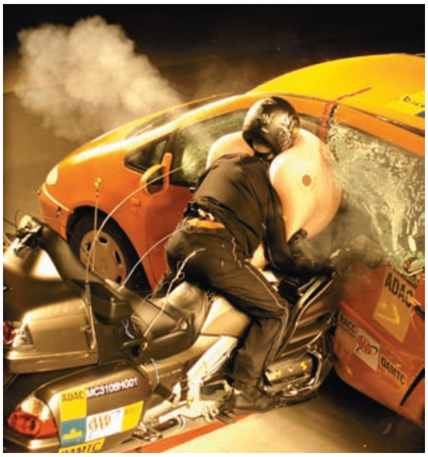


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Introducing Physics

Why do we need to use models to explain the world around us?

How is the word "law" used differently in physics than in the legal system?

How do we solve physics problems?

I.1 What is physics?

Physics is a fundamental experimental science encompassing subjects such as mechanical motion, waves, light, electricity, magnetism, atoms, and nuclei. Knowing physics allows you to understand many aspects of the world, from why bending over to lift a heavy load can injure your back to why Earth's climate is changing. Physics explains the very small—atoms and subatomic particles—and the very large—planets, galaxies, and celestial bodies such as white dwarfs, pulsars, and black holes.

In each chapter, we will apply our knowledge of physics to other fields of science and technology such as biology, medicine, geology, astronomy, architecture, engineering, agriculture, and anthropology. For instance, in this book you will learn about techniques used by archeologists to determine the age of

Physics in the field. Archaeologists applied principles from physics to determine that this skeleton of *Australopithecus afarensis*, nicknamed "Lucy," lived about 3.2 million years ago.

bones, about electron microscopes and airport metal detectors, about ways in which thermal energy is gained and lost in homes, about the development of stresses and tensions in body muscles, and why high blood pressure indicates problems with the circulatory system.

In this book we will concentrate not only on developing an understanding of the important basic laws of physics but also on the processes that physicists employ to discover and use these laws. The processes (among many) include:

- Collecting and analyzing experimental data.
- Making explanations and experimentally testing them.
- Creating different representations (pictures, graphs, bar charts, etc.) of physical processes.
- Finding mathematical relations between different variables.
- Testing those relations in new experiments.

The search for rules

Physicists search for general rules or **laws** that bring understanding to the chaotic behavior of our surroundings. In physics the word *law* means a mathematical relation between variables inferred from the data or through some reasoning process. The laws, once discovered, often seem obvious, yet their discovery usually requires years of experimentation and theorizing. Despite being called "laws," these laws are temporary in the sense that new information often leads to their modification, revision, and, in some cases, abandonment.

For example, in 200 B.C. Apollonius of Perga watched the Sun and the stars moving in arcs across the sky and adopted the concept that Earth occupied the center of a revolving universe. Three hundred years later, Ptolemy provided a theory to explain the complicated motion of the planets in that Earth-centered universe. Ptolemy's theory, which predicted with surprising accuracy the changing positions of the planets, was accepted for the next 1400 years. However, as the quality of observations improved, discrepancies between the predictions of Ptolemy's theory and the real positions of the planets became bigger and bigger. A new theory was needed. Copernicus, who studied astronomy at the time that Columbus sailed to America, developed a theory of motion for the heavenly bodies in which the Sun resided at the center of the universe while Earth and the other planets moved in orbits around it. More than 100 years later the theory was revised by Johannes Kepler and later supported by careful experiments by Galileo Galilei. Finally, 50 years after Galileo's death, Isaac Newton formulated three simple laws of motion and the universal law of gravitation, which together provided a successful explanation for the orbital motion of Earth and the other planets. These laws also allowed us to predict the positions of new planets, which at the time were not yet known. For nearly 300 years Newton's ideas went unaltered until Albert Einstein made several profound improvements to our understanding of motion and gravitation at the beginning of the 20th century.

Newton's inspiration provided not only the basic resolution of the 1800-year-old problem of the motion of the planets but also a general framework for analyzing the mechanical properties of nature. Newton's simple laws give us the understanding needed to guide rockets to the moon, to build skyscrapers, and to lift heavy objects safely without injury.

It is difficult to appreciate the great struggles our predecessors endured as they developed an understanding that now seems routine. Today, similar struggles occur in most branches of science, though the questions being investigated have changed. How does the brain work? What causes Earth's magnetism? What is the nature of the pulsating sources of X-ray radiation in our galaxy? Is the recently discovered accelerated expansion of the universe really caused by a mysterious "dark energy," or is our interpretation of the observations of distant supernovae that revealed the acceleration incomplete?

Newton's laws. Thanks to Newton, we can explain the motion of the Moon. We can also build skyscrapers.

Does this understanding make the world a better place?

The pursuit of basic understanding often seems greatly removed from the activities of daily living. If J. J. Thomson's peers had asked him in 1897 if there was any practical application for his discovery of the electron, he probably could not have provided a satisfactory answer. Yet a little over a century later, the electron plays an integral part in our everyday technology. Moving electrons in electric circuits produce light for reading and warmth for cooking. Knowledge of the electron has made it possible for us to transmit the information that we see as images on our smart phones and hear as sound from our MP3 players. Could the discovery of dark energy mentioned above lead to a similar technological revolution sometime in the future? It is certainly possible, but the details of that revolution would be very difficult to envision today, just as Thomson could not envision the impact his discovery of the electron would have throughout the 20th and 21st centuries.

The processes for devising and using new rules

Physics is an experimental science. To answer questions, physicists do not just think and dream in their offices but constantly engage in experimental investigations. Physicists use special measuring devices to observe phenomena (natural and planned), describe their observations (carefully record them using words, numbers, graphs, etc.), find repeating features called patterns (for example, the distance traveled by a falling object is directly proportional to the square of the time in flight), and then try to explain these patterns. By doing this, physicists answer the questions of "why" or "how" the phenomenon happened and then deduce the rules that explain the phenomenon.

However, a deduced rule is not automatically accepted as true. Every rule needs to undergo careful testing. When physicists test a rule, they use the rule to predict the outcomes of new experiments. As long as there is no experiment whose outcome is inconsistent with predictions made using the rule, the rule is not disproved. The rule is consistent with all experimental evidence gathered so far. However, a new experiment could be devised tomorrow whose outcome is not consistent with the prediction made using the rule. The point is that there is no way to "prove" a rule once and for all. At best, the rule just hasn't been disproven yet.

A simple example will help you understand some processes that physicists follow when they study the world. Imagine that you walk into the house of your acquaintance Bob and see 10 tennis rackets of different quality and sizes. This is an **observational experiment**. During an observational experiment a scientist collects data that seem important. Sometimes it is an accidental or unplanned experiment. The scientist has no prior expectation of the outcome. In this case the number of tennis rackets and their quality and sizes represent the data. Having so many tennis rackets seems unusual to you, so you try to explain the data you collected (or, in other words, to explain why Bob has so many rackets) by devising several hypotheses. A **hypothesis** is an explanation of some sort that usually is based on some mechanism that is behind what is going on. One hypothesis is that Bob has lots of children and they all play tennis. A second hypothesis is that he makes his living by fixing tennis rackets. A third hypothesis is that he is a thief and he steals tennis rackets.

How do you decide which hypothesis is correct? You reason: if Bob has many children, and I walk around the house checking the sizes of clothes that I find, then I will find clothes of different sizes. Checking the clothing sizes is a new experiment, called a **testing experiment**. A testing experiment is different from an observational experiment. In a testing experiment, a specific hypothesis is being "put on trial." This hypothesis is used to construct a clear expectation of the outcome of the experiment. This clear expectation (based on the hypothesis being tested) is called a **prediction**. So, you conduct the testing experiment and walk around the house checking the closets. You do find clothes of different sizes. This is the outcome of your testing experiment. Does it mean for absolute certain that Bob has the rackets because all of his children play tennis? He could still be a racket repairman or a thief. Therefore, if the outcome of the testing experiment matches the prediction based on your hypothesis, you cannot say that you proved the hypothesis. All you can say is that you failed to disprove it. However, if you walk around the house and do not find any children's clothes, you can say with more confidence that the number of rackets in the house is not due to Bob having lots of children who play tennis. Still, this conclusion would only be valid if you made an **assumption:** Bob's children live in the house and wear clothes of different sizes. Generally, in order to reject a hypothesis you need to check the additional assumptions you made and determine if they are reasonable.

Imagine you have rejected the first hypothesis (you didn't find any children's clothes). Next you wish to test the hypothesis that Bob is a thief. This is your reasoning: If Bob is a thief (the hypothesis), and I walk around the house checking every drawer (the testing experiment), I should not find any receipts for the tennis rackets (the prediction). You perform the experiment and you find no receipts. Does it mean that Bob is a thief? He might just be a disorganized father of many children or a busy repairman. However, if you find all of the receipts, you can say with more confidence that he is not a thief (but he could still be a repairman). Thus it is possible to disprove (rule out) a hypothesis, but it is not possible to prove it once and for all. The process that you went through to create and test your hypotheses is depicted in **Figure I.1**. At the end of your investigation you might be left with a hypothesis that you failed to disprove. As a physicist you would now have some confidence in this hypothesis and start using it to solve other problems.

TIP Notice the difference between a hypothesis and a prediction. A *hypothesis* is an idea that explains why or how something that you observe happens. A *prediction* is a statement of what should happen in a particular experiment if the hypothesis being tested were true. The prediction is based on the hypothesis and cannot be made without a specific experiment in mind.

Using this book you will learn physics by following a process similar to that described above. Throughout the book are many observational experiments and descriptions of the patterns that emerge from the data. After you read about the observational experiments and patterns, think about possible

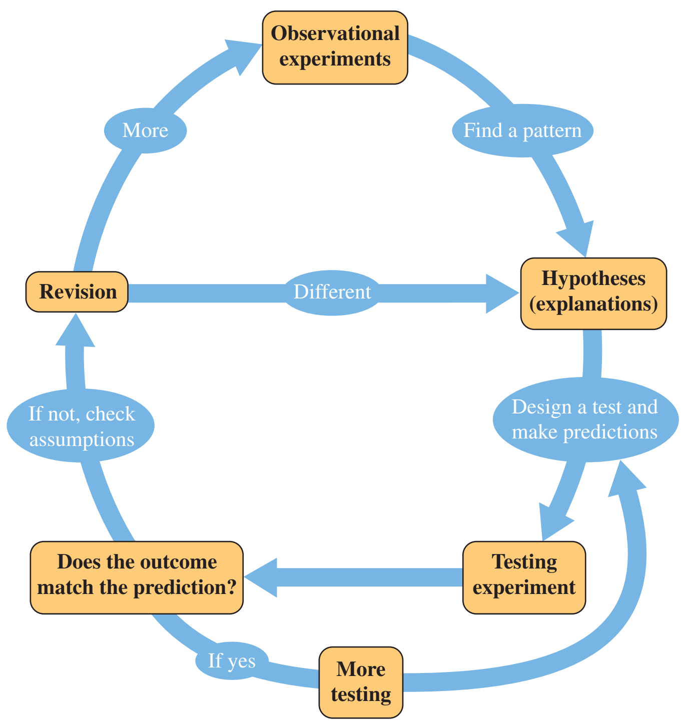


Figure I.1 Science is a cyclical process for creating and testing knowledge.

explanations for these patterns. The book will then describe possible experiments to test the proposed explanations and also the predicted outcomes based on the hypotheses being tested. Then it will describe the outcomes of the actual experiments. Sometimes the outcomes of the actual experiments will match the predicted outcomes, and sometimes they will not. Based on the experimental results and the analysis of the assumptions that were made, the book will help you make a judgment about the hypothesis being tested.

What language do physicists use?

Physicists use words and the language of mathematics to express ideas about the world. But they also represent these ideas and the world itself in other ways—sketches, diagrams, and even cut-out paper models (James Watson made a paper model of DNA when trying to determine its structure). In physics, however, the ultimate goal is to understand the mechanisms behind physical phenomena and to devise mathematical rules that allow for quantitative predictions of new phenomena. Thus, a big part of physics is identifying measurable properties of the phenomena (**physical quantities**, such as mass, speed, force), collecting quantitative data, and finding the patterns in that data.

How will learning physics change your interactions with the world?

Even if you do not plan on becoming a professional physicist, learning physics can change the way you think about the world. For example, why do you feel cold when you wear wet clothes? Why is it safe to sit in a car during a lightning storm? Why, when people age, do they have trouble reading small-sized fonts? Why are parts of the world experiencing more extreme climate events? Knowing physics will also help you understand what underlies many important technologies. How does an MRI work? How can a GPS know your present position and guide you to a distant location? How do power plants generate electric energy?

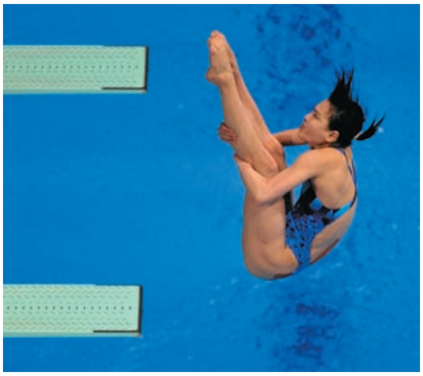
Studying physics is also a way to acquire the processes of knowledge construction, which will help you make decisions based on evidence rather than on personal opinions. When you hear an advertisement for a shampoo that makes your hair 97.5% stronger, you will ask: How do they know this? Did this number come from an experiment? If it did, was it tested? What assumptions did they make? Did they control for the food consumed, exercise, air quality, etc.? Understanding physics will help you differentiate between actual evidence and unsubstantiated claims. For instance, before you accept a claim, you might ask about the data supporting the claim, what experiments were used to test the idea, and what assumptions were made. Thinking critically about the messages you hear will change the way you make decisions as a consumer and a citizen.

Modeling. Physicists often model complex structures as point-like objects.

(a)

(b)

(c)



I.2 Modeling

Physicists study how the complex world works. To start the study of some aspect of that world, they often begin with a simplified version. Take a common phenomenon: a falling leaf. It twists and zigzags when falling. Different leaves move differently. If we wish to study how objects fall, a leaf is a complicated object to use. Instead, it is much easier to start by observing a small, round object falling. When a small, round object falls, all of its points move the same way—straight down. As another example, consider how you move your body when you walk. Your back foot on the pavement lifts and swings forward, only to stop for a short time when it again lands on the pavement, now ahead of you. Your arms swing back and forth. The trunk of your body moves forward steadily. Your head also moves forward but bobs up and down slightly, especially if you run. It would be very difficult to start our study of motion by analyzing all these complicated parts and movements. Thus, physicists create in their minds simplified representations (called **models**) of physical phenomena and then think of the phenomena in terms of those models. Physicists begin with very simple models and then add complexity as needed to investigate more detailed aspects of the phenomena.

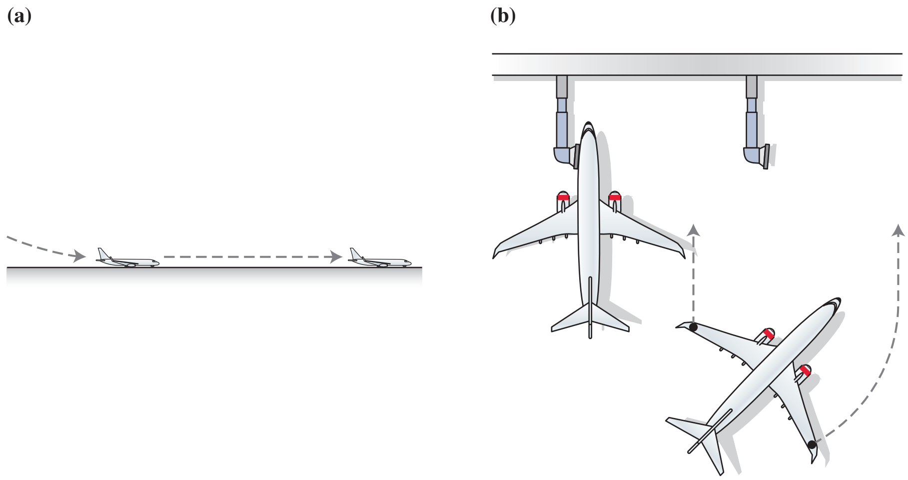
A simplified object

To simplify real objects, physicists often neglect both the dimensions of objects (their sizes) and their structures (the different parts) and instead regard them as single **point-like objects**.

Is modeling a real object as a point-like object a good idea? Imagine a 100-meter race. The winner is the first person to get a body part across the finish line. It might be a runner's toe or it might be the head. The judge needs to observe the movement of all body parts (or a photo of the parts) across a very small distance near the finish line to decide who wins. Here, that very small distance near the finish line is small compared to the size of the human body. This is a situation where modeling the runners as point-like objects is not reasonable. However, if you are interested in how long it takes a person to run 100 meters, then the movement of different body parts is not as important, since 100 meters is much larger than the size of a runner. In this case, the runners can be modeled as point-like objects. Even though we are talking about the same situation (a 100-meter race), the aspect of the situation that interests us determines how we choose to model the runners.

Consider an airplane landing on a runway (**Figure I.2a**). We want to determine how long it takes for it to stop. Since all of its parts move together, the part we study does not matter. In that case it is reasonable to model the airplane as a point-like object. However, if we want to build a series of gates for planes to unload passengers (Figure I.2b), then we need to consider the

Figure I.2 An airplane can be considered a point-like object (a) when landing, (b) but not when parking.



motion of the different parts of the airplane. For example, there must be enough room for an airplane to turn while maneuvering into and out of the gate. In this case the airplane cannot be modeled as a point-like object.

Point-like object **A point-like object is a simplified representation of a real object. As a rule of thumb, you can model a real object as a point-like object when one of the following two conditions are met: (a) when all of its parts move in the same way, or (b) when the object is much smaller than the other relevant lengths in the situation. The same object can be modeled as a point-like object in some situations but not in others.**

Modeling

The process that we followed to decide when a real object could be considered a point-like object is an example of what is called **modeling**. The modeling of objects is a first step that physicists use when they study natural phenomena. In addition to simplifying the objects that they study, scientists simplify the interactions between objects and also the processes that are occurring in the real world. Then they add complexity as their understanding grows. Galileo Galilei is believed to be the first scientist to consciously model a phenomenon. In his studies of falling objects in the early 17th century, he chose to simplify the real phenomenon by ignoring the interactions of the falling objects with the air.

Modeling **A model is a simplified representation of an object, a system (a group of objects), an interaction, or a process. A scientist creating the model decides which features to include and which to neglect.**

I.3 Physical quantities

To describe physical phenomena quantitatively, physicists construct **physical quantities:** features or characteristics of phenomena that can be measured experimentally. Measurement means comparing the characteristic to an assigned **unit** (a chosen standard).

Units of measure

Physicists describe physical quantities using the **SI system**, or ***Le Système international d'unités***, whose origin goes back to the 1790s when King Louis XVI of France created a special commission to invent a new metric system of units. For example, in the SI system length is measured in meters. One meter is approximately the distance from your nose to the tip of the fingers of your outstretched arm. A long step is about one meter. Other units of length are related to the meter by powers of 10 using prefixes (milli, kilo, nano, …). These prefixes relate smaller or bigger versions of the same unit to the basic unit. For example, 1 millimeter is 0.001 meter; 1 kilometer is 1000 meters. The prefixes are used when a measured quantity is much smaller or much larger than the basic unit. If the distance is much larger than 1 m, you might want to use the kilometer (10^3 m) instead. The most common prefixes and the powers of 10 to which they correspond are given on the inside of the book's back cover. In addition to the unit of length, the SI system has six other basic units, summarized in **Table I.1**.

The table provides a "feel" for some of the units but does not say exactly how each unit is defined. More careful definitions are important in order that measurements made by scientists in different parts of the world are consistent. However, to understand the precise definitions of these units, one needs to know more physics. We will learn how each unit is precisely defined when we investigate the concepts on which the definition is based.

Measuring instruments

Physicists use a measuring instrument to compare the quantity of interest with a standardized unit. Each measuring instrument is calibrated so that it reads in multiples of that unit. Some examples of measuring instruments are a thermometer to measure temperature (calibrated in degrees Celsius or degrees Fahrenheit), a watch to measure time intervals (calibrated in seconds), and a

Table I.1 Basic SI physical quantities and their units.

Physical quantity	Unit name and symbol	Physical description
Time	Second, s	One second is the time it takes for the heart to beat once.
Length	Meter, m	One meter is the length of one stride.
Mass	Kilogram, kg	One kilogram is the mass of 1 liter of water.
Electric current	Ampere, A	One ampere is the electric current through a 100-watt lightbulb in an American household
Temperature	Kelvin, K	One Kelvin degree is the same as 1 degree on the Celsius scale or about 2 degrees on the Fahrenheit scale.
Amount of matter	Mole, mol	One mole of oxygen is about 32 g.
Intensity of light	Candela, cd	One candela is the intensity of light produced by a relatively large candle at a distance of 1 m.

meter stick to measure the height of an object (calibrated in millimeters). We can now summarize these ideas about physical quantities and their units.

Physical quantity **A physical quantity is a feature or characteristic of a physical phenomenon that can be measured in some unit. A measuring instrument is used to make a quantitative comparison of this characteristic with a unit of measure. Examples of physical quantities are your height, your body temperature, the speed of your car, and the temperature of air or water.**

Significant digits

When we measure a physical quantity, the instrument we use and the circumstances under which we measure it determine how precisely we know the value of that quantity. Imagine that you wear a pedometer (a device that measures the number of steps that you take) and wish to determine the number of steps on average that you take per minute. You walk for 26 min (as indicated by your analog wristwatch) and see that the pedometer shows 2254 steps. You divide 2254 by 26 using your calculator, and it says 86.692307692307692. If you accept this number, it means that you know the number of steps per minute within plus or minus 0.000000000000001 steps/min. If you accept the number 86.69, it means that you know the number of steps to within 0.01 steps/min. If you accept the number 90, it means that you know the number of steps within 10 steps/min. Which answer should you use?

To answer this question, let's first focus on the measurements. Although your watch indicated that you walked for 26 min, you could have walked for as few as 25 min or for as many as 27 min. The number 26 does not give us enough information to know the time more precisely than that. The time measurement 26 min has two **significant digits**, or two numbers that carry meaning contributing to the precision of the result. The pedometer measurement 2254 has four significant digits. Should the result of dividing the number of steps by the amount of time you walked have two or four significant digits? If we accept four, it means that the number of steps per minute is known more precisely than the time measurement in minutes. This does not make sense. The number of significant digits in the final answer should be the same as the number of significant digits of the quantity used in the calculation that has the *smallest number of significant digits*. Thus, in our example, the average number of steps per minute should be 86, plus or minus 1 step/min: 86 ± 1.

Let's summarize the rule for determining significant digits. The precision of the value of a physical quantity is determined by one of two cases. If the quantity is measured by a single instrument, its precision depends on the instrument used to measure it. If the quantity is calculated from other measured quantities, then its precision depends on the least precise instrument out of all the instruments used to measure a quantity used in the calculation.

Another issue with significant digits arises when a quantity is reported with no decimal points. For example, how many significant digits does 6500 have—two or four? This is where scientific notation helps. **Scientific notation** means writing numbers in terms of their power of 10. For example, we can write 6500 as 6.5×10^3. This means that the 6500 actually has two significant digits: 6 and 5. If we write 6500 as 6.50×10^3, it means 6500 has three significant digits: 6, 5, and 0. The number 6.50 is more precise than the number 6.5, because it means that you are confident in the number to the hundredths place. Scientific notation provides a compact way of writing large and small numbers and also allows us to indicate unambiguously the number of significant digits a quantity has.

Measuring and estimating. In everyday life, rough estimates are often sufficient.

I.4 Making rough estimates

Sometimes we are interested in making a rough estimate of a physical quantity. The ability to make rough estimates is useful in a variety of situations, such as the following. (1) You need to decide whether a goal is worth pursuing—for example, can you make a living as a piano tuner in a town that already has a certain number of tuners? (2) You need to know roughly the amount of material needed for some activity—for instance, the food needed for a party or the number of bags of fertilizer needed for your lawn. (3) You want to estimate a number before it is measured—for example, how rapid a time-measuring device should be to detect laser light reflected from a distant object. (4) You wish to check whether a measurement you have made is reasonable—for instance, the measurement of the time for light to travel to a mountain and back or the mass of oxygen consumed by a hummingbird. (5) You wish to determine an unknown quantity—for example, an estimation of the number of cats in the United States or the compression force on the disks in your back when lifting a box of books in different ways.

The procedure for making rough estimates usually means selecting some basic physical quantities whose values are known or can be estimated and then combining the numbers using a mathematical procedure that leads to the desired answer. For example, suppose we want to estimate the number of pounds of food that an average person eats during a lifetime. First, assume that the average person consumes about 2000 calories/day to maintain a healthy metabolism. This food consists of carbohydrates, proteins, and fat. Using the labels of food packaging we find that 1 gram of carbohydrate or 1 gram of protein gives us about 4 calories, and 1 g of fat gives us about 9 calories. Thus, we assume that each gram of food consumed gives us on average 5 calories. Thus, each day, according to our assumptions, the person consumes about

$$(2000 \text{ calories/day})(1 \text{ g/5 calories}) = 400 \text{ g/day}$$

There are 365 days in a year, and we assume that the average life expectancy of a person is 70 years. Thus, the total food consumed during a lifetime is

$$(2000 \text{ calories/day})(1 \text{ g/5 calories})(365 \text{ days/year})(70 \text{ years/lifetime}) \\ = 10{,}080{,}000 \text{ g/lifetime}$$

From the conversion table on the inside front cover, we see that 2.2 lb is 1000 g. Thus, our estimate of the number of pounds of food consumed in a lifetime is

$$(10{,}080{,}000 \text{ g/lifetime})(2.2 \text{ lb}/1000 \text{ g}) = 22{,}176 \text{ lb/lifetime}$$

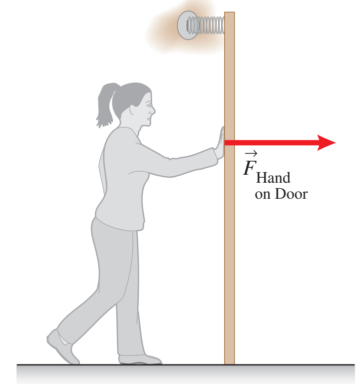
Our estimated result has five significant digits. Is this appropriate? To answer this, we need to look at the number of significant digits in each quantity used in the estimate. The calories/day quantity is probably uncertain by about 500 calories. That means the 2000 calories/day has just one significant digit. The ratio $(1 \text{ g/5 calories}) = 0.20$ could probably be $(1 \text{ g/6 calories}) = 0.17$, or about 0.03 different from our estimate. So that quantity has one or two significant digits. The life expectancy (70 years) could be off by about 10 years. Again, that's just one significant digit. Since the least certain quantity used in the calculation (the calories/day) has one significant digit, the final result should also be reported with just one significant digit. That would be 20,000 lb/lifetime.

I.5 Vector and scalar physical quantities

There are two general types of physical quantities—those that contain information about magnitude as well as direction and those that contain magnitude information only. Physical quantities that do not contain information about direction are called **scalar quantities** and are written using *italic* symbols (m, T, etc). Mass is a scalar quantity, as is temperature. To manipulate scalar quantities, you use standard arithmetic and algebra rules—addition, subtraction, multiplication, division, etc. You add, subtract, multiply, and divide scalars as though they were ordinary numbers.

Physical quantities that contain information about magnitude and direction are called **vector quantities** and are represented by italic symbols with an arrow on top ($\vec{F}$, $\vec{v}$, etc.). The little arrow on top of the symbol always points to the right. The actual direction of the vector quantity is shown in a diagram. For example, force is a physical quantity with both magnitude and direction (direction is very important if you are trying to hammer a nail into the wall). When you push a door, your push can be represented with a force arrow on a diagram; the stronger you push, the longer that arrow must be. The direction of the push is represented by the direction of that arrow (**Figure I.3**). The arrow's direction indicates the direction of the vector, and the arrow's relative length indicates the vector's magnitude. The methods for manipulating vector quantities (adding and subtracting them as well as multiplying a vector quantity by a scalar quantity and multiplying two vector quantities) are introduced as needed in the following chapters. Such manipulations are also summarized in the appendix Working with Vectors.

Figure I.3 The force that your hand exerts on a door is a vector quantity represented by an arrow.



Scalar quantities. Temperature is a scalar quantity; it has magnitude, but not direction.

I.6 How to use this book to learn physics

A textbook is only one part of a learning system, but knowing how to use it most effectively will make it easier to learn and to succeed in the course. This textbook will help you construct understanding of some of the most important ideas in physics, learn to use physics knowledge to analyze physical phenomena, and develop the general process skills that scientists use in the practice of science.

Learning new material

Read the book as soon as possible after new material is discussed in class while the material is still fresh in your mind. First, scan the relevant sections and, if necessary, the whole chapter. Does it appear that the material involves completely new ideas, or is it just the application of what you have already learned? If the material does involve new ideas, how do the new ideas fit into what you have already learned? Then, read the relevant new section(s) slowly. Keep relating what you read to your current understanding. Pay attention to the Tips—they will help prevent confusion and future difficulties.

The most important strategy that will help you learn better is called **interrogation.** Interrogation means continually asking yourself the same question when reading the text. This question is so important that we put it in the box below:

Why is this true?

Make sure that you ask yourself this question as often as possible so that eventually it becomes a habit. Out of all the strategies that are recommended for reading comprehension, this is the one that is directly connected to better learning outcomes. For example, consider the first sentence of the next paragraph: "Solving physics problems is much more than plugging numbers into an equation." Ask yourself, "Why is this true?" Possibly, because one needs to understand what physics concepts are relevant, or what simplifying assumptions are important. There can be other reasons. By just stopping and interrogating yourself as often as possible about what is written in the book you will be able to understand and remember this information better.

Problem solving

Solving physics problems is much more than plugging numbers into an equation. To use the book for problem-solving practice, focus on the problem-solving steps used in the worked examples.

Step 1: *Sketch and Translate* First, read the text of the problem several times slowly to make sure you understand what it says. Next, try to visualize the situation or process described in the text of the problem. Try to imagine what is happening. Draw a sketch of the process and label it with any information you have about the situation. This often involves an initial situation and a final situation. Often, the information in the problem statement is provided in words and you will need to *translate* it into physical quantities. Having the problem information in a visual sketch also frees some of your mind so that you can use its resources for other parts of the problem solving.

Step 2: *Simplify and Diagram* Decide how you can simplify the process. How will you model the object of interest (the object you are investigating)? What interactions can you neglect? To diagram means to represent the problem process using some sort of diagram, bar chart, graph, or picture that includes physics quantities. Diagrams bridge the gap between the verbal and sketch representations of the process and the mathematical representation of it.

Step 3: *Represent Mathematically* Construct a mathematical description of the process. You will use the sketch from Step 1 and the diagram(s) from Step 2 to help construct this mathematical description and evaluate it to see if it is reasonable. By representing the situation in these multiple ways and learning to translate from one way to the other, you will start giving meaning to the abstract symbols used in the mathematical description of the process.

Step 4: *Solve and Evaluate* Finally, solve the mathematical equations and evaluate the results. Do the numbers and signs make sense? Are the units correct? Another method involves evaluating whether the answer holds in extreme cases—you will learn more about this technique as you progress through the book.

Try to solve the example problems that are provided in the chapters by using this four-step strategy without looking at the solution. After finishing, compare your solution to the one described in the book. Then do the *Try It Yourself* part of the example problem and compare your answer to the book's answer. If you are still having trouble, try to use the same strategy to actively solve other example problems in the text or from the Active Learning Guide (if you are using that companion book). Uncover the solutions to these worked examples only after you have tried to complete the problem on your own. Then try the same process on the homework problems assigned by your instructor.

Notice that quantitative exercises and conceptual exercises in the book have fewer steps: *Represent Mathematically* and *Solve and Evaluate* for the quantitative exercises, and *Sketch and Translate* and *Simplify and Diagram* for the conceptual exercises. Sketching the process and representing it in different ways is an important step in solving any problem.

Summary

We are confident that this book will act as a useful companion in your study of physics and that you will take from the course not just the knowledge of physics but also an understanding of the process of science that will help you in all your scientific endeavors. Learning physics through the approach used in this book builds a deeper understanding of physics concepts and an improved ability to solve difficult problems compared to traditional learning methods. In addition, you will learn to reason scientifically and be able to transfer those reasoning skills to many other aspects of your life.

1 Kinematics: Motion in One Dimension

What is a safe following distance between you and the car in front of you?

Can you be moving and not moving at the same time?

Why do physicists say that an upward thrown object is falling?

Be sure you know how to:

- Define what a point-like object is (Introducing Physics).
- Use significant digits in calculations (Introducing Physics).

When you drive, you are supposed to follow the 3-second tailgating rule. When the car in front of you passes some fixed sign at the side of the road, your car should be far enough behind so that it takes you 3 seconds to reach the same sign. You then have a good chance of avoiding a collision if the car in front stops abruptly. If you are 3 seconds behind the car in front of you when you see its brake lights, you should be able to step on the brake and avoid a collision. If you are closer than 3 seconds away, a collision is likely. In this chapter we will learn the physics behind the 3-second rule.

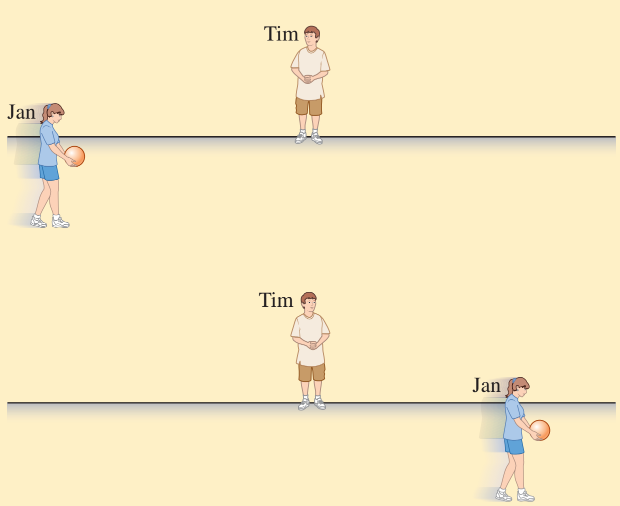
Scientists often ask questions about things that most people accept as being "just the way it is." For example, in the northern hemisphere, we have more hours of daylight in June than in December. In the southern hemisphere, it's just the opposite. Most people simply accept this fact. However, scientists want explanations for such simple phenomena. In this chapter, we learn to describe a phenomenon that we encounter every day but rarely question—motion.

1.1 What is motion?

When describing motion, we need to focus on two important aspects: the object whose motion we are describing (**the object of interest**) and the person who is doing the describing (**the observer**). Consider Observational Experiment **Table 1.1**, which analyzes how the description of an object's motion depends on the observer.

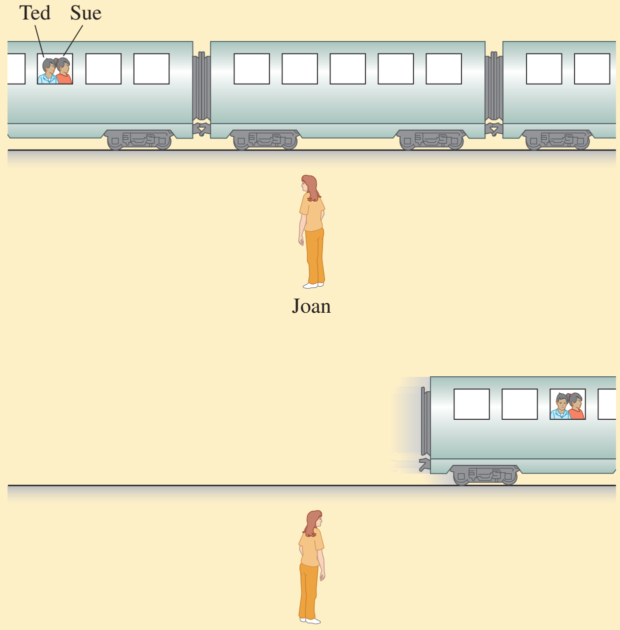
OBSERVATIONAL EXPERIMENT TABLE

1.1 Different observers describe an object's motion.

Observational experiment	Analysis
Experiment 1. Jan observes a ball in her hands as she walks across the room. Tim, sitting at a desk, also observes the ball. Jan reaches the other side of the room without taking her eyes from the ball; her head did not turn. Tim's head has turned in order to follow the ball. 	The two observers (Jan and Tim) see the same object of interest (the ball) differently. With respect to Jan, the ball's position does not change. With respect to Tim, its position does change.

(*continued*)

Observational experiment	Analysis
Experiment 2. Ted and Sue are passengers on the same train. Ted does not have to turn his head to keep his eyes on Sue. Joan, standing on the station platform, turns her head to follow Sue.	Ted and Joan see the same object of interest (Sue) differently. With respect to Ted, Sue's position does not change. With respect to Joan, Sue's position changes.



Pattern

Different observers can describe the same process differently, including whether or not motion is even occurring.

In Table 1.1, we saw that different observers can describe the same process differently. One person sees the object of interest moving while another does not. They are both correct from their own perspectives. In order to describe the motion of something, we need to identify the observer.

> **Motion is a change in an object's position relative to a given observer during a certain change in time. Without identifying the observer, it is impossible to say whether the object of interest moved. Physicists say *motion is relative,* meaning that the motion of any object of interest depends on the point of view of the observer.**

Are you moving as you read this book? Your friend walking past you first sees you in front of her, then she sees you next to her, and finally she sees you behind her. Though you are sitting in a chair, you definitely are moving with respect to your friend. You are also moving with respect to the Sun or with respect to a bird flying outside.

What makes the idea of relative motion confusing at first is that people intuitively use Earth as the object of reference—the object with respect to which they describe motion. If an object does not move with respect to Earth, many people would say that the object is not moving. That is why it took scientists thousands of years to understand the reason for days and nights on Earth. An observer on Earth uses Earth as the object of reference and sees the Sun moving in an arc across the sky (**Figure 1.1a**). An observer on a distant spaceship sees Earth rotating on its axis so that different parts of its surface face the Sun at different times (Figure 1.1b).

Reference frames

Specifying the observer before describing the motion of an object of interest is an extremely important part of constructing what physicists call a **reference frame.** A reference frame includes an object of reference, a coordinate system with a scale for measuring distances, and a clock to measure time. If the object of reference is large and cannot be considered a point-like object, it is important to specify where on the object of reference the origin of the coordinate system is placed. For example, if you want to describe the motion of a bicyclist and choose your object of reference to be Earth, you place the origin of the coordinate system at the surface, not at Earth's center.

Reference frame **A reference frame includes three essential components:**
(a) An *object of reference* with a specific *point of reference* on it.
(b) A *coordinate system*, which includes one or more coordinate axes, such as, *x, y, z*, and an origin located at the point of reference. The coordinate system also includes a unit of measurement (a scale) for specifying distances along the axes.
(c) A *clock*, which includes an origin in time called $t = 0$ and a unit of measurement for specifying times and time intervals.

Modeling motion

When we model objects, we make simplified assumptions in order to analyze complicated situations. Just as we simplified an object to model it as a point-like object, we can also simplify a process involving motion. What is the simplest way an object can move?

Imagine that you haven't ridden a bike in a while. You would probably start by riding in a straight line before you attempt a turn. This kind of motion is called **linear motion** or **one-dimensional motion**.

Linear motion **is a model of motion that assumes that an object, considered as a point-like object, moves along a straight line.**

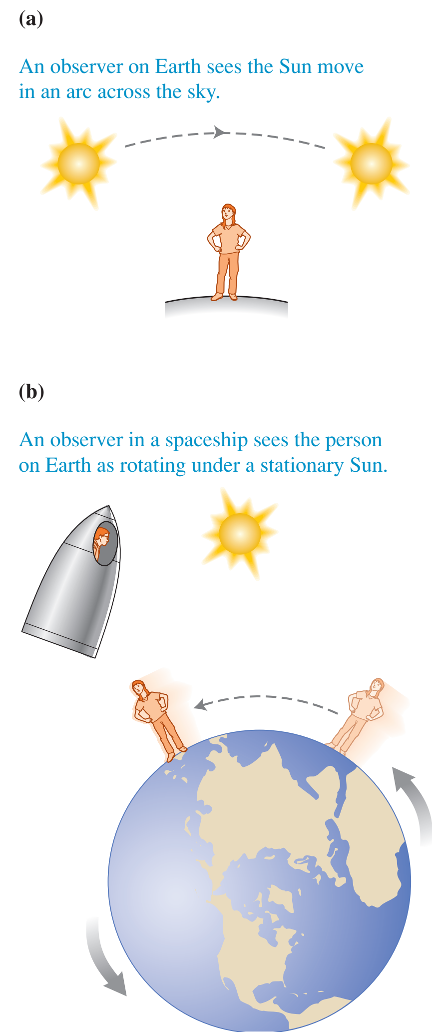
For example, we want to model a car's motion along a straight stretch of highway. We can assume the car is a point-like object (it is small compared to the length of the highway) and the motion is linear motion (the highway is long and straight).

Review Question 1.1 Physicists say, "Motion is relative." Why is this true?

1.2 A conceptual description of motion

To describe linear motion more precisely, we start by devising a visual representation. Consider Observational Experiment **Table 1.2**, in which a bowling ball rolls on a smooth floor.

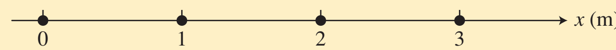
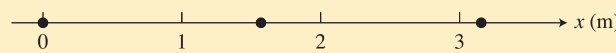
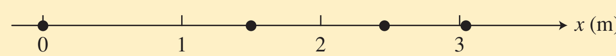
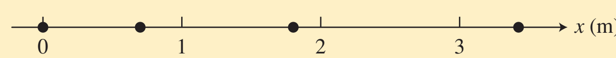
Figure 1.1 Motion is relative. Two observers explain the motion of the Sun relative to Earth differently.



OBSERVATIONAL EXPERIMENT TABLE

1.2 Using dots to represent motion.

VIDEO 1.2

Observational experiment	Analysis
Experiment 1. You push a bowling ball (the object of interest) once and let it roll on a smooth linoleum floor. You place beanbags each second beside the bowling ball. The beanbags are evenly spaced.	We can represent the locations of the bags each second for the slow-moving bowling ball as dots on a diagram. 
Experiment 2. You repeat Experiment 1, but you push the ball harder before you let it roll. The bean-bags are farther apart but are still evenly spaced.	The dots in this diagram represent the evenly spaced bags, which are separated by a greater distance than the bags in Experiment 1. 
Experiment 3. You push the bowling ball and let it roll on a carpeted floor instead of a linoleum floor. The distance between the beanbags decreases as the ball rolls.	The dots in this diagram represent the decreasing distance between the bags as the ball rolls on the carpet. 
Experiment 4. You roll the ball on the linoleum floor and gently and continually push on it with a board. The beanbag separation spreads farther apart as the pushed ball rolls.	The dots in this diagram represent the increasing distance between bags as the ball is continually pushed across the linoleum floor. 

Pattern

- The spacing of the dots allows us to visualize motion.
- When the object travels without speeding up or slowing down, the dots are evenly spaced.
- When the object slows down, the dots get closer together.
- When the object moves faster and faster, the dots get farther apart.

Motion diagrams

In the experiments in Table 1.2, the beanbags were an approximate record of where the ball was located as time passed and help us visualize the motion of the ball. We can represent motion in even more detail by adding **velocity arrows** to each dot that indicate which way the object is moving and how fast it is moving as it passes a particular position (see **Figure 1.2**). These new diagrams are called **motion diagrams.** The longer the arrow, the faster the motion. The small arrow above the letter v indicates that this characteristic of motion has a direction as well as a magnitude—called a **vector quantity**. In Figure 1.2a, the dots are evenly spaced, and the velocity arrows all have the same length and point in the same direction. This means that the ball was moving equally fast in the same direction at each point. Similar diagrams with velocity arrows for the other three experiments in Table 1.2 are shown in Figures 1.2b–d.

Velocity change arrows

In Experiment 4 the bowling ball was moving increasingly fast while being pushed. The velocity arrows in the motion diagram thus got increasingly longer. We can represent this change with a **velocity change arrow** $\Delta\vec{v}$. The Δ(delta) means a change in whatever quantity follows the Δ, a change in $\vec{v}$ in this case. The $\Delta\vec{v}$ doesn't tell us the exact increase or decrease in the velocity; it only indicates a qualitative difference between the velocities at two adjacent points in the diagram.

REASONING SKILL Constructing a motion diagram.

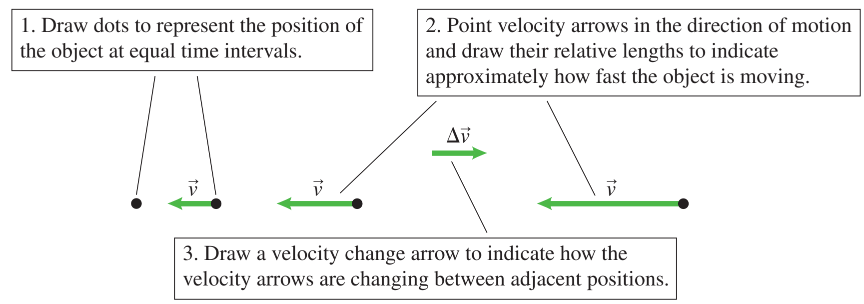
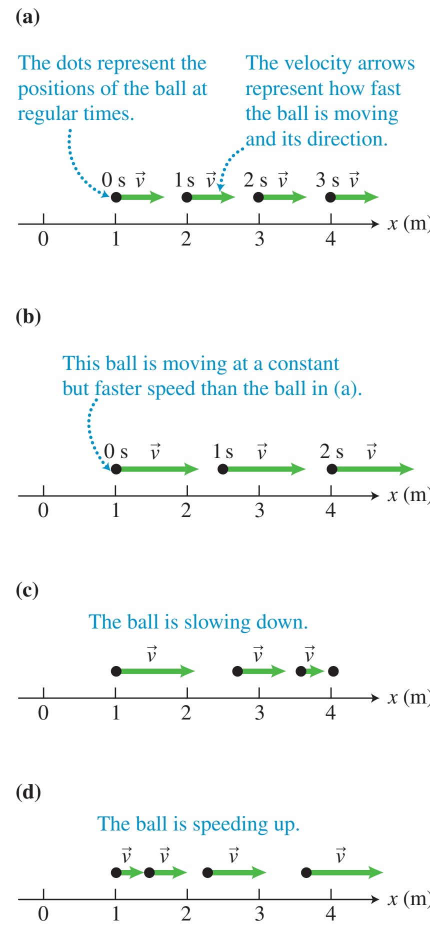


Figure 1.2 Motion diagrams represent the types of motion shown in Table 1.2.



Note that we have redrawn the diagram shown in Figure 1.2d in **Figure 1.3a**. For illustration purposes only, we number the $\vec{v}$ arrows consecutively for each position: $\vec{v}_1$, $\vec{v}_2$, $\vec{v}_3$, etc. To draw the velocity change arrow as the ball moves from position 2 to position 3 in Figure 1.3a, we place the second arrow $\vec{v}_3$ directly above the first arrow $\vec{v}_2$, as shown. The $\vec{v}_3$ arrow is longer than the $\vec{v}_2$ arrow. This tells us that the object was moving faster at position 3 than at position 2. To visualize the change in velocity, we need to think about how arrow $\vec{v}_2$ can be turned into $\vec{v}_3$. We can do it by placing the tail of a velocity change arrow $\Delta\vec{v}_{23}$ at the head of $\vec{v}_2$ so that the head of $\Delta\vec{v}_{23}$ makes the combination $\vec{v}_2 + \Delta\vec{v}_{23}$ the same length as $\vec{v}_3$ (Figure 1.3b). Since they are the same length and in the same direction, the two vectors $\vec{v}_2 + \Delta\vec{v}_{23}$ and $\vec{v}_3$ are equal:

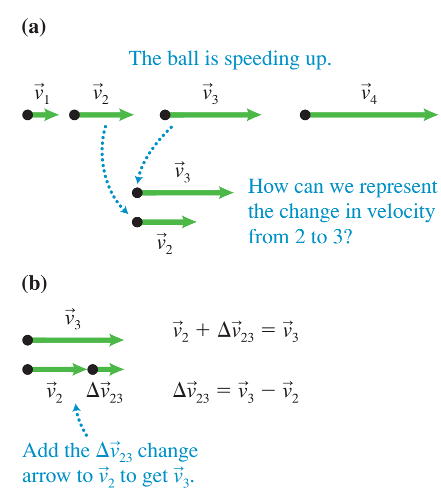
$$\vec{v}_2 + \Delta\vec{v}_{23} = \vec{v}_3$$

Note that if we move $\vec{v}_2$ to the other side of the equation, then

$$\Delta\vec{v}_{23} = \vec{v}_3 - \vec{v}_2$$

Thus, $\Delta\vec{v}_{23}$ is the difference of the third velocity arrow and the second velocity arrow—the change in velocity between position 2 and position 3. (To learn more about vector addition, read the appendix Graphical Addition and Subtraction of Vectors.)

Figure 1.3 Determining the magnitude and the direction of the velocity change arrow in a motion diagram.

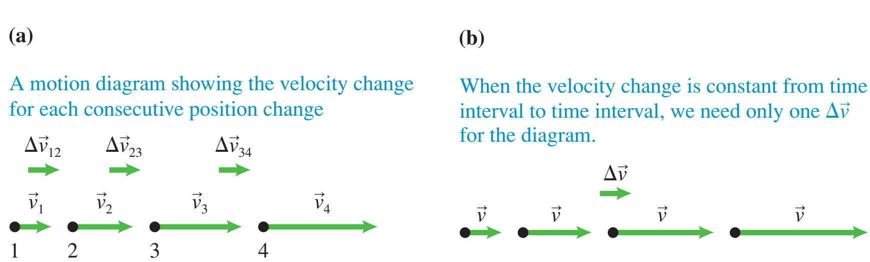


Making a complete motion diagram

We now place the $\Delta\vec{v}$ arrows above and between the dots in our diagrams where the velocity change occurred (see **Figure 1.4a**). The dots in these more detailed motion diagrams indicate the object's position at equal time intervals; velocity arrows and velocity change arrows are also included. A $\Delta\vec{v}$ arrow points in the same direction as the $\vec{v}$ arrows when the object is speeding up; the $\Delta\vec{v}$ arrow points in the opposite direction of the $\vec{v}$ arrows when the object is slowing down. When velocity changes by the same amount during each consecutive time interval, the $\Delta\vec{v}$ arrows for each interval are the same length. In such cases we need only one $\Delta\vec{v}$ arrow for the entire motion diagram (see Figure 1.4b).

The Reasoning Skill box summarizes the procedure for constructing a motion diagram. Notice that in the experiment represented in this diagram, the object is moving from right to left and slowing down.

Figure 1.4 Two complete motion diagrams, including position dots, $\vec{v}$ arrows, and $\Delta\vec{v}$ arrows.



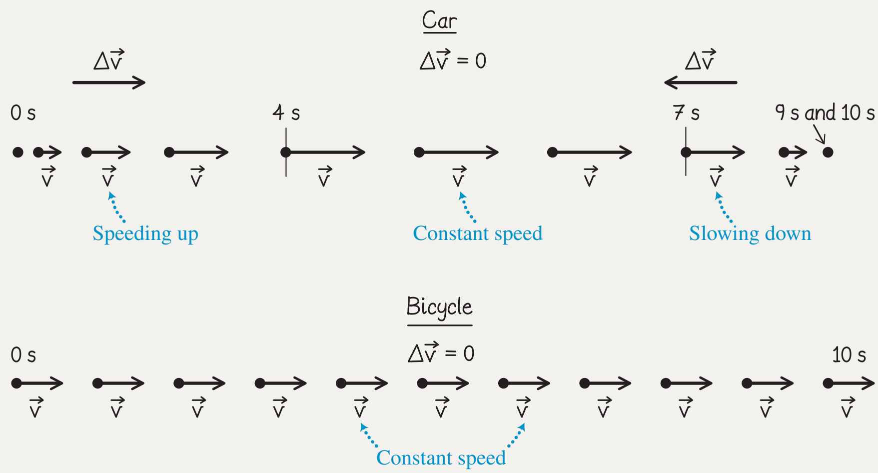
TIP When drawing a motion diagram, always specify the position of the observer. In the Reasoning Skill box, the observer is on the ground.

Read Conceptual Exercise 1.1 several times and visualize the situation. If possible, draw a sketch of what is happening. Then construct a physics representation (in this case, a motion diagram) for the process.

CONCEPTUAL EXERCISE 1.1

Driving in the city

A car at rest at a traffic light starts moving faster and faster when the light turns green. The car reaches the speed limit in 4 seconds, continues at the speed limit for 3 seconds, then slows down and stops in 2 seconds while approaching the second stoplight. There, the car is at rest for 1 second until the light turns green. Meanwhile, a cyclist approaching the first green light keeps moving without slowing down or speeding up. She reaches the second stoplight just as it turns green. Draw a motion diagram for the car and another for the bicycle as seen by an observer on the ground. If you place one diagram below the other, it will be easier to compare them.



Sketch and translate Visualize the motion for the car and for the bicycle as seen by the observer on the ground. The car and the bicycle will be our objects of interest.

The motion of the car has four distinct parts:

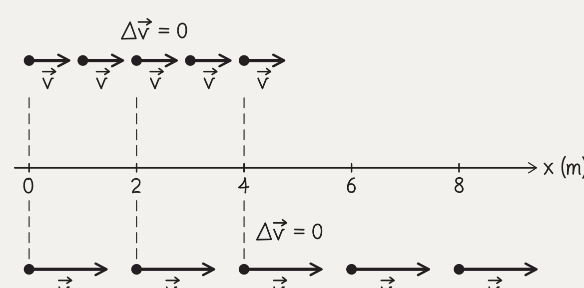
1. starting at rest and moving faster and faster for 4 seconds;
2. moving at a constant rate for 3 seconds;
3. slowing down to a stop for 2 seconds; and
4. sitting at rest for 1 second.

The bicycle moves at a constant rate with respect to the ground for the entire time.

Simplify and diagram We can model the car and the bicycle as point-like objects (dots). In each motion diagram, there will be 11 dots, one for each second of time (including one for time zero). The last two dots for the car will be on top of each other since the car was at rest from time = 9 s to time = 10 s. The dots for the bicycle are evenly spaced.

Try it yourself: Two bowling balls are rolling along a linoleum floor. One of them is moving twice as fast as the other. At time zero, they are next to each other on the floor. Construct motion diagrams for each ball's motion during a time of 4 seconds, as seen by an observer on the ground. Indicate on the diagrams the locations at which the balls were next to each other at the same time. Indicate possible mistakes that a student can make answering the question above.

Answer: See the figure below. The balls are side by side only at time zero—the first dot for each ball. It looks like they are side by-side when at the 2-m position, but the slow ball is at the 2-m position at 2 s and the faster ball is there at 1 s. Similar reasoning applies for the 4-m positions—the balls reach that point at different times.



Review Question 1.2 What information about a moving object can we extract from a motion diagram?

1.3 Quantities for describing motion

A motion diagram helps represent motion qualitatively. To analyze situations more precisely, for example, to determine how far a car will travel after the brakes are applied, we need to describe motion quantitatively. In this section, we devise some of the quantities we need to describe linear motion.

Time and time interval

People use the word "time" to talk about the reading on a clock and how long a process takes. Physicists distinguish between these two meanings with different terms: time (a clock reading) and time interval (a difference in clock readings).

> **Time and time interval** ***Time*** **(clock reading)** t **is the reading on a clock or some other time-measuring instrument.** ***Time interval*** **$(t_2 - t_1)$ or Δt is the difference of two times. In the SI system (metric units), the unit of time and of time interval is the second. Other units are minutes, hours, days, and years. Time and time interval are both scalar quantities.**

Position, displacement, distance, and path length

Along with a precise definition for time and time interval, we need to precisely define four quantities that describe the location and motion of an object: position, displacement, distance, and path length.

> **Position, displacement, distance, and path length** **The** ***position*** **of an object is its location with respect to a particular coordinate system (usually indicated by x or y). The** ***displacement*** **of an object, usually indicated by $\vec{d}$, is a vector that starts from an object's initial position and ends at its final position. The magnitude (length) of the displacement vector is called** ***distance d.*** **The** ***path length l*** **is how far the object moved as it traveled from its initial position to its final position. Imagine laying a string along the path the object took. The length of string is the path length.**

Figure 1.5 Position, displacement, distance, and path length for a short car trip.

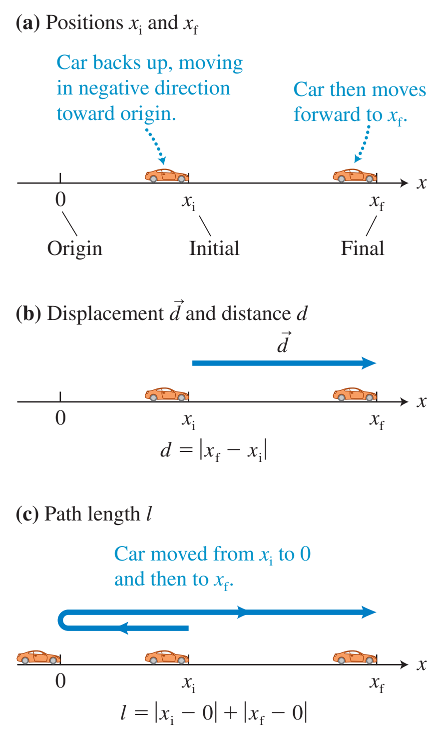


Figure 1.5a shows a car's initial position x_i at initial time t_i. The car first backs up (moving in the negative direction) toward the origin of the coordinate system at $x = 0$. The car stops and then moves in the positive x-direction to its final position x_f. Notice that the *initial position* and the *origin* of a coordinate system are not necessarily the same points! The displacement $\vec{d}$ for the whole trip is a vector that points from the starting position at x_i to the final position at x_f (Figure 1.5b). The distance for the trip is the magnitude of the displacement (always a positive value). The path length l is the distance from x_i to 0 plus the distance from 0 to x_f (Figure 1.5c). Note that the path length does not equal the distance.

> **TIP** Sometimes we use the subscripts 1, 2, and 3 for times and the corresponding positions to communicate a sequence of different and distinguishable stages in any process, and sometimes we use i (initial) and f (final) to communicate the sequence.

Scalar component of displacement for motion along one axis

To describe linear motion quantitatively we first specify a reference frame. For simplicity we can point one coordinate axis either parallel or antiparallel (opposite in direction) to the object's direction of motion. For linear motion,