GLOBAL EDITION

Conceptual Integrated Science

THIRD EDITION

Hewitt
Lyons
Suchocki
Yeh

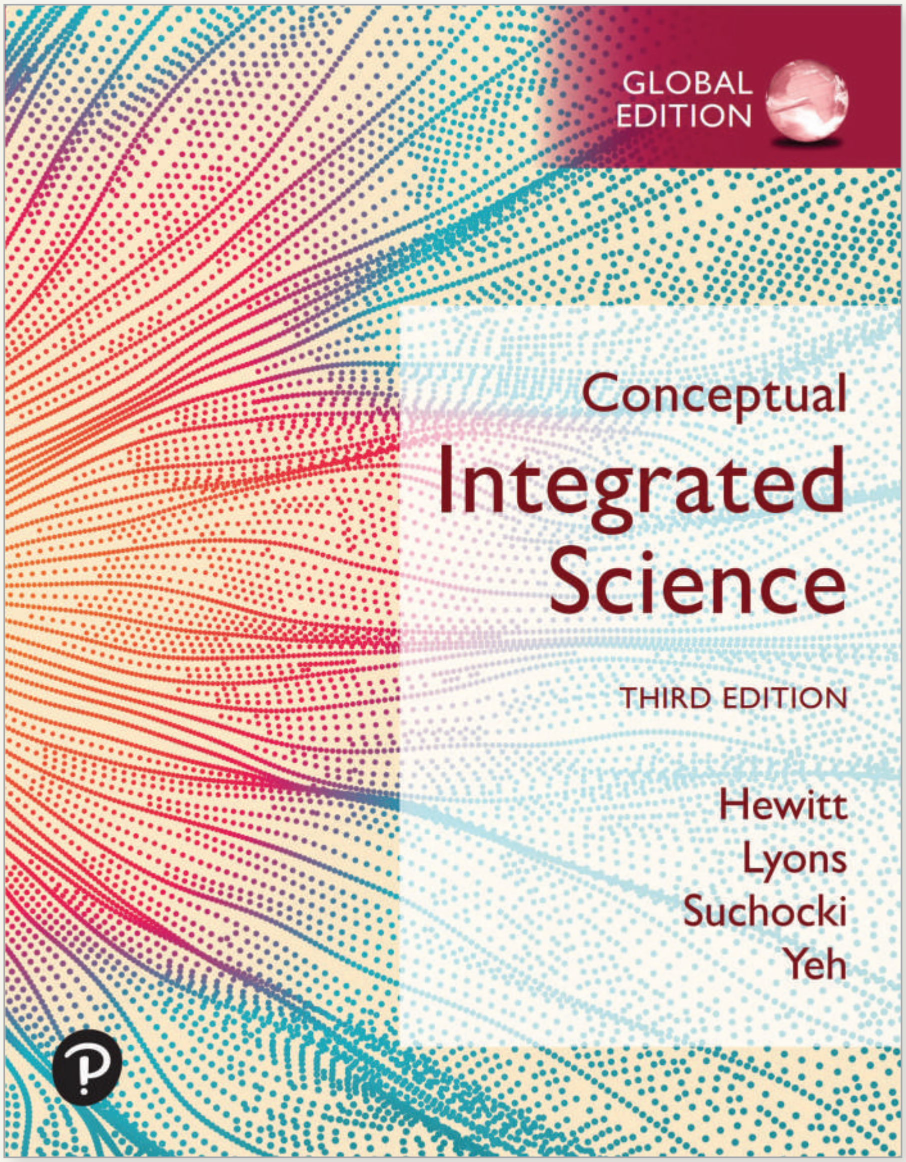
SOME UNIFYING CONCEPTS OF SCIENCE

Listed below are some key concepts that you will encounter across scientific disciplines. These are highlighted in the text with the Unifying Concept label as shown below. Take special care to understand these ideas because they have many applications. You will see that many of these principles are from physics. This is to be expected, because physics is the most fundamental science in the following sense: Chemistry builds on physics. Earth sciences and astronomy apply physical and chemical principles to the planets and beyond, while biology brings concepts from physics and chemistry to the study of life. For all their complexity, the subjects we investigate in the natural sciences are based on a small number of fundamental ideas.

UNIFYING CONCEPTS	Definition
• The Scientific Method Section 1.3	The practice of science that typically incorporates the following steps: Observe, Question, Hypothesize, Predict, Test Predictions, and Draw a Conclusion.
• Density Section 2.3	The compactness of the matter making up an object; described by the object's density, or mass/volume.
• Friction Section 2.8	Whenever two objects are in contact, the resistive force that acts in such a way as to prevent or slow their relative motion.
• Newton's First Law Section 3.1	Every object continues in a state of rest, or in a state of motion in a straight line at constant speed, unless it is compelled to change that state by a force exerted on it.
• Newton's Second Law Section 3.2	The acceleration produced by a net force on an object is directly proportional to the net force, is in the same direction as the net force, and is inversely proportional to the mass of the object. In symbols, $a = F/m$.
• Newton's Third Law Section 3.4	For every force in nature, there is a matching equal and opposite force.
• The Law of Conservation of Momentum Section 4.4	In the absence of an external force, the momentum of a system remains unchanged.
• The Law of Conservation of Energy Section 4.11	Energy cannot be created or destroyed.
• The Gravitational Force Section 5.3	The mutually attracting force due to mass with which every body in the universe attracts every other body. For two bodies, this force is directly proportional to the product of their masses and inversely proportional to the square of the distance between them: $F = Gm_1m_2/r^2$.
• The Second Law of Thermodynamics Section 6.5	Natural systems tend to disperse from concentrated and organized energy states toward diffuse and disorganized states.
• Convection Section 6.9	The transfer of thermal energy in which, as a fluid is heated from below, the molecules at the bottom move faster, spread apart more, become less dense, and are buoyed upward.
• The Electric Force Section 7.1	The force through which like charges repel and unlike charges attract. The magnitude of this force is proportional to the products of the charges (q_1 and q_2) and inversely proportional to the square of the distance r between them: $F = kq_1q_2/r^2$.
• Waves Section 8.1	Disturbances generated by a vibrating object, which transport energy away from the source.
• The Atomic Nature of Matter Section 9.1	Material objects are made of atoms, which means they are composed of electrons and protons and neutrons.
• Mass–Energy Equivalence Section 10.5	All objects have an "energy of being" or rest energy, which is equal to the object's rest mass times the speed of light squared: $E = mc^2$.
• Feedback Loop Section 19.2	A control mechanism in which changes in one variable affect a second variable, and changes in the second variable in turn affect the first variable.
• The Ecosystem Section 21.1	A dynamic and complex whole in which organisms and the physical environment influence one another.
• Exponential Growth and Decay Appendix D	A quantity that increases (or decreases) at a rate that is proportional to its value.

Emphasize concepts and enable students to connect ideas across the sciences

The best-selling ***Conceptual Integrated Science*** provides an engaging overview of physics, chemistry, Earth science, astronomy, and biology at a level appropriate for nonscience students. Hewitt's engaging narrative emphasizes unifying concepts across physical and life sciences through a clear, friendly writing style and fun, relevant examples that motivate students. Enhanced digital tools and additional practice problems in **Mastering™ Physics** and the **Pearson eTextbook** ensure students master the basic content needed to succeed in this course.



Build a foundation across the sciences

LEARNING OBJECTIVE
Relate energy conservation to living things.

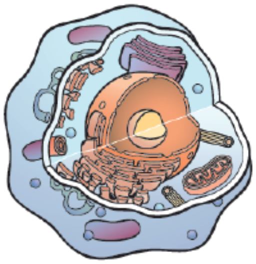


FIGURE 4.27
This cutaway view of a generalized animal cell shows various specialized structures, including the orange and yellow nucleus in the center. The pink structure at the lower right and the others scattered throughout the cell are *mitochondria*, which provide the cell with energy through cellular respiration.

FIGURE 4.28
Plants capture solar energy and transform it into chemical energy, which is stored in large molecules. When other organisms consume the plants, they obtain the energy they need for life.

Integrated Science 4B
BIOLOGY AND CHEMISTRY

Glucose: Energy for Life

Your body is in many ways a machine—a fantastically complex machine. It is made up of smaller machines, the living cells (Figure 4.27). Like any machine, a living cell needs a source of energy. The principal energy source used by most living things is the sugar glucose, $C_6H_{12}O_6$. One glucose molecule contains six atoms of carbon (C), twelve atoms of hydrogen (H), and six atoms of oxygen (O). The glucose molecule is rich in stored energy (chemical potential energy). Organisms break down glucose in their cells and harvest the energy it contains to power the chemical and physical processes that sustain life, as discussed in more detail in Chapter 15.

You obtain glucose from the food you eat indirectly, by way of some rather complex chemical reactions. A few super-sweet foods contain glucose, but most consist of other, more complex carbohydrates, such as starch, or some combination of carbohydrates, fats, and proteins. Your body must break down these nutrients to produce glucose, a raw fuel that is then passed on to your cells. Glucose molecules are taken apart inside your cells, where energy is liberated from them. The actual energy harvesting typically takes place through ***cellular respiration***, a process that occurs in specialized structures within the cell—mitochondria, the "power plants" of the cells. Cells use the released energy to do all the tasks they must do to stay alive and to perform their specialized functions.

Green plants, on the other hand, manufacture glucose directly during ***photosynthesis***. Photosynthesis is the process by which plants, algae, and certain kinds of bacteria convert light energy from the Sun into chemical energy in sugar molecules. Almost all life on Earth is either directly or indirectly dependent on photosynthesis. The overall chemical reaction for photosynthesis is

$$6CO_2 + 6H_2O + \text{sunlight} \rightarrow C_6H_{12}O_6 + 6O_2$$

Carbon dioxide, water, and sunlight go in; glucose and oxygen come out. Glucose is typically converted by plant tissues into complex carbohydrates, which are long molecules built of glucose units. Some plants, of course, don't have the opportunity to consume the glucose they make for themselves, instead donating it to the animals that consume them. A potato, for instance, is crammed with glucose stored in a thicket of starch molecules. The potato's starch molecules are broken down to glucose in your mouth and small intestine, and the glucose is transported to your cells, powering their lives—and yours.

P. 114

New and Revised!
Integrated Science sections
in every chapter, and at the end of each part, show how foundational ideas in science connect the different sciences. Added visuals accompany this feature, and end-of-chapter questions are tied to the sections and assignable within Mastering Physics.

Expanded!
Think Integrated Science questions
at the end of each chapter tie in more closely with the chapter content.

THINK INTEGRATED SCIENCE

4A—The Impulse–Momentum Relationship in Sports

28. (a) Why is it a good idea to have your hand extended forward when you are getting ready to catch a fast-moving baseball with your bare hand? (b) Why should a boxer never move into a gloved fist? (c) What role does the duration of contact play in a karate impact?
29. In Figure 4.8, how does the force that Cassy exerts on the bricks compare with the force exerted on her hand?
30. How will the impulse differ if Cassy's hand bounces back when striking the bricks?
31. We know that falling on a mat is preferable to falling on a concrete floor. Explain why in terms of the impulse-momentum relationship.
32. In terms of the impulse-momentum relationship, explain why falling and bouncing from a solid pavement is more forceful than merely coming to rest upon impact.

4B—Glucose: Energy for Life

33. The word *burn* is often used to describe the process of cellular respiration, in which cells release energy from the chemical bonds in food molecules. How is the "burning" that goes on in cells different from literal burning—for example, burning a log on a campfire?
34. In what sense are you powered by solar energy?

P. 119

with an integrated and relevant approach

First we talked about force × time: impulse. Now we talk about force × distance: work.

The word *work*, in common usage, means physical or mental exertion. Don't confuse the science definition of work with the everyday notion of work.

P. 106

Updated! FYI marginal notes provide a more applied focus with information relevant to today's students.

Updated! Technology boxes present contemporary and relevant applications that connect science with students' everyday lives. New topics include Thermal Windows and Glassware (Chapter 6), Genome Editing with CRISPR-Cas9 (Chapter 16), and Wind Power and Global Winds (Chapter 26).

TECHNOLOGY

Reducing Fluid Friction

Have you experienced frustration with ketchup that resists flowing from a bottle? Or with mayonnaise that stubbornly remains behind in a jar? Or paint that sticks to the inside of a pail when the pail is "empty"? The culprit is unwanted friction. In 2012, a new product called LiquiGlide was invented at Massachusetts Institute of Technology (MIT) that greatly reduces friction and enhances slipperiness.

LiquiGlide is a transparent thin film that adheres to the inner surfaces of the smooth walls of glass, plastic, ceramic, or metal containers. The film surface is impregnated with nano-sized grooves. At this point, LiquiGlide is not yet slippery; not until a specially customized liquid is introduced that nestles in the grooves to form a coating held in place by capillary forces. This liquid coating creates a slippery surface fixed to the interior surface that enables the liquid product, ketchup for example, to easily slide from the bottle. The ketchup is not in contact with the glass or plastic bottle, but with the customized film coating. Hence the near frictionless flow of the ketchup, which pours out of the bottle leaving nothing behind. What works for ketchup, however, won't work for mayonnaise. Each specific liquid coating in the grooves of the LiquiGlide works with the product liquid. One customized coating for ketchup, another for spaghetti sauce, and another for mayonnaise.

LiquiGlide is without flavor, odor, and is composed of non-toxic FDA-approved materials. Furthermore, the coating does not interfere with recycling. A container completely clean of the once-held product improves recycling and decreases waste. Watch for this amazing new reducer of friction—not only in bottles in your kitchen or bathroom, but in medical devices, oil pipelines, and in yet unexpected places.

P. 60

Help students succeed

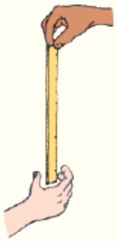
THINK AND DO (HANDS-ON APPLICATION)

38. Place your phone on top of a sheet of paper on a desk or table. Pull the paper horizontally with a quick snap. What concept of physics does this illustrate?

39. By any method you choose, determine both your walking speed and your running speed.

40. Try this with your friends: Hold a dollar bill so that the midpoint hangs between a friend's fingers and challenge your friend to catch it by snapping her fingers shut when you release it. She won't be able to catch it! Explanation: From $d = \frac{1}{2}gt^2$, the bill will fall a distance of 8 centimeters (half the length of the bill) in a time of 1/8 second, but the time required for the necessary impulses to travel from her eyes to her brain is at least 1/7 second.

41. Drop a ruler between a friend's fingers as shown. The number of centimeters that pass through his fingers relates to his reaction time. You can express the result in fractions of a second by rearranging $d = \frac{1}{2}gt^2$. Expressed for time it is $t = \sqrt{2d/g} = 0.045\sqrt{d}$, where d is in centimeters.

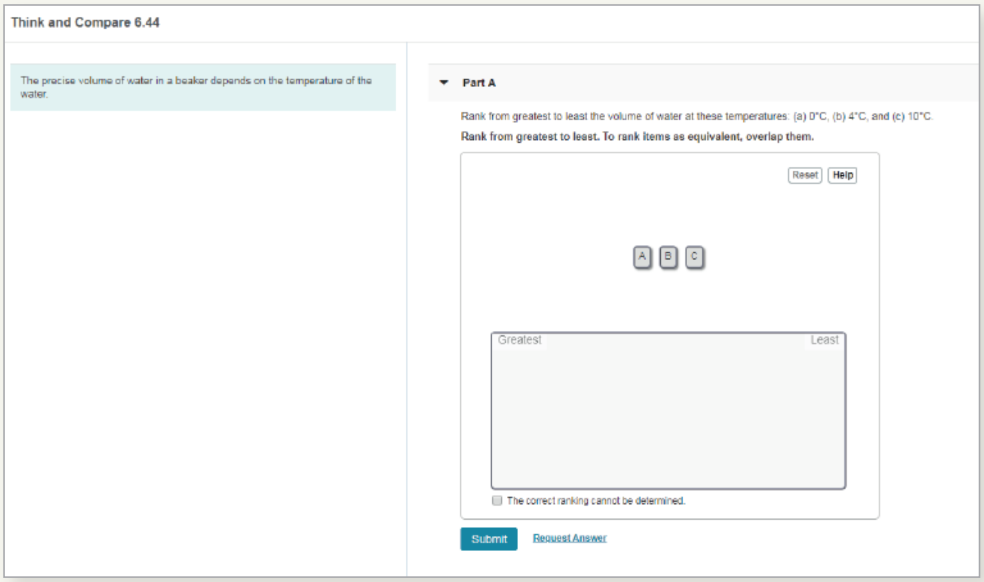


42. Stand flat-footed next to a wall and make a mark at the highest point you can reach. Then jump vertically and make another mark at the highest possible point. The distance between these two marks is your vertical jumping distance. Use this distance to calculate your personal hang time.

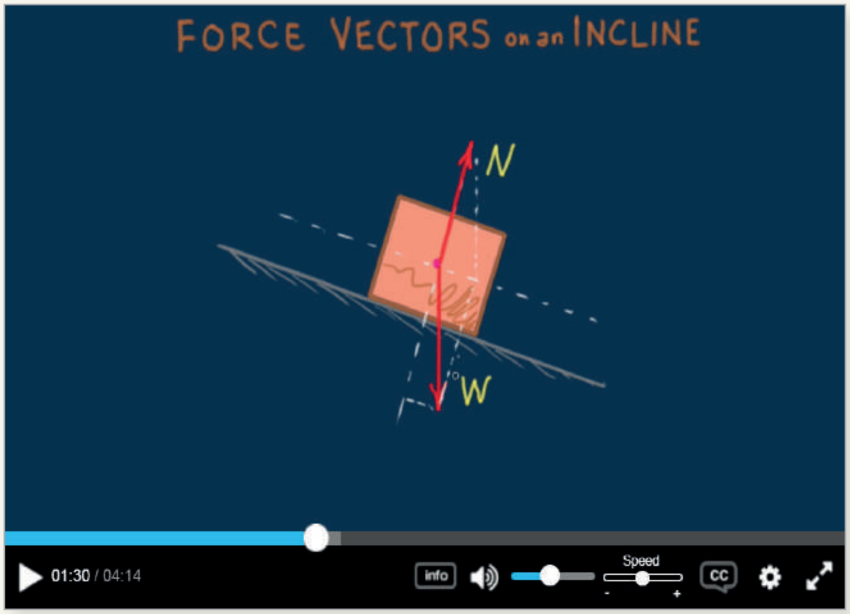
P. 68

New and Updated! End-of-chapter questions allow students to practice their knowledge, comprehension, hands-on application, formula familiarization, analysis, mathematical application, synthesis, and evaluation skills by answering questions that relate to the chapter material.

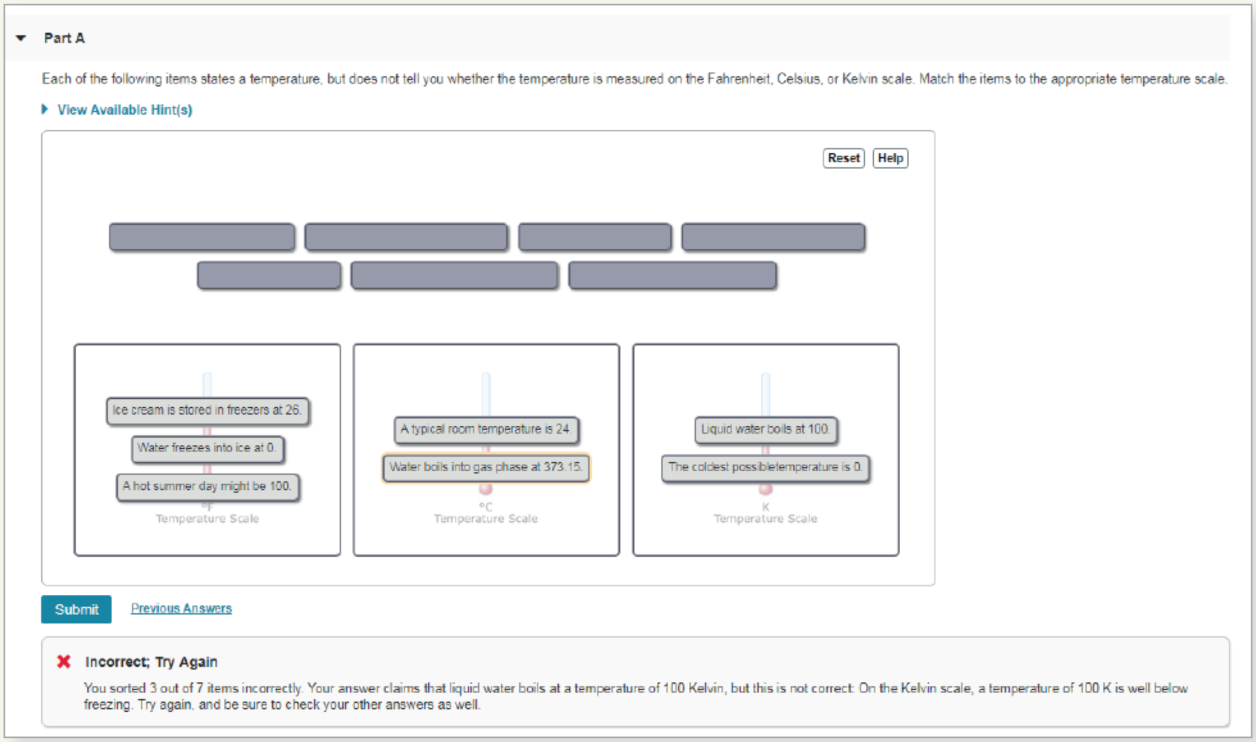
In Mastering Physics, enhanced end-of-chapter questions provide students with opportunities to practice, providing personalized feedback when and where students need it, including links to the eText, tutorials, and wrong-answer feedback for homework assignments.



with effective pedagogy and engaging content



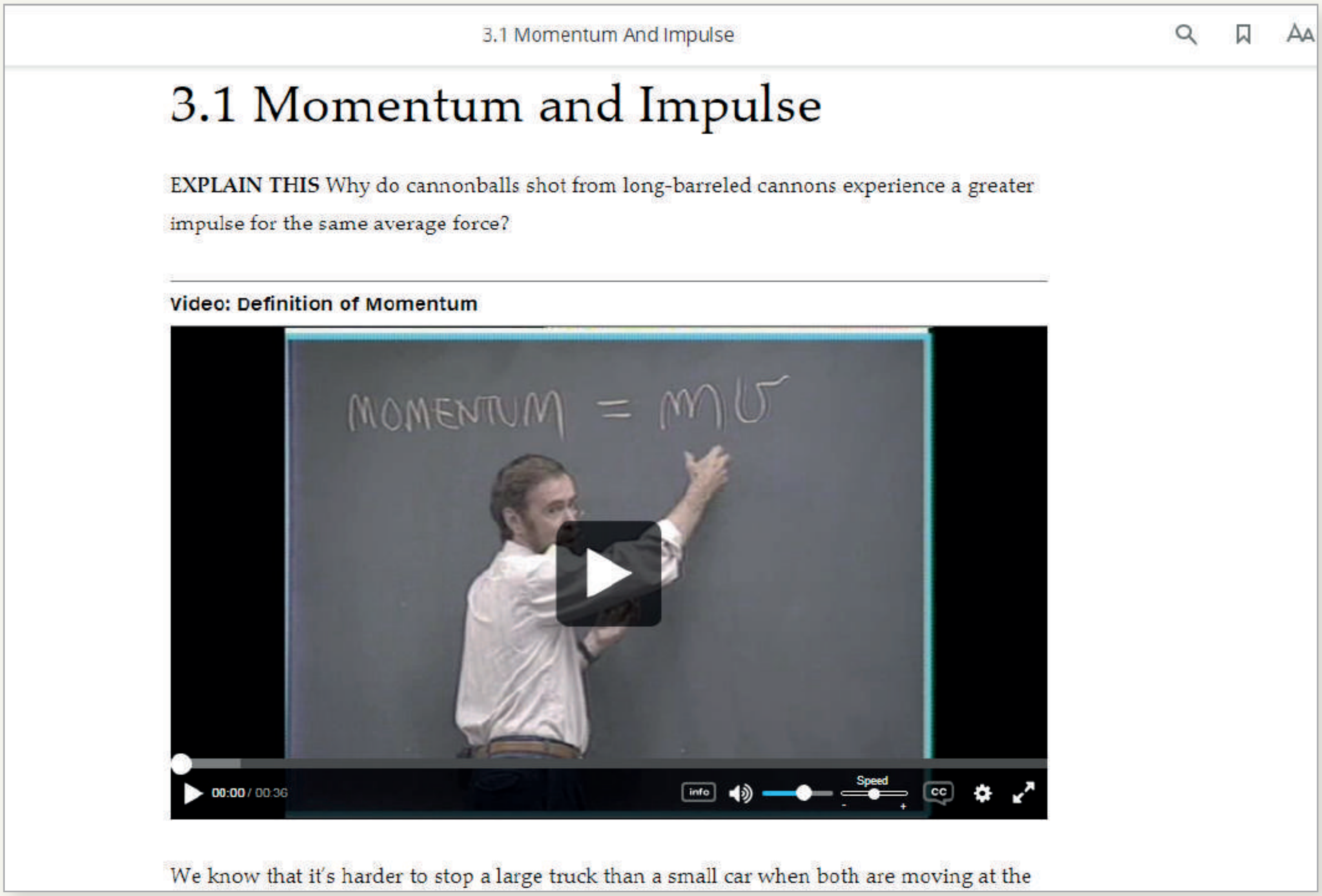
Video tutorials include screencasts created by the authors to help students arrive in class prepared. These lessons complement chapter material by giving students the context they need to read with greater understanding. In the eText, students can access and view by clicking on the video icon.



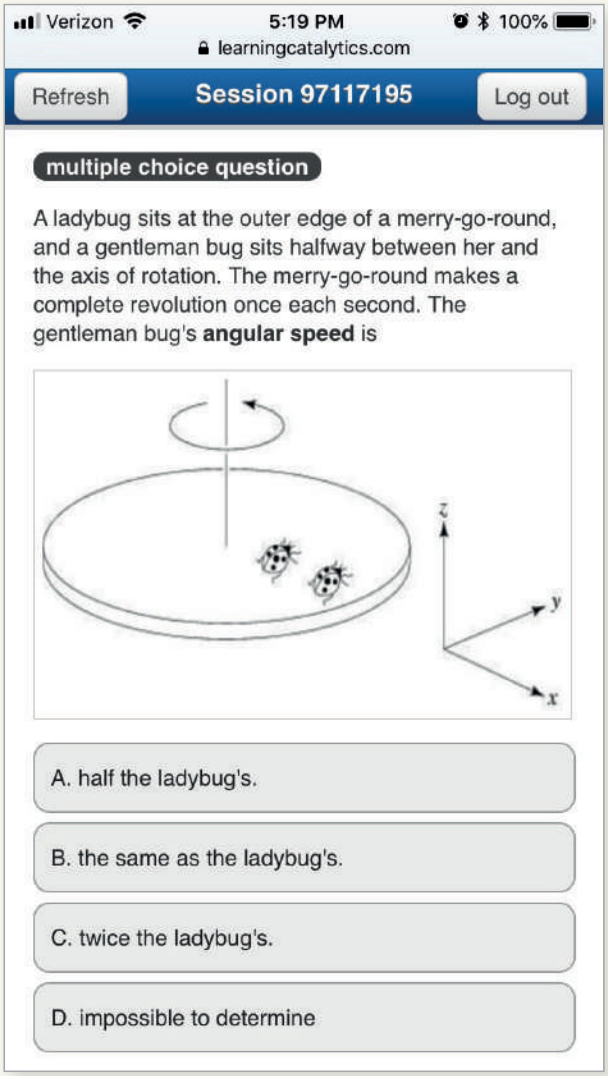
Tutorials and Coaching Activities help students learn science by practicing science. Assignable activities guide students through the toughest topics with wrong answer feedback and hints that emulate the office hour experience.

Give students anytime, anywhere access with the Pearson eTextbook

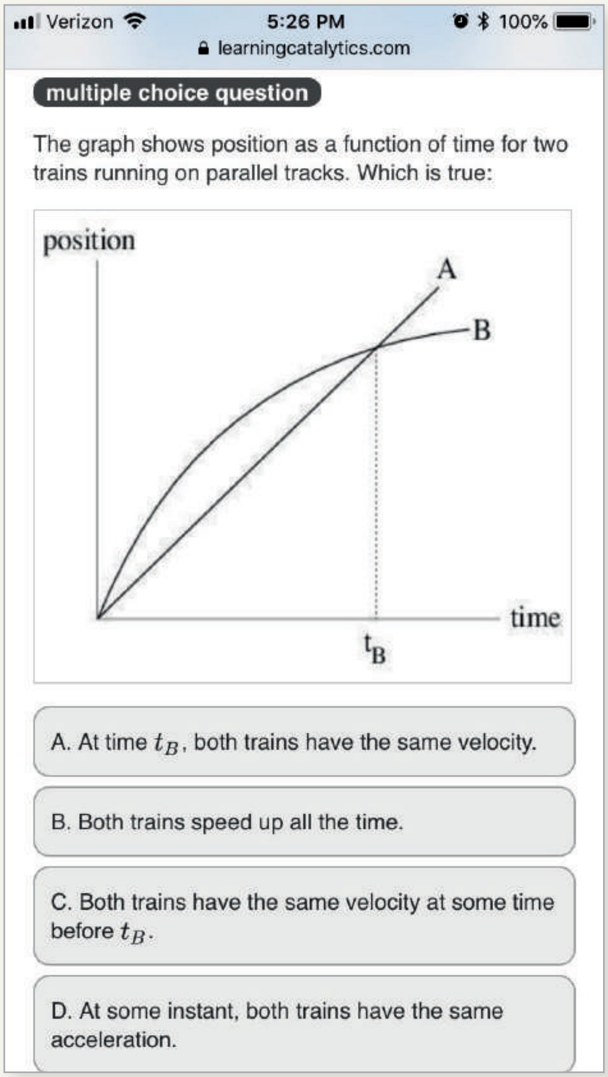
The Pearson eTextbook is a simple-to-use, mobile-optimized, personalized reading experience available within Mastering. It allows students to easily highlight, take notes, and review key vocabulary all in one place—even when offline. Seamlessly integrated videos, rich media, and interactive self-assessment questions engage students and give them access to the help they need, when they need it. The Pearson eTextbook is available within Mastering Physics when packaged with a new book; students can also purchase Mastering with the Pearson eTextbook online. For instructors not using Mastering, the Pearson eTextbook can also be adopted on its own as the main course material.



Reach every student with Learning Catalytics



With **Learning Catalytics,** you'll hear from every student when it matters most. You pose a variety of questions that help students recall ideas, apply concepts, and develop critical-thinking skills. Your students respond using their own smartphones, tablets, or laptops.



You can monitor responses with real-time analytics and find out what your students do — and don't — understand. Then, you can adjust your teaching accordingly, and even facilitate peer-to-peer learning, helping students stay motivated and engaged. Learning Catalytics includes prebuilt questions for topics in ***Conceptual Integrated Science,* 3rd Edition, Global Edition.**

Instructor support you can rely on

Conceptual Integrated Science **includes a full suite of instructor support materials in the Instructor Resources area in Mastering Physics. Resources include lecture presentations, images and clicker questions in PowerPoint; all figures and photos from the text; interactive figures and videos; answers to all end-of-chapter questions; an instructor's manual; and a test bank.**

Download instructor resources from the links below.

PowerPoint Presentation Tools

Chapter 7 Image PowerPoint	pptx, 25.9 MB
Chapter 7 Lecture Outline PowerPoint	zip, 16.4 MB
Chapter 7 Reading Quiz Clicker PowerPoint	pptx, 3.4 MB
Chapter 7 Review Clicker PowerPoint	pptx, 3.3 MB

JPEG Images

Appendices Labeled JPEG Images Labeled images from appendices in the text.	zip, 11.5 MB
Chapter 7 Labeled JPEG Images Labeled images from the text.	zip, 24.7 MB
Chapter 7 Unlabeled JPEG Images Unlabeled images from the text.	zip, 6.2 MB

CONCEPTUAL
Integrated Science

THIRD EDITION

GLOBAL EDITION

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Authorized adaptation from the United States edition, entitled *Conceptual Integrated Science,* Third Edition, ISBN 978-0-13-519739-4, by Paul G. Hewitt, Suzanne Lyons, John Suchocki, and Jennifer Yeh, published by Pearson Education, Inc. © 2020.

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ISBN 10 (Print): 1-292-72612-1
ISBN 13 (Print): 978-1-29-272612-0
ISBN 13 (eBook uPDF): 978-1-292-72609-0

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

eBook formatted by B2R Technologies Pvt. Ltd.

To all students and educators devoted to a greener and sustainable tomorrow.

Brief Contents

Detailed Contents

Special Features

MATH CONNECTION

SCIENCE AND SOCIETY

HISTORY OF SCIENCE

TECHNOLOGY

The *Conceptual Integrated Science* Photo Album

This is a very personal book by the authors as evident by photographs of family and friends throughout the book. Author Paul is seen on the Part 1 opening photo on page 47 with his great nephew and author John's son Evan Suchocki (pronounced Su-hock-ee, with silent c). Paul's photos continue on pages 111, 188, and 225 and again with his wife Lillian on pages 87 and 155. Other photos of Lil are on pages 39, 202, 205, and 236. Lil's dad, Wai Tsan Lee, shows magnetism on page 191. Paul's sister (and John's mom) Marjorie Hewitt Suchocki is shown reflectively on page 214. Paul's brother Steve on page 96 shows the essence of Newton's third law, that he can't touch his daughter Gretchen without being touched.

Paul's children begin with eldest daughter Jean Hurrell on page 189, along with her daughters Marie and Kara Mae also on pages 55 and 82. Son Paul illustrates thermodynamics on page 165. Daughter Leslie, co-author of *Conceptual Physical Science* 6e, shows atomic structure on page 265. Their late mom, and author Paul's first wife Millie, defies the heat of hot steam on page 166.

Paul's grandchildren begin with Manuel Hewitt on pages 153 and 234, Alexander Hewitt skateboards on page 135, and his sister Gracie Hewitt opens Chapter 1 on page 33. Nephew Mike Luna escapes a falling crate while in his Corvette on page 147. Niece Joan Lucas rides her horse on page 61. Niece Stephanie Hewitt illustrates refraction on page 236. Grandniece Ester Alexandria Gonzales illustrates Newton's third law interacting with a tree on page 96. Great grandnephew Hudson Hendricks, playing Superman, opens Chapter 2 on page 48 and again is seen on page 90. Great grandnephew Richard Hernandez opens Chapter 6 with awe on page 175.

City College of San Francisco friends and colleagues include Will Maynez on pages 106 and 188, Jill Evans on page 116, Roger King on page 169, and Chelcie Liu with his two-ball racing track in Appendix B on page 923.

Paul's friends include, in order of appearance, Burl Grey on page 54, Mike Jukes on page 62 and his wife Jane on page 97, Andrea Wu on pages 99 and 122. Andrea also opens Part 2 on page 241. Howie Brand is on page 101, Cassy Cosme on page 103, Bob Miner on page 106, Tenny Lim on page 108 and again with Lil on page 205, physics professor Chuck Stone on page 147, Francesco Ming Giovannuzzi on page 152, Anette Zetterberg on page 160, Jim Stith on page 181, William Davis on page 190, Karen Jo Mastler on page 197, Abby Dijamco on page 210, Bay Johnson on page 210, Exploratorium scientist Patti O'Plasma on page 211, Lab manual author Dean Baird on page 217, physics teacher Bree Barnett Dreyfuss on page 227, Carlos Vasquez on page 232, and Peter Hopkinson on page 236.

Chemistry and astronomy author John's sister-in-law Stephanie Kellar with nephew Kempten Kellar grace page 244 showing that the closeness between us is within the heart. Old friend Rinchin Tashe peers through a spectrosope on page 256 while cousin George Webster is seen beside his electron microscope on page 260. John's recent radio-technician, Elwyn Owen, shows off his radiation detecting badge on page 273, while John's wife, Tracy, and their younger son Evan demonstrate that growing up is a chemical change on page 307. Two of John's former students, Kai Dodge and Maile Ventura are shown testing the pH of solutions on page 389, while John's daughter eyes the chemistry of ice cream on page 395. Mike Lucas, John's nephew, is a rocket engineer for SpaceX as can be seen in the Part Opener for astronomy on page 841. The authors' colleagues Bruce and Linda Novak are seen holding the basketball and tennis ball on page 859 illustrating the relative sizes and distance between Earth and the Moon. Lab author, Dean Baird, and another dear colleague, Paul Doherty, recently passed, are seen gazing upon pinhole images of solar eclipses, both partial and annular on page 863.

Biology author Jennifer's nephew, Van Savage, opens up Biology on page 429. Jennifer's kids Io and Pico Gilman show off their sunscreen and sunhats on page 488. Jennifer's youngest daughter, Daphne Gilman, appears with her dimples on page 497. Daphne and her prized sunflower appear again on page 528. Io also appears on page 567, where she engages in her favorite pastime. Jennifer's husband, Nils Gilman, shoots a basketball on page 608. And Jennifer's sister Pam Yeh, who is also a biologist, shows a specimen she caught (and later released) during an ecological study in Nepal on page 624.

Earth science author Suzanne Lyons with her children Simone and Tristan are shown on page 232. Tristan is on page 60 demonstrating friction and Simone is on page 218 pondering the color of a rose. Suzanne's husband Pete demonstrates thermodynamics in everyday life on page 154. Suzanne appreciates the reflectivity of snow on page 824. Finally, Tristan and Simone, now all grown up, enjoy Earth science-playfully on page 832.

These photographs are of people very dear to the authors, which makes *Conceptual Integrated Science* all the more a labor of love.

Paul G. Hewitt

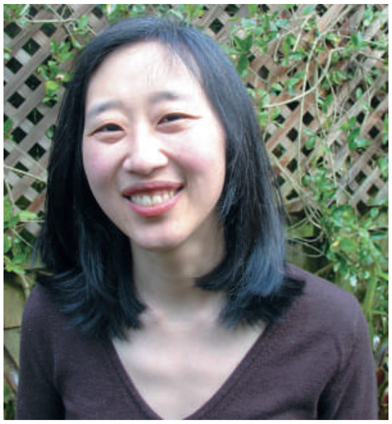
Former silver-medal boxing champion, sign painter, uranium prospector, and soldier, Paul began college at the age of 27, with the help of the GI Bill. He pioneered the conceptual approach to teaching physics at the City College of San Francisco. He has taught as a guest teacher at various middle schools and high schools, the University of California at both the Berkeley and Santa Cruz campuses, and the University of Hawaii at both the Manoa and Hilo campuses. He also taught for 20 years at the Exploratorium in San Francisco, which honored him with its Outstanding Educator Award in 2000. He is the author of *Conceptual Physics* and a co-author of *Conceptual Physical Science* and *Conceptual Physical Science Explorations* (with John Suchocki and Leslie Hewitt Abrams).

Suzanne Lyons

Suzanne received her B.A. in physics from the University of California, Berkeley. She earned her M.A. in education and her California teaching credential both from Stanford University. She earned another M.A. degree in Integrated Earth Sciences from California State University Sacramento. Suzanne was editor of *Conceptual Physics* and other books in the *Conceptual* series for 16 years and has authored 7 books on physics, hands-on science activities, and other topics in science and education. She has taught science and education courses to students of diverse ages and ability levels, from elementary school through college. She is always interested in developing new ways to teach and to that end, she founded the small business CooperativeGames.com.

John A. Suchocki

John is the author of *Conceptual Chemistry* and coauthor of *Conceptual Physical Science*. John obtained his Ph.D. in organic chemistry from Virginia Commonwealth University where he also completed a postdoctoral fellowship in pharmacology. As a tenured professor at Leeward Community College, his interests turned to science education, the development of distance learning programs, and student-centered learning curricula. Currently an adjunct professor at Saint Michael's College in Vermont, John also produces science multimedia through his company Conceptual Productions. His popular tutorial video lessons, as well as those of his coauthors, are freely available at ConceptualAcademy.com.



Jennifer Yeh

Jennifer earned a Ph.D. in integrative biology from the University of Texas, Austin, for her work on frog skeleton evolution. She obtained her B.A. in physics and astronomy from Harvard University. Following her graduate work, Jennifer was a postdoctoral fellow at the University of California, San Francisco, where she studied the genetics of breast cancer. Jennifer has taught courses in physics, cell biology, human embryology, vertebrate anatomy, and ecology and evolution. She is the author of various scientific papers as well as the book *Endangered Species: Must They Disappear?* (Thomson/Gale, © 2002, 2004). Jennifer continues to work on a wide variety of introductory biology materials, including various online materials.

To the Student

WELCOME TO *Conceptual Integrated Science*. The science you'll learn here is INTEGRATED. That means we'll explore the individual science disciplines of physics, chemistry, biology, Earth science, and astronomy PLUS the areas where these disciplines overlap. Most of the scientific questions you're curious about, or need to know about, involve not just one discipline, but several of them in an overlapping way. How did the universe originate? That's astronomy + physics. How are our bodies altered by the foods we eat, the medicines we take, and the way we exercise? That's chemistry + biology. What's the greenhouse effect? Will it trigger irreversible global warming, threatening life on our planet? Physics, chemistry, biology, and Earth science are all needed to understand the answers.

We're convinced that the CONCEPTUAL orientation of this book is the way in which students best learn science. That means that we emphasize concepts *before* computation. Although much of science is mathematical, a firm qualitative grasp of concepts is also important. Too much emphasis on mathematical problem solving early in your science studies can actually distract you from the concepts and prevent you from fully comprehending them. If you continue in science, you may follow up with classes requiring advanced mathematical methods. Whether you do or don't, we think you'll be glad you learned the concepts first with just enough math to make them clearer.

This course provides plenty of resources beyond the text as well. For example, the interactive figures, interactive tutorials, and demonstration videos on www.masteringphysics.com will help you visualize science concepts, particularly processes that vary over time, such as the velocity of an object in free fall, the phases of the Moon, or the formation of chemical bonds. The activities in the *Laboratory Manual* will build your gut-level feeling for concepts and your analytical skills. Ponder the puzzlers in the *Conceptual Integrated Science Practice Book* and work through the simple review questions—all this will increase your confidence and mastery of science.

As with all things, what you get out of this class depends on what you put into it. So study hard, ask all the questions you need to, and most of all enjoy your scientific tour of the amazing natural world!

To the Instructor

This third edition of *Conceptual Integrated Science*, with its important ancillaries, provides your students an enjoyable and readable introductory coverage of the natural sciences. As with the previous edition, the 29 chapters are divided into five main parts—Physics, Chemistry, Biology, Earth Science, and Astronomy. We begin with physics, the basic science that provides a foundation for chemistry, which in turn underlies biology, which extends to Earth science and astronomy.

For the nonscience student, this book affords a means of viewing nature perceptively. One can see that surprisingly few relationships make up its rules, most of which are the laws of physics presented in Part One. Physics laws are nature's secret codes. Here they are expressed both in words and in equation form. We view equations as *guides to thinking*. Even students who shy away from mathematics can learn to read equations to guide their thinking—to see how concepts connect. The symbols in equations are akin to musical notes that guide musicians.

For the science student, this same foundation affords a springboard to further study. For quantitatively oriented students, ample end-of-chapter material provides problem-solving activity through the *Think and Solve* problems.

Physics begins with static equilibrium so that students can start with forces before studying velocity and acceleration. After success with simple forces, the coverage touches lightly on kinematics, enough preparation for Newton's laws of motion. The pace picks up with the conventional order of mechanics topics followed by heat, thermodynamics, electricity and magnetism, sound, and light. Physics chapters lead to the realm of the atom—a bridge to chemistry.

The chemistry chapters begin with a look at the submicroscopic world of the atom, which is described in terms of subatomic particles and the periodic table. Students are then introduced to the atomic nucleus and its relevance to radioactivity, nuclear power, as well as astronomy. Subsequent chemistry chapters follow a traditional approach covering chemical changes, bonding, molecular interactions, and the formation of mixtures. With this foundation, students are then set to learn the mechanics of chemical reactions and the behavior of organic compounds. As with previous editions, chemistry is related to the student's familiar world—the fluorine in their toothpaste, the Teflon on their frying pans, and the flavors produced by various organic molecules. The environmental aspects of chemistry are also highlighted—from how our drinking water is purified to how atmospheric carbon dioxide influences the pH of rainwater and our oceans.

The biology section begins by asking—what constitutes life? Each of the first three chapters focuses on a key feature of living things. We begin with a discussion of cells, move on to genes, and finally, tackle evolution and the origin of life. From here, we proceed to an overview of the different kinds of living things found on Earth. This overview is followed by two chapters on humans, our own species. In these chapters, we study the human body and how it works. Finally, we look at ecology, the study of how living organisms interact with their environments.

The Earth science chapters begin with plate tectonics, the theory that establishes the underlying framework of the geosciences. The next chapter is about rocks and minerals, the principal materials that make up the solid Earth. Then comes a tour of Earth's landforms, surface features, and geography followed by a chapter on surficial processes—those processes of weathering, erosion, and deposition that originate at Earth's surface and shape the planet's contours. Plate tectonics is about Earth's interior, and the chapters on rock, landforms, and surficial processes describe Earth's surface. The next chapter in the sequence rises higher still—into the atmosphere—with weather. The subject of weather is broken down into elements from atmospheric pressure to wind to precipitation that can be learned separately but then applied to complex phenomena such as weather systems. The Earth science unit concludes with a chapter on environmental geology, which is new to the second edition. It provides an updated review of earthquakes, tsunami, hurricanes, volcanic eruptions, and other geologic hazards. Most importantly, it features expanded coverage of our changing climate including extensive discussion of natural and anthropogenic climate change.

The applications of physics, chemistry, biology, and the Earth sciences applied to other massive bodies in the universe culminate in Part Five—astronomy. This unit introduces the basic structure of the universe from our local solar system and the stars we see at night to galaxies and superclusters of galaxies. Focus is given to modern theories describing how this structure evolved and is continuing to evolve. Many recent discoveries are featured in this edition, illustrating that science is more than a growing body of knowledge; it is an arena in which humans actively and systematically reach out to learn more about our place in the universe.

What's New to This Edition

Conceptual Integrated Science now comes with a powerful media package including **Mastering™ Physics**, the most widely used, educationally proven, and technologically advanced tutorial and homework system available.

Mastering Physics contains:

- A **library of assignable and automatically graded content**, including tutorials, visual activities, end-of-chapter problems, and test bank questions so instructors can create the most effective homework assignments with just a few clicks. A **color-coded gradebook** instantly identifies vulnerable students or topic areas that are challenging for students in the class.
- A **student study area** with practice quizzes, Interactive Figures, self-guided tutorials, flashcards, videos, access to the Pearson eText version of the book, and more.
- An **instructor resources section** with PowerPoint lectures, clicker questions, Instructor Manual files and more.

Another significant revision for this third edition lies with the development of the end-of-chapter review. New questions were added while older ones were either discarded or reworded for improved quality. All questions were then organized following Bloom's taxonomy of learning as follows:

Summary of Terms (Knowledge)
These key terms match the definitions given within the chapter and are now listed in alphabetical order so that they appear as a mini-glossary for the chapter.

Reading Check Questions (Comprehension)
These questions frame the important ideas of each section in the chapter. They are for review and a check of reading comprehension. They are simple questions and all answers can easily be discovered in the chapter.

Think Integrated Science
Questions pertaining to the Integrated Science sections of each chapter are contained in this section. Questions range from straightforward, reading-check type questions to critical-thinking exercises.

Think and Do (Hands-On Application)
The *Think and Do* items are easy-to-perform hands-on activities designed to help students experience physical science concepts for themselves.

Think and Solve (Mathematical Application)

The *Think and Solve* questions blend simple mathematics with concepts. They allow students to apply problem-solving techniques, many of which are featured in the Math Connection boxed features.

Think and Compare (Analysis)

The *Think and Compare* questions ask students to make comparisons of quantities. For example, when asked to rank quantities such as momentum or kinetic energy, appreciably more judgment is called for than in providing numerical answers. Some *Think and Compare* analyze trends, as in ranking atoms in order of increasing size based upon student understanding of the periodic table. This feature elicits critical thinking that goes beyond *Think and Solve*.

Think and Explain (Synthesis)

The *Think and Explain* questions, by a notch or two, are the more challenging questions at the end of each chapter. Many require critical thinking while others are designed to prompt the application of science to everyday situations. All students wanting to perform well on exams should be directed to the *Exercises* because these are the questions that directly assess student understanding. Accordingly, many of the *Exercises* have been adapted to a multiple-choice format and integrated into the *Conceptual Integrated Science, 3e* Test Bank. This will hopefully allow the instructor to reward those students who put time and effort into the *Exercises*.

Think and Discuss (Evaluation)

The *Think and Discuss* topics provide students the opportunity to apply science concepts to real-life situations, such as whether a cup of hot coffee served to you in a restaurant cools faster when cream is added promptly or a few minutes later. Other discussion questions allow students to present their educated opinions on a number of science-related hot topics, such as the appearance of pharmaceuticals in drinking water.

Readiness Assurance Test

Each chapter review concludes with a set of 10 multiple-choice questions that students can take for self-assessment. They are advised to study further if they score less than 7 correct answers.

Also in this edition are the solutions to the odd-numbered end-of-chapter questions in the back of this book. As before, solutions to all end-of-chapter questions are available to instructors through the Instructor Manual for *Conceptual Integrated Science*, which is found in the Instructor Resource Center and in the Instructor Resource area of Mastering Physics.

This third edition features a new and, we think, refreshing page layout design. Integrated into this design are **learning objectives** that appear alongside each chapter section head. Each learning objective begins with an active verb that specifies what the student should be able to do after studying that section, such as "Calculate the energy released by a chemical reaction." These section-specific learning objectives are further integrated into the new Mastering Physics online tutorial/assessment tool.

The text of all chapters has been edited for accuracy, better readability, and also updated to reflect current events, such as the new data and images from space crafts and orbiting telescopes and the popularity of personal DNA testing.

The scope and sequence of chapters is revised for this third edition. The material on the atom has been folded into the chemistry unit so that the atomic theory is explained at the point of use. In Part Three—Biology, the genetics chapter has been reorganized, and much new material has been added on DNA technology, its uses, and its potential dangers. The ecology chapter has also been reorganized with new attention to human population growth and human ecological footprints. The Earth science material has been reorganized such that the geography material is now separated from the discussion of surficial processes, allowing for more discussion of the oceans. A chapter on Historical Geology was eliminated with the most important concepts (such as the geologic time scale, Cretaceous extinction, and the nature of the rock record) being integrated into other chapters. The elimination of Historical Geology allowed the new chapter on Environmental Geology to be added with in-depth coverage of climate change. In Part Five—Astronomy, aside from updates from recent discoveries, the first section of Chapter 28 has been heavily revised in its presentation of nebular theory and the second chapter of this unit is expanded greatly to include discussions of cosmology.

Ancillary Materials

Most significantly, *Conceptual Integrated Science* is available with Mastering Physics—a homework, tutorial, and assessment system based on years of research into how students work problems and precisely where they need help. Studies show that students who use Mastering Physics significantly increase their scores compared to hand-written homework. Mastering Physics achieves this improvement by providing students with instantaneous feedback specific to their wrong answers and simpler sub-problems upon request when they get stuck. Instructors can also assign End-of-Chapter (EOC) problems from every chapter including multiple-choice questions, section-specific exercises, and general problems. Quantitative problems can be assigned with numerical answers and randomized values or solutions.

The Pearson eText of *Conceptual Integrated Science* is available through Mastering Physics. Allowing students access to the text wherever they have access to the Internet, the Pearson eText comprises the full text, including figures that can be enlarged for better viewing, popup definitions and terms, a note-taking feature, and more.

Tutorial video lessons and screencasts featuring the authors are now available to students at ConceptualAcademy.com. This is a must-visit website for any student who needs a bit of extra help. It is also a great tool for the online component of any course and as a support for instructors seeking to include more student activities during class.

The ***Instructor Manual for Conceptual Integrated Science*** which you'll find to be different from most instructors' manuals, allows for a variety of course designs to fit your taste. It contains many lecture ideas and topics not treated in the textbook as well as teaching tips and suggested step-by-step lectures and demonstrations. It has full-page answers to all the end-of-chapter material in the text.

The ***Conceptual Integrated Science Practice Book*** is a pencil and paper workbook that we see as our most creative work. Student interactions include filling in the blanks, making calculations, completing diagrams, and visualizing concepts being learned—all of which is student engagement with subject matter at its best. And quite nicely, this third edition has added Practice Pages to all five parts of the textbook. It spans a wide use of analogies and intriguing situations, all with a user-friendly tone.

The ***Test Bank for Conceptual Integrated Science*** has more than 3000 multiple-choice questions. The questions are categorized according to level of difficulty. The Test Bank allows you to edit questions, add questions, and create multiple test versions.

Another valuable media resource available to you is the ***Instructor Resource Center (Download Only) for Conceptual Integrated Science***. Available in Mastering Physics, these resources provide instructors with the largest library available of purpose-built, in-class presentation materials, including all the images from the book in high-resolution JPEG format; interactive figures™ and videos; PowerPoint® lecture outlines and clicker questions in PRS-enabled format for each chapter, all of which are written by the authors; and Hewitt's acclaimed Next-Time Questions in PDF format. The *Instructor Resource Center* provides you with everything you need to prepare for dynamic, engaging lectures in no time.

Go to it! Your conceptual integrated science course really can be the most interesting, informative, and worthwhile science course your students will ever take.

Acknowledgments

THE AUTHORS WISH TO express their sincere appreciation to the many talented and generous people who helped make *Conceptual Integrated Science*, now in its Third Edition, come to life. To the teachers and professors who reviewed the manuscript, giving generously of their time, we express heartfelt appreciation.

We thank all the contributors to this third and previous editions of *Conceptual Integrated Science*, as well as the many people who contributed to the other books in the *Conceptual* series: *Conceptual Physics*, *Conceptual Chemistry*, *Conceptual Physical Science*, and *Conceptual Integrated Science—Explorations*. For helping to shape the physics content over the years, in the student editions as well as our many supplements, we thank: Dean Baird, Tsing Bardin, Howie Brand, Alexi Cogan, William Davis, Paul Doherty, Marshall Ellenstein, Ken Ford, Lillian Lee Hewitt, Jim Hicks, Ron Hipschman, David Housden, John Hubisz, Scotty Graham, Will Maynez, Fred Myers, Bruce Novak, Ron Perkins, Diane Reindeau, David Williamson, Larry Weinstein, Phil Wolf, and Dean Zollman.

For development of chemistry chapters, thanks go to Adedoyin Adeyiga, John Bonte, Emily Borda, Charles Carraher, Natashe Cleveland, Sara Devo, Andy Frazer, Kenneth French, Marcia Gillette, Chu-Ngi Ho, Frank Lambert, Jeremy Mason, Daniel Predecki, Britt Price, Jeremy Ramsey, Kathryn Rust, William Scott, Anne Marie Sokol, Jason Vohs, Bob Widing, and David Yates.

For advice and wide-ranging contributions to the biology section, we thank Pamela Yeh, Sarah Ying, Nina Shapley, Nils Gilman, Todd Schlenke, Howard Ying, Brian West, Robert Dudley, Vivianne Ding, Mike Fried, W. Bryan Jennings, Rachel Zierzow, Ernie Brown, and Lil Hewitt.

For Earth science inspiration, input, and advice, we are grateful to Leslie Hewitt Abrams and Bob Abrams. They gave generously of their time to share insights gained from their work authoring and teaching Earth science. We are also grateful to Tsing Bardin, Judy Kusnick, Bruce Gervais, Lil Hewitt, Diane Carlson, and Lynne Cherry.

For space science, we are grateful to Jeffrey Bennett, Megan Donahue, Nicholas Schneider, and Mark Volt for permission to use many of the graphics that appear in their textbook *The Cosmic Perspective*, 6th edition. Also, for reviews of the astronomy chapters, we remain grateful to Richard Crowe, Bjorn Davidson, Stacy McGaugh, Michelle Mizuno-Wiedner, John O'Meara, Neil de Grass Tyson, Joe Wesney, Lynda Williams, and Erick Zackrisson.

Our colleagues at Pearson have been our partners in this project and given us much support and guidance. For this third edition, we are grateful to editor Jessica Moro, and her editorial assistants, Sabrina Marshall and Frances Lai. We thank our project manager Heidi Aguiar and science content producer Heidi Allgair for their competent and insightful handling of the production process.

The *Conceptual Integrated Science* authors are fortunate to have helpful and loving spouses who have supported us through the long hours and contributed to our efforts. Thanks go to Lillian Lee Hewitt, Pete Lang (Suzanne's husband), Tracy Suchocki, and Nils Gilman (Jennifer's husband). And to our kids, we send our love and gratitude: Tristan and Simone Lyons Lang; Ian, Evan, and Maitreya Suchocki; and Io, Pico, and Daphne Yeh Gilman.

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Acknowledgments for the Global Edition

Pearson would like to acknowledge and thank the following for the Global Edition:

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Kathryn Ford, University of Bristol
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CHAPTER ONE

1 About Science

LITTLE GRACIE Hewitt ponders successive positions of the Moon approaching Earth's shadow in a lunar eclipse—not completely dark, but reddish, due to sunlight on the way to the Moon grazing and refracting through Earth's atmosphere, casting a zillion Earth sunsets on Moon's surface all at once!

Gracie will go on to learn how science describes the order in nature, an ongoing human activity that represents the collective efforts, findings, and wisdom of the human race. The task of science educators is to nurture scientific curiosity in the Gracies among us.

Science, after all, is about nature's rules. We know you can't enjoy a game—whether it's a ball game, a computer game, or simply a party game—unless you know its rules. Likewise, we can't fully appreciate our surroundings until we understand the rules of nature. Science is the study of these rules, which show how everything in nature is beautifully connected.

We will see that science is best comprehended when it is integrated—when connections are evident between physics, chemistry, biology, geology, and astronomy—which is the focus of the following chapters.

LEARNING OBJECTIVE
Acknowledge contributions to science by various cultures.

1.1 A Brief History of Advances in Science

When a light goes out in your room, you ask, "How did that happen?" You might check to see if the lamp is plugged in or if the bulb is burned out, or you might look at homes in your neighborhood to see if there has been a power outage. When you think and act like this, you are searching for *cause-and-effect* relationships—trying to find out what events cause what results. This type of thinking is *rational thinking*, applied to the physical world. It is basic to science.

Today, we use rational thinking so much that it's hard to imagine other ways of interpreting our experiences. But it wasn't always this way. In other times and places, people relied heavily on superstition and magic to interpret the world around them. They were unable to analyze the *physical* world in terms of *physical* causes and effects.

The ancient Greeks used logic and rational thought in a systematic way to investigate the world around them and make many scientific discoveries. They learned that Earth is round and determined its circumference (page 36). They discovered why things float and suggested that the apparent motion of the stars throughout the night is due to the rotation of Earth. The ancient Greeks founded the science of botany—the systematic study and classification of plants—and even proposed an early version of the principle of natural selection. Such scientific breakthroughs, when applied as technology, greatly enhanced the quality of life in ancient Greece. For example, engineers applied principles articulated by Archimedes and others to construct an elaborate public waterworks, which brought fresh water into the towns and carried sewage away in a sanitary manner.

When the Romans conquered ancient Greece, they adopted much of Greek culture, including the scientific mode of inquiry, and spread it throughout the Roman Empire. When the Roman Empire fell in the 5th century AD, advancements in science came to a halt in Europe. Nomadic tribes destroyed much in their paths as they conquered Europe and brought in the Dark Ages. While religion held sway in Europe, science continued to advance in other parts of the world.

FIGURE 1.1
A view of the Acropolis, or "high city," of ancient Greece. The buildings that make up the Acropolis were built as monuments to the achievements of residents of the area.

The Chinese and Polynesians were charting the stars and the planets. Arab nations developed mathematics and learned to make glass, paper, metals, and certain chemicals. Finally, during the 10th through 12th centuries, Islamic people brought the spirit of scientific inquiry back into Europe when they entered Spain. Then universities sprang up. When the printing press was invented by Johannes Gutenberg in the 15th century, science made a great leap forward. People were able to communicate easily with one another across great distances. The printing press did much to advance scientific thought, just as computers and the Internet are doing today.

Up until the 16th century, most people thought Earth was the center of the universe. They thought that the Sun circled the stationary Earth. This thinking was challenged when the Polish astronomer Nicolaus Copernicus quietly published a book proposing that the Sun is stationary and Earth revolves around it. These ideas conflicted with the powerful institution of the Church and were banned for 200 years.

Modern science began in the 17th century, when the Italian physicist Galileo Galilei revived the Copernican view. Galileo used experiments, rather than speculation, to study nature's behavior (we'll say more about Galileo in chapters that follow). Galileo was arrested for popularizing the Copernican theory and for his other contributions to scientific thought. But, a century later, his ideas and those of Copernicus were accepted by most educated people.

Scientific discoveries are often opposed, especially if they conflict with what people want to believe. In the early 1800s, geologists were condemned because their findings differed from religious accounts of creation. Later in the same century, geology was accepted but theories of evolution were condemned. Every age has had its intellectual rebels who have been persecuted, vilified, condemned, or suppressed but then later regarded as harmless and even essential to the advancement of civilization and the elevation of the human condition. “At every crossway on the road that leads to the future, each progressive spirit is opposed by a thousand men appointed to guard the past.”*

1.2 Mathematics and Conceptual Integrated Science

LEARNING OBJECTIVE
Recount how mathematics is a key in formulating good science.

Pure mathematics is different from science. Math studies relationships among numbers. When math is used as a tool of science, the results can be astounding. Measurements and calculations are essential parts of the powerful science we practice today. For example, it would not be possible to send missions to Mars if we were unable to measure the positions of spacecraft or to calculate their trajectories.

You will make some calculations in this course, especially when you make measurements in lab. In this book, we don’t make a big deal about math. Our focus is on understanding concepts in everyday language. We use equations as guides to thinking rather than as recipes for “plug-and-chug” computational work. Mathematics is essential to the scientist, but not for nonscience students who nevertheless value acquiring knowledge of science. Our experience is that focusing on computations too early, especially with math-based problem solving, is counterproductive. Overemphasis on computation is burdensome for a significant number of students, and it is a roadblock for many. So, in this book the mathematical equations of science are most helpful as guides to thinking. Only when concepts are understood does computational problem solving make sense.

1.3 The Scientific Method—A Classic Tool

LEARNING OBJECTIVE
List the steps in the classic scientific method, and cite other processes that advance science.

UNIFYING CONCEPT
The Scientific Method

The practice of **science** usually encompasses keen observations, rational analysis, and experimentation. In the 17th century, Galileo and the English philosopher Francis Bacon were the first to formalize a particular method for doing science. What they outlined has come to be known as the classic **scientific method**. It essentially includes the following steps:

1. **Observe** Closely observe the physical world around you.
2. **Question** Recognize a question or a problem.
3. **Hypothesize** Make an educated guess—a *hypothesis*—to answer the question.
4. **Predict** Predict consequences that can be observed if the hypothesis is correct. The consequences should be *absent* if the hypothesis is not correct.
5. **Test predictions** Do experiments to see if the consequences you predicted are present.
6. **Draw a conclusion** Formulate the simplest general rule that organizes the hypothesis, predicted effects, and experimental findings.

Although the scientific method is powerful, good science is often done differently, in a less systematic way. In the Integrated Science feature at the end of Part 1, page 238. “The Scientific Method and an Investigation of Sea Butterflies,” you will see a recent application of the classic scientific method. However, many scientific advances involve trial and error, experimenting without guessing, or just plain accidental discovery. More important than a particular method, the success of science has to do with an attitude common to scientists. This attitude is one of inquiry, experimentation, and humility before the facts.

Science is a way to teach how something gets to be known, what is not known, to what extent things are known (for nothing is known absolutely), how to handle doubt and uncertainty, what the rules of evidence are, how to think about things so that judgments can be made, how to distinguish truth from fraud, and from show.—*Richard Feynman*

* From Count Maurice Maeterlinck’s “Our Social Duty.”

MATH CONNECTION

How Eratosthenes Measured the Size of Earth

In about 235 BC in Egypt, the first measurement of Earth's size is credited to the Greek mathematician and geographer Eratosthenes, the chief librarian at the famed Mouseion in Alexandria.

From library information, Eratosthenes learned that when the Sun is highest in the sky at noon on the day of the summer solstice, June 22, sunlight shining straight down a deep well in the southern city of Syene (the present-day site of the Aswan Dam) is reflected straight up again—the only time the Sun's reflection can be seen in the well (Figure 1.2)—so at this special time the Sun was directly overhead in Syene.

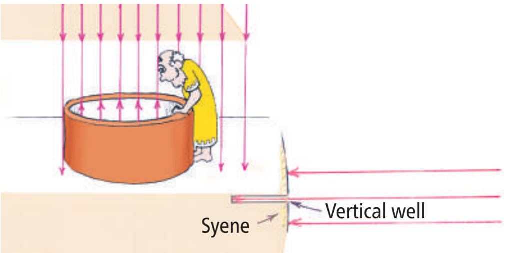


FIGURE 1.2
The Sun, directly overhead in Syene.

The Sun was *not* directly overhead at this time in Alexandria, as evidenced by a shadow cast by a tall vertical pillar there. Eratosthenes correctly assumed that rays from the very distant Sun are essentially parallel to one another by the time they reach Earth. He measured the noontime angle between the pillar and the Sun's rays to be 7.2° (Figure 1.3).

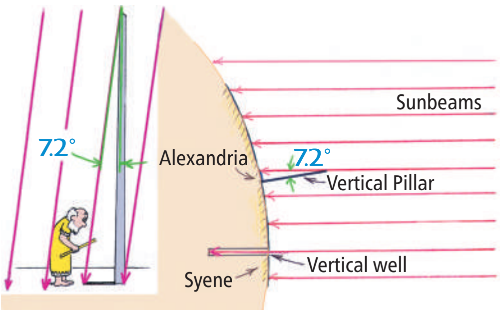


FIGURE 1.3
Important 7.2° angles.

Eratosthenes further reasoned that if a line along the vertical well in Syene were extended into Earth, it would pass through Earth's center, as would a vertical line in Alexandria (or any point on the spherical Earth). Both verticals extend to the center of Earth (Figure 1.4).

Quite remarkably, these lines to Earth's center form the same 7.2° angle that the Sun's rays make with the pillar at Alexandria!

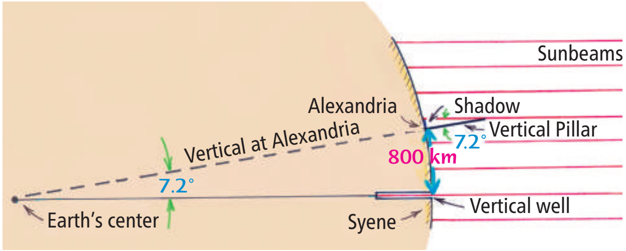


FIGURE 1.4
Distance between cities.

The distance between Syene and Alexandria, quite flat and frequently traveled, was measured by surveyors to be about 5000 stadia, or 800 kilometers in today's measurements. So, remarkably, Eratosthenes reasoned that 7.2° subtends the 800-km distance between the two cities at Earth's surface, as would all other 800-km segments around Earth. How many 7.2° segments make up Earth's circumference of 360°? The answer is $360°/7.2° = 50$, which means that Earth's circumference must be 50 times greater than the 800-km distance between Alexandria and Syene: 40,000 kilometers (Figure 1.5)!

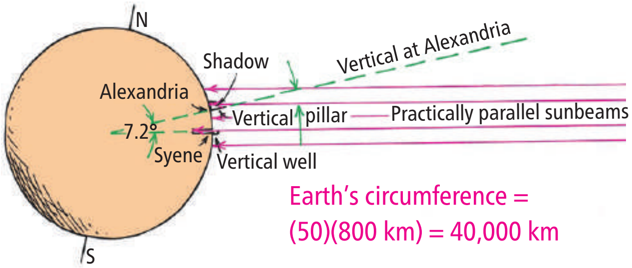


FIGURE 1.5
Earth's circumference.

Today, Eratosthenes is remembered for his amazing calculation of Earth's size, using only good thinking and a bit of math. Seventeen hundred years after Eratosthenes's death, Christopher Columbus studied Eratosthenes's findings before setting sail for the New World. Rather than heed Eratosthenes's findings, Columbus chose to accept more up-to-date maps that indicated Earth's circumference as one-third smaller. If Columbus had accepted Eratosthenes's larger circumference, then he would have known that the land he encountered was not China or the East Indies but, rather, a new world.

CHECK YOURSELF

1. **If the same 7.2° subtended 500 km (instead of 800 km), would the Earth's circumference be smaller, larger, or the same? Defend your answer.**

CHECK YOUR ANSWER

1. As Figure 1.5 suggests, Earth's circumference would be 50×500 km $=$ 25,000 km, appreciably smaller.

1.4 The Scientific Hypothesis

LEARNING OBJECTIVE
Describe the value of testing for furthering scientific knowledge.

A scientific **hypothesis** is an educated guess that tentatively answers a question or solves a problem in regard to the physical world. Typically, experiments are done to test hypotheses.

The cardinal rule in science is that all hypotheses must be testable—in other words, they must, at least in principle, be capable of being shown wrong. In science, it is more important that there be a means of proving an idea wrong than that there be a means of proving it right. This is a major feature that distinguishes science from nonscience. The idea that scientific hypotheses must be capable of being proven wrong is a pillar of the philosophy of science, and it is stated formally as the **principle of falsifiability:**

> **For a hypothesis to be considered scientific, it must be testable—it must, in principle, be capable of being proven wrong.**

At first, this principle may seem strange, for when we wonder about most things, we concern ourselves with ways of finding out whether they are true. Scientific hypotheses are different. In fact, if you want to determine whether a hypothesis is scientific or not, look to see whether there is a test for proving it wrong. If there is no test for possible wrongness, then the hypothesis is not scientific. Albert Einstein put it well: "No number of experiments can prove me right; a single experiment can prove me wrong."

For example, Einstein hypothesized that light is bent by gravity. This idea might be proven wrong if starlight that grazed the Sun and could be seen during an eclipse were not deflected from a normal path. But starlight *is* found to bend as it passes close to the Sun, just as Einstein's hypothesis would have predicted. If and when a hypothesis or scientific claim is confirmed, it is regarded as, useful and as a stepping stone to additional knowledge.

Consider another hypothesis: "The alignment of planets in the sky determines the best time for making decisions." Many people believe it, but this hypothesis is not scientific. It cannot be proven wrong, nor can it be proven right. It is speculation. Likewise, the hypothesis "Intelligent life exists on planets somewhere in the universe besides Earth" is not scientific.* Although it can be proven correct by the verification of a single instance of life existing elsewhere in the universe, there is no way to prove it wrong if no life is ever found. If we searched the far reaches of the universe for eons and found no life, we would not prove that it doesn't exist "around the next corner."

* The search for intelligent life in the universe is, however, ongoing. This search is based on this *question*: Might there be intelligent life somewhere besides on Earth? This question is the starting point for scientific observations of the physical world, but strictly speaking it is not a scientific hypothesis. A hypothesis is a sharper scientific tool than a question—a better, more finely honed instrument for separating scientific fact from fiction.

A hypothesis that is capable of being proven right but not capable of being proven wrong is not a scientific hypothesis. Many such statements are quite reasonable and useful, but they lie outside the domain of science.

CHECK YOURSELF

Which statements are *scientific* hypotheses?

(a) Better stock market decisions are made when the planets Venus, Earth, and Mars are aligned.

(b) Atoms are the smallest particles of matter that exist.

(c) The Moon is made of Swiss cheese.

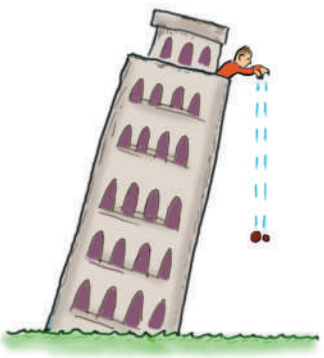
(d) Outer space contains a kind of matter whose existence can't be detected or tested.

(e) Albert Einstein was the greatest physicist of the 20th century.

CHECK YOUR ANSWER

All these statements are hypotheses, but only statements (a), (b), and (c) are scientific hypotheses because they are testable. Statement a can be tested (and proven wrong) by researching the performance of the stock market during times when these planets were aligned. Not only can statement b be tested; it has been tested. Although the statement has been found to be untrue (many particles smaller than atoms have been discovered), the statement is nevertheless a scientific one; likewise for statement c, where visits to the Moon have proven that the statement is wrong. Statement d, on the other hand, is easily seen to be unscientific because it can't be tested. Last, statement e is an assertion that has no test. What possible test, beyond collective opinion, could prove that Einstein was the greatest physicist? How could we know? Greatness is a quality that cannot be measured in an objective way.

LEARNING OBJECTIVE
Discuss how experimentation helps prevent the acceptance of false ideas.



1.5 The Scientific Experiment

A well-known scientific hypothesis that turned out to be incorrect was that of the greatly respected Greek philosopher Aristotle (384–322 BC), who claimed that heavy objects naturally fall faster than light objects. This hypothesis was considered to be true for nearly 2000 years—mainly because nearly everyone who knew of Aristotle's conclusions had such great respect for him as a thinker that they simply assumed he couldn't be wrong. Also, in Aristotle's time, air resistance was not recognized as an influence on how quickly an object falls. We've all seen that stones fall faster than leaves fluttering in the air. Without investigating further, we can easily accept false ideas.

Galileo very carefully examined Aristotle's hypothesis. Then he did something that caught on and changed science forever. He *experimented*. Galileo showed the falseness of Aristotle's claim with a single experiment—dropping heavy and light objects from the Leaning Tower of Pisa. Legend tells us that the objects fell at equal speeds. In the scientific spirit, one experiment that can be reproduced outweighs any authority, regardless of reputation or the number of advocates.

Scientists must accept their experimental findings even when they would like them to be different. They must strive to distinguish between the results they see and those they wish to see. This is not easy. Scientists, like most people, are capable of fooling themselves. People have always tended to adopt general rules, beliefs, creeds, ideas, and hypotheses without thoroughly questioning their validity. And sometimes we retain these ideas long after they have been shown to be meaningless, false, or at least questionable. The most widespread assumptions are often the least questioned. Too often, when an idea is adopted, great attention is given to the instances that support it. Contrary evidence is often distorted, belittled, or ignored.

The fact that scientific statements will be thoroughly tested before they are believed helps to keep science honest. Sooner or later, mistakes (or deceptions) are found out. A scientist exposed for cheating doesn't get a second chance in the community of scientists. Honesty, so important to the progress of science, thus becomes a matter of self-interest to scientists. There is relatively little bluffing in a game where all bets are called.

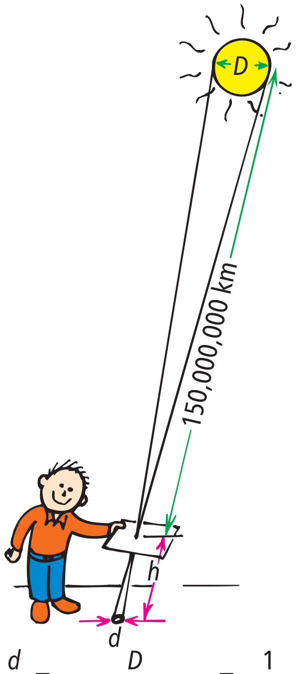
Experiment, not philosophical discussion, decides what is correct in science.

Science Experiment with the Sun

With only a small piece of card, a meterstick, and a sunny day, you can measure the diameter of the Sun. Here's how: With the tip of a sharp pencil, poke a small hole in the card, not more than a millimeter in diameter—an "optical pinhole." Hold the card in the sunlight so that light from the Sun passes through the hole and forms a spot of light on the surface below. Lo and behold, the spot is an *image of the Sun*. You'll see that the size of the image does not depend on the size of the pinhole but, rather, on how far away the pinhole is from the image. Bigger holes make brighter images, not bigger ones. Of course, if the hole is very big, no image is formed.

Careful measurement will show that the ratio of image size d to pinhole distance h is 1/110—the same as the ratio *Sun diameter/Sun–Earth distance* (Figure 1.6). The Sun–Earth distance is 150,000,000 kilometers. So the Sun's diameter is 1/110 this Sun–Earth distance, which is about 1,400,000 kilometers. This is yum physics!

There's more. The next time you walk beneath a sunlit tree, take heed and carefully examine the shape of spots of sunlight on the ground that have made their way through small openings between leaves above. Voilà! If the Sun is high in the sky, the spots are circles—pinhole images of the Sun (Figure 1.7). If the Sun is low in the sky, the circles are stretched out to be ellipses. This goes to show that physics is all around you. Sometimes you need a helping hand to see and appreciate that physics and science in general—which is what this textbook is all about—is helping you to know what to look for!



$$\frac{d}{h} = \frac{D}{150{,}000{,}000\text{ km}} = \frac{1}{110}$$

FIGURE 1.6
The round spot of light cast by the pinhole is an image of the Sun. Its ratio *d/h* is the same ratio as *Sun diameter/Sun-Earth distance*, 1/110.

FIGURE 1.7
Small openings between leaves above cast solar images around Lillian. The distance between the leaf openings to the solar-circle images on the ground is about 110 times the diameters of the solar circles. With this information the diameter of the Sun can be calculated.

CHECK YOURSELF

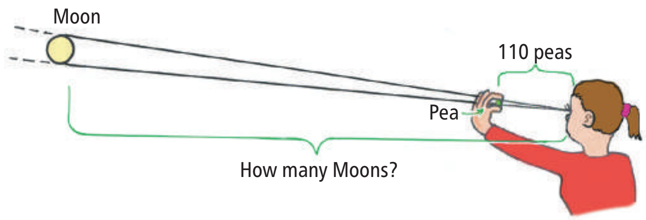
During a partial solar eclipse, when the Sun in the sky is crescent shaped, what will be the shape of solar images on the ground beneath sunlit trees?

CHECK YOUR ANSWER

Light spots on the ground will be crescents—images of the Sun at that special time.

MATH CONNECTION

How many Moons away is the Moon?



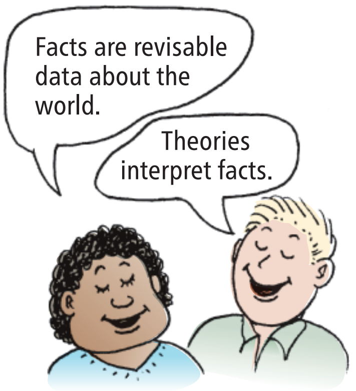
At the time of a nearly full or full Moon, do a remarkable experiment. First, measure the diameter of a green pea (or any tiny sphere). Then hold the pea at a distance from your eye (with the other eye closed) that just blocks out the Moon. In effect, the pea eclipses the Moon. With the help of a friend, measure the distance from your eye to the pea. If you do this carefully, you'll find the distance is about 110 times longer than the diameter of the pea. This means that 110 peas would fit in the distance between your eye and the pea. Is this a big deal? No, if that's all you do. But it is a big deal if you think further.

How does the angle the pea makes with your eye compare with the angle the Moon makes with your eye? The answer is, "The same," which happens to be 0.5°! Some serious thinking tells you that the 0.5° angle applies to both the pea and the Moon. This means that just as the held pea is 110 peas away from your eye, the Moon is 110 Moons away from your eye. So the Moon is 110 Moons away from Earth.

There's more! The fact that the Moon and the Sun appear the same size in the sky tells us that the same 0.5° angle subtends the Sun (quite evident during a solar eclipse). So how far away is our Sun? In terms of solar diameters, the Sun is 110 Suns away. You can impress your friends with this information!

LEARNING OBJECTIVE
Distinguish among facts, theories, and laws.

Those who can make you believe absurdities can make you commit atrocities.—*Voltaire*



We each need a *knowledge filter* to tell the difference between what is true and what only pretends to be true. The best knowledge filter ever invented for explaining the physical world is science.

1.6 Facts, Theories, and Laws

When a scientific hypothesis has been tested over and over again and has not been contradicted, it may become known as a **law** or *principle*. A scientific **fact**, on the other hand, is generally something that competent observers can observe and agree to be true. For example, it is a fact that an amputated limb of a salamander can grow back. Anyone can watch it happen. It is not a fact—yet—that a severed limb of a human can grow back.

Scientists use the word *theory* in a way that differs from its use in everyday speech. In everyday speech, a theory is the same as a hypothesis—a statement that hasn't been tested. But scientifically speaking, a **theory** is a synthesis of facts and well-tested hypotheses. Physicists use quantum theory to explain the behavior of light. Chemists have theories about how atoms bond to form molecules. The theory of evolution is key to the life sciences. Earth scientists use the theory of plate tectonics to explain why the continents move, and astronomers speak of the theory of the Big Bang to account for the observation that galaxies are moving away from one another.

Theories are a foundation of science, but they are not fixed. Rather, they evolve. They pass through stages of refinement. For example, since the theory of the atom was proposed 200 years ago, it has been refined many times in light of new evidence. Those who know only a little about science may argue that scientific theories can't be taken seriously because they are always changing. Those who understand science, however, see it differently: Theories grow stronger and more precise as they evolve to include new information.

Science Has Limitations

Science deals with only hypotheses that are testable. Its domain is therefore restricted to the observable natural world. Although scientific methods can be used to debunk various paranormal claims, they have no way of accounting for testimonies involving the supernatural. The term *supernatural* literally means "above nature." Science works within nature, not above it. Likewise, science is unable to answer philosophical questions such as "What is the purpose of life?" or religious questions such as "What is the nature of the human spirit?" Although these questions are valid and may have great importance to us, they rely on subjective personal experience and do not lead to testable hypotheses. They lie outside the realm of science.

SCIENCE AND SOCIETY

Pseudoscience

For a claim to qualify as "scientific," it must meet certain standards. For example, the claim must be reproducible by others who have no stake in whether the claim is true or false. The data and subsequent interpretations are open to scrutiny in a social environment where it's okay to have made an honest mistake but not okay to have been dishonest or deceiving. Claims that are presented as scientific but do not meet these standards are what we call **pseudoscience**, which literally means "fake science." In the realm of pseudoscience, skepticism and tests for possible wrongness are downplayed or flatly ignored.

Examples of pseudoscience abound. Astrology is an ancient belief system that supposes a person's future is determined by the positions and movements of planets and other celestial bodies. Astrology mimics science in that astrological predictions are based on careful astronomical observations. Yet astrology is not a science because there is no validity to the claim that the positions of celestial objects influence the events of a person's life. After all, the gravitational force exerted by celestial bodies on a person is smaller than the gravitational force exerted by objects making up the earthly environment: trees, chairs, other people, bars of soap, and so on. Further, the predictions of astrology do not hold true; there just is no evidence that astrology works.

For more examples of pseudoscience, look no further than the Internet. You can find advertisements for a plethora of pseudoscientific products. Watch out for remedies for ailments from baldness to obesity to cancer, for air-purifying mechanisms, and for "germ-fighting" cleaning products in particular. While many such products do operate on solid science, others are pure pseudoscience. Buyer beware!

Humans are very good at denial, which may explain why pseudoscience is such a thriving enterprise. Many pseudoscientists themselves do not recognize their efforts as pseudoscience. A practitioner of "absent healing," for example, may truly believe in her ability to cure people she will never meet except through e-mail and credit card exchanges. She may even find anecdotal evidence to support her contentions. The placebo effect, as discussed in Chapter 20, can mask the ineffectiveness of various healing modalities. In terms of the human body, what people believe *will* happen often *can* happen because of the physical connection between the mind and the body.

That said, consider the enormous downside of pseudoscientific practices. Today, there are many thousands of practicing astrologers in the United States. Do people listen to these astrologers just for the fun of it? Or do they base important decisions on astrology?

Meanwhile, the results of science literacy tests given to the general public show that most Americans lack an understanding of the basic concepts of science. Most American adults are unaware that the mass extinction of the dinosaurs occurred long before the first human evolved; about three quarters do not know that antibiotics kill bacteria but not viruses. What we find is a rift—a growing divide—between those who have a realistic sense of the capabilities of science and those who do not understand the nature of science and its core concepts or, worse, think that scientific knowledge is too complex for them to understand. Science is a powerful method for understanding the physical world—and a whole lot more reliable than pseudoscience as a means for bettering the human condition.

1.7 Science, Art, and Religion

LEARNING OBJECTIVE
Discuss some similarities and differences among science, art, and religion.

The search for a deeper understanding of the world around us has taken different forms, including science, art, and religion. Science is a system by which we discover and record physical phenomena and think about possible explanations for such phenomena. The arts are concerned with personal interpretation and creative expression. Religion addresses the source, purpose, and meaning of it all. Simply put, science asks *how*, art asks *who*, and religion asks *why*.

Science and the arts have certain things in common. In the art of literature, we find out about what is possible in human experience. We can learn about emotions from rage to love, even if we haven't yet experienced them. The arts describe these experiences and suggest what may be possible for us. Similarly, knowledge of science tells us what is possible in nature. Scientific knowledge helps us to predict possibilities in nature even before they have been experienced. It provides us with a way of connecting things, of seeing relationships between and among them, and of making sense of the great variety of natural events around us. While art broadens our understanding of ourselves, science broadens our understanding of our environment.

Art is about cosmic beauty. Science is about cosmic order. Religion is about cosmic purpose.

Science and religion have similarities also. For example, both are motivated by curiosity about the natural world. Both have great impact on society. Science, for example, leads to useful technological innovations, while religion provides a foothold for many social services. Science and religion, however, are basically different due to different domains. The domain of science is nature—the *natural*. The domain of religion is the *supernatural*. Both domains are as different as apples and oranges, and need not contradict each other. We should never feel forced into choosing one over the other. Scientific truth is a matter of public scrutiny; religion is a deeply personal matter.

No wars have ever been fought over science.

That science and religion can work very well together deserves special emphasis. When we study the nature of light later in this book, we will treat light as both a wave and a particle. At first, waves and particles may appear to be contradictory. You might believe that light can be only one or the other and that you must choose between them. What scientists have discovered, however, is that light waves and light particles *complement* each other and that, when these two ideas are taken together, they provide a deeper understanding of light. In a similar way, it is mainly people who are either uninformed or misinformed about the deeper natures of both science and religion who feel that they must choose between believing in religion and believing in science. Unless one has a shallow understanding of either or both, there is no contradiction in being religious in one's belief system and being scientific in one's understanding of the natural world.* What your religious beliefs are and whether you have any religion at all are, of course, private matters for you to decide. The tangling up of science and religion has led to many unfortunate arguments over the course of human history.

CHECK YOURSELF

Which of the following activities involves the utmost human expression of passion, talent, and intelligence?

(a) painting and sculpture
(b) literature
(c) music
(d) religion
(e) science

CHECK YOUR ANSWER

All of them. In this book, we focus on science, which is an enchanting human activity shared by a wide variety of people. With present-day tools and know-how, scientists are reaching further and finding out more about themselves and their environment than people in the past were ever able to do. The more you know about science, the more passionate you feel toward your surroundings. There is science in everything you see, hear, smell, taste, and touch!

LEARNING OBJECTIVE
Relate technology to the furthering of science, and science to the furthering of technology.

1.8 Technology—The Practical Use of Science

Science and technology are also different from each other. Science is concerned with gathering knowledge and organizing it. **Technology** enables humans to use that knowledge for practical purposes, and it provides the instruments scientists need to conduct their investigations.

Technology is a double-edged sword. It can be both helpful and harmful. We have the technology, for example, to extract fossil fuels from the ground and then burn the fossil fuels to produce useful energy. Energy production from fossil fuels has benefited society in countless ways. On the flip side, the burning of fossil fuels damages the environment. It is tempting to blame technology itself for such problems as pollution, resource depletion, and even overpopulation. These problems, however, are not the fault of technology any more than a stabbing is the fault of the knife. It is humans who use the technology, and humans who are responsible for how it is used.

* Of course, this does not apply to certain religious extremists, who steadfastly assert that one cannot embrace both their brand of religion and science, or religions that are distinctly anti-science.

Remarkably, we already possess the technology to solve many environmental problems. This 21st century will likely see a switch from fossil fuels to more sustainable energy sources such as solar and wind—and, despite misgivings, a greater role of nuclear power. In some parts of the world, progress is being made toward limiting human population growth, a serious threat that worsens almost every problem faced by humans today. Difficulty solving today's problems results more from social inertia than from failing technology. Technology is our tool. What we do with this tool is up to us. The promise of technology is a cleaner and healthier world. Wise applications of technology *can* improve conditions on planet Earth.

1.9 The Natural Sciences: Physics, Chemistry, Biology, Earth Science, and Astronomy

LEARNING OBJECTIVE
Compare the fields of physics, chemistry, biology, Earth science, and astronomy.

Science is the present-day equivalent of what used to be called *natural philosophy*. Natural philosophy was the study of unanswered questions about nature. As the answers were found, they became part of what is now called *science*. The study of science today branches into the study of living things and nonliving things: the life sciences and the physical sciences. The *life sciences* branch into such areas as molecular biology, microbiology, and ecology. The *physical sciences* branch into such areas as physics, chemistry, the Earth sciences, and astronomy. In this book, we address the life sciences and physical sciences and the ways in which they overlap—or *integrate*. This gives you a foundation for more specialized study in the future and a framework for understanding science in everyday life and in the news, from the greenhouse effect to tsunamis to genetic engineering.

A few words of explanation about each of the major divisions of science: Physics is the study of such concepts as motion, force, energy, matter, heat, sound, light, and the components of atoms. Chemistry builds on physics by telling us how matter is put together, how atoms combine to form molecules, and how the molecules combine to make the materials around us. Physics and chemistry, applied to Earth and its processes, make up Earth science—geology, meteorology, and oceanography. When we apply physics, chemistry, and geology to other planets and to the stars, we are speaking about astronomy. Biology is more complex than the physical sciences because it involves matter that is alive. Underlying biology is chemistry, and underlying chemistry is physics. So physics is basic to both the physical sciences and the life sciences. That is why we begin this book with physics, then follow with chemistry and biology, and finally investigate Earth science and conclude with astronomy. All are treated conceptually, with the twin goals of enjoyment and understanding.

There are many paths scientists can follow in doing science. Scientists who explore the ocean floor or who chart new galaxies, for example, are focused on making and recording new observations.

1.10 Integrated Science

LEARNING OBJECTIVE
Relate learning integrated science to an increased appreciation of nature.

Because science helps us learn the rules of nature, it also helps us appreciate nature. You may see beauty in a tree, but you'll see more beauty in that tree when you understand how trees and other plants trap solar energy and convert it into the chemical energy that sustains nearly all life on Earth. Similarly, when you look at the stars, your sense of their beauty is enhanced if you know how stars are born from mere clouds of gas and dust—with a little help from the laws of physics, of course. And when you look at the myriad objects in your environment, how much richer it is to know that they are all composed of atoms—amazing, ancient, invisible systems of particles regulated by an eminently knowable set of laws.

Understanding the physical world—to appreciate it more deeply or to have the power to alter it—requires concepts from different branches of science. For example, the process by which a tree transforms solar energy to chemical energy—photosynthesis—involves the ideas of radiant energy (physics), bonds in molecules (chemistry), gases in the atmosphere (Earth science), the Sun (astronomy), and the nature of life (biology). Thus, for a complete understanding of photosynthesis and its importance, concepts beyond biology are required. And so it is for most of the real-world phenomena we are interested in. Put another way, the physical world integrates science, so to understand the world we need to look at science in an integrated way.

If the complexity of science intimidates you, bear this in mind: All the branches of science rest upon a relatively small number of basic ideas. Some of the most important unifying concepts are identified at the back of this book and in the page margins where they come up. Learn these underlying ideas, and you will have a tool kit to bring to any phenomenon you wish to understand.

Go to it—we live in a time of rapid and fascinating scientific discovery!

LEARNING OBJECTIVE
To connect the different sciences to the Northern nighttime sky.

Integrated Science 1A
PHYSICS, CHEMISTRY, EARTH SCIENCE, BIOLOGY, AND ASTRONOMY

The Aurora Borealis

Author Paul received a birthday present plus a bucket-list wish from his wife, Lillian: to view nature's spectacular display of the aurora borealis (Northern Lights) in the winter of Iceland. Witnessing the aurora was extra meaningful because it nicely spans the sciences of physics, chemistry, Earth science, biology, and astronomy.

The aurora is caused by electrically charged particles, mostly electrons and protons, ejected from the Sun and steered by the Earth's magnetic field toward our planet's north and south magnetic poles. When these particles strike atoms and molecules in the upper atmosphere, they are set aglow, producing nature's spectacular light show. Interestingly, mirror-like auroras called the aurora australis (Southern Lights) with similar shapes and colors light up the Antarctic skies in the Southern Hemisphere at the same time.

The common green color of the aurora is produced by the glowing of oxygen molecules. Oxygen at still higher altitudes produces a reddish color, and nitrogen produces a blue or purplish-red aurora. Often, a varied display of colors from a variety of atmospheric particles compose the aurora.

A solar wind of aurora-producing particles bombards Earth at all times of the year, as witnessed by inhabitants of the International Space Station. From Earth's surface the aurora is mainly visible during a dark nighttime sky, which is why it is rarely seen in northern latitudes during summer months when the sky, even at night, is not completely dark. Similarly, we can't view the ever-present stars unless the sky is dark. Our nights in Iceland were not as dark as hoped, due to the presence of a super-bright full moon. Hence, the photos we took were less impressive than the one in Figure 1.8. Spectacular views of the aurora are easily seen on the Internet.

FIGURE 1.8
The aurora borealis is caused by electrically-charged particles ejected from the Sun that strike molecules in the upper atmosphere.

We can see the science of the aurora borealis as charged particles ejected and hurled by the Sun encounter Earth's magnetic fields (physics), as particles moored to Earth's magnetic poles (Earth science), and in the swirling lights and colors characteristic of the atmospheric molecules (chemistry). Not so nice is the incidence of solar flares upon astronauts above Earth's protective atmosphere (biology). Auroras occur not only on Earth but also on other planets as well and likely on exoplanets or any astronomical bodies with magnetic fields (astronomy).

Interestingly, years earlier, I discovered that the best viewing of the corona during a solar eclipse is with the naked eye. Shimmering ultra-thin lines of light emanating from the Sun are blurred during the shutter time of a photographic shot. Viewing the aurora, however, is best with a camera, when dim light is gathered during the longer exposure of a photographic shot. If there were shimmering auroral lines, we didn't see them.

For instructor-assigned homework, go to https://mlm.pearson.com

SUMMARY OF TERMS (KNOWLEDGE)

Fact A phenomenon about which competent observers can agree.

Hypothesis An educated guess or a reasonable explanation. When the hypothesis can be tested by experiment, it qualifies as a *scientific hypothesis*.

Law A general hypothesis or statement about the relationship of natural quantities that has been tested over and over again and has not been contradicted; also known as a *principle*.

Principle of falsifiability For a hypothesis to be considered scientific, it must be testable—it must, in principle, be capable of being proven wrong.

Pseudoscience A theory or practice that is considered to be without scientific foundation but purports to use the methods of science.

Science The collective findings of humans about nature, and the process of gathering and organizing knowledge about nature.

Scientific method An orderly method for gaining, organizing, and applying new knowledge.

Technology The means of solving practical problems by applying the findings of science.

Theory A synthesis of a large body of information that encompasses well-tested hypotheses about certain aspects of the natural world.

READING CHECK QUESTIONS (COMPREHENSION)

1.1 A Brief History of Advances in Science

1. What launched the era of modern science in the 17th century?

1.2 Mathematics and Conceptual Integrated Science

2. Why do we believe that focusing on math too early is counterproductive in an introductory science course?

1.3 The Scientific Method—A Classic Tool

3. Specifically, what do we mean when we say that a scientific hypothesis must be testable?

1.4 The Scientific Hypothesis

4. When does a scientific hypothesis become a law?

1.5 The Scientific Experiment

5. How did Galileo disprove Aristotle's idea that heavy objects fall faster than light objects?

1.6 Facts, Theories, and Laws

6. Distinguish among a scientific fact, a hypothesis, a law, and a theory.
7. How does the definition of the word *theory* differ in science versus in everyday life?
8. Your friend says that scientific theories cannot be believed because they are always changing. What can you say to counter this argument?

1.7 Science, Art, and Religion

9. What are the two domains of science and religion?
10. Why must one not have to choose between science and religion?

1.8 Technology—The Practical Use of Science

11. Clearly distinguish between science and technology.

1.9 The Natural Sciences: Physics, Chemistry, Biology, Earth Science, and Astronomy

12. In what sense does physics underlie chemistry?
13. In what sense is biology more complex than the physical sciences?

1.10 Integrated Science

14. What is the value of studying integrated science, rather than the realms of science separately?

THINK INTEGRATED SCIENCE

1A—The Aurora Borealis

15. How does the aurora borealis relate to the field of biology?
16. Why is the aurora borealis best seen in winter months?

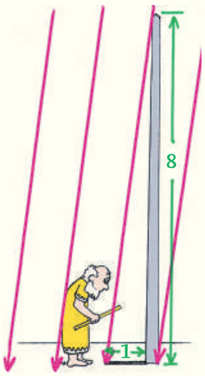
THINK AND DO (HANDS-ON APPLICATION)

17. Take note of the length of shadows of vertical structures such as flagpoles throughout the day. When are shadows least, and when are they longer?
18. Do the activity of Figure 1.6 on page 39.
19. Take a photo of solar images on the ground that are cast by openings between tree leaves above on a sunny day.
20. Do the pea and Moon measurements at the top of page 40. Rather than a pea, tape a coin to your window in a position where it will eclipse the Moon in the nighttime sky (or in daytime if the Moon is clearly visible). Check to see if the distance of "eclipse" is indeed about 110 coin diameters away from you.

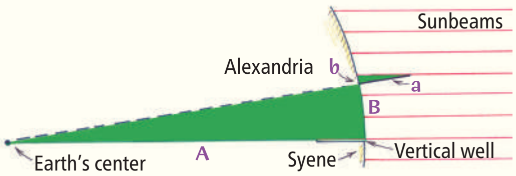
THINK AND SOLVE (MATHEMATICAL APPLICATION)

21. If the Sun's rays were at 45° to a vertical pillar, how would the length of its shadow compare with its height?

22. Eratosthenes measured the height of the vertical pillar in Alexandria to be 8 times greater than the length of the shadow it cast at high noon. So the ratio of (length of shadow)/(height of pillar) is 1/8. If the Sun were lower in the sky, would the ratio be smaller or larger?



23. Examine the nearly similar small and large green "triangles"—the small one with sides **a** and shadow **b**, and the larger one with corresponding sides Earth's radius **A** and the 800-km distance **B** between Alexandria and Syene. Note equal ratios **a/b** = **A/B**. Knowing that **a/b** = **1/8**, calculate **A**, the radius of the Earth.



24. Knowing and using Earth's radius, show that the circumference of Earth is about 40,000 km, in agreement with Eratosthenes's findings. (*Hint*: What is the formula for the circumference of a circle?)
25. If the angle between the two verticals extended to Earth's center (Figure 1.4) were 10° instead of 7.2°, still subtending 800 km, what would be Eratosthenes's value for Earth's circumference? (*Hint*: How many 10° segments circle Earth?)

THINK AND EXPLAIN (SYNTHESIS)

26. Are the various branches of science separate, or do they overlap? Give several examples to support your answer.
27. In what way is the printing press like the Internet in the history of science?
28. Which of the following are scientific hypotheses? (a) The bacteria *Escherichia coli* are happier in dark environments. (b) Wind is caused by the motion of trees. (c) There are an infinite number of parallel universes, but no communication is possible between them.
29. If Earth were smaller than it is, but the Alexandria-to-Syene distance were the same, would the shadow cast by the vertical pillar in Alexandria be longer or shorter at noon during the summer solstice?
30. If the height of the card in Figure 1.6 were positioned so the solar image matched the size of a coin (a good way to accurately measure the diameter of the solar image), then 110 of these coins would fit end-to-end in the space between the card and the image beneath. How many Suns would similarly fit between Earth and the Sun?

THINK AND DISCUSS (EVALUATION)

31. Discuss the value Galileo placed on experimentation over philosophical discussions.
32. What do science, art, and religion have in common? How are they different?
33. If the tree that casts solar images around Lillian (photo on page 39) were taller, would the images be larger or remain about the same size?
34. A nonscientist friend tells you that science and religion are both based on references to authority, and that a science textbook (such as this one) is similar to a religious text (such as a bible). What argument(s) could you use to convince your friend that there are important differences between a science textbook and a religious text?

1 PART ONE Physics

Wow, Great Uncle Paul! Before this chickie exhausted its inner space resources and poked out of its shell, it must have thought it was at its last moments. But what seemed like its end was a new beginning. Are we like chickies, ready to poke through to a new environment and a new understanding of our place in the universe?

CHAPTER TWO

2 Describing Motion

EVERYTHING MOVES—ATOMS, molecules, clouds, ocean tides, planets, galaxies, and little Hudson Hendricks, who is delightfully set into motion by his dad. A physics description of Hudson's motion involves three main concepts: speed (how fast), distance (how far), and acceleration (how fast speed changes). After becoming familiar with these three concepts you can begin to understand many forms of motion. What causes things to move? Do they *start* moving spontaneously, or is something needed to make them move? Do they *stop* moving on their own, or is something needed to stop them? We will see that a force (a push or pull) is required to change motion—whether the blowing wind, your car on the freeway, or the path of a crawling bug. Although motion can involve a variety of complexities, in this chapter we'll treat the simplest form of motion—linear motion—along a straight-line path.

2.1 Aristotle on Motion

LEARNING OBJECTIVE
Establish Aristotle's influence on classifying motion.

Aristotle divided motion into two classes: *natural motion* and *violent motion.* Natural motion had to do with the nature of bodies. Light things like smoke rose, and heavy things like dropped boulders fell. The motions of stars across the night sky were natural. Violent motion, on the other hand, resulted from pushing or pulling forces. Objects whose motions were unnatural were either pushed or pulled. Aristotle believed that natural laws could be understood by logical reasoning.

Two assertions of Aristotle held sway for some 2000 years. One was that heavy objects necessarily fall faster than lighter objects. The other was that moving objects must necessarily have forces exerted on them to keep them moving.

These ideas were completely turned around in the 17th century by Galileo, who held that experiment was superior to logic in uncovering natural laws. Galileo demolished the idea that heavy things fall faster than lighter things in his famous Leaning Tower of Pisa experiment, where he allegedly dropped objects of different weights and showed that—except for differences due to the effects of air resistance—they fell to the ground together.

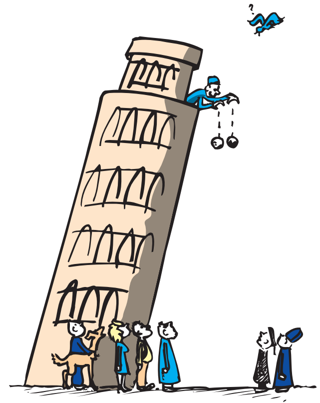


FIGURE 2.1
Galileo's famous demonstration.

CHECK YOURSELF

Isn't it common sense to think that Earth is in its proper place and that a force to move it is inconceivable, as Aristotle held, and that the Earth *is* at rest in this universe? (*Think and formulate your own answer. Then check your thinking below.*)

CHECK YOUR ANSWER

Common sense is relative to one's time and place. Aristotle's views were logical and consistent with everyday observations. So unless you become familiar with the physics to follow, Aristotle's views about motion do make common sense (and are held by many uneducated people today). But as you acquire new information about nature's rules, you'll likely find your common sense progressing beyond Aristotelian thinking.

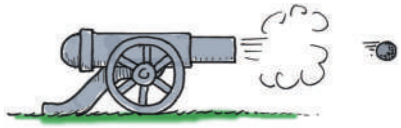
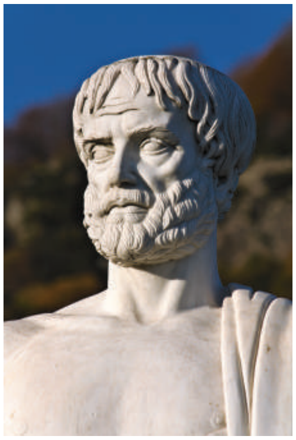


FIGURE 2.2
Does a force keep the cannonball moving after it leaves the cannon?

HISTORY OF SCIENCE

Aristotle (384–322 BC)

Aristotle was the foremost philosopher, scientist, and educator of his time. Born in Greece, he was the son of a physician who personally served the king of Macedonia. At age 17, he entered the Academy of Plato, where he worked and studied for 20 years until Plato's death. He then became the tutor of young Alexander the Great. Eight years later, he formed his own school. Aristotle's aim was to systematize existing knowledge, just as Euclid had systematized geometry. Aristotle made critical observations; collected specimens; and gathered, summarized, and classified almost all of the existing knowledge of the physical world. His systematic approach became the method from which Western science later arose. After his death, his voluminous notebooks were preserved in caves near his home and were later sold to the library at Alexandria. Scholarly activity ceased in most of Europe through the Dark Ages, and the works of Aristotle were forgotten and lost in the scholarship that continued in the Byzantine and Islamic empires. Several of his texts were reintroduced to Europe during the 11th and 12th centuries and were translated into Latin. The Church, the dominant political and cultural force in Western Europe, at first prohibited the works of Aristotle and then accepted and incorporated them into Christian doctrine.



LEARNING OBJECTIVE
Establish Galileo's influence in understanding motion.

2.2 Galileo's Concept of Inertia

Galileo tested his revolutionary idea by *experiment*. After studying balls rolling on planes inclined at various angles, he concluded that an object, once moving, continues to move *without* the application of forces. In the simplest sense, a **force** is a push or a pull. Although a force is needed to start an object moving, Galileo showed that once it is moving, no force is needed to keep it moving, except for the force needed to overcome friction (more about friction in Section 2.7). When friction is absent, a moving object needs no force to keep it moving. Galileo reasoned that a ball moving horizontally would move forever if friction were entirely absent. A ball would move of itself, of its own **inertia**, the property by which objects resist changes in motion.

This was the beginning of modern science. Experiment, not philosophical speculation, is the test of truth.

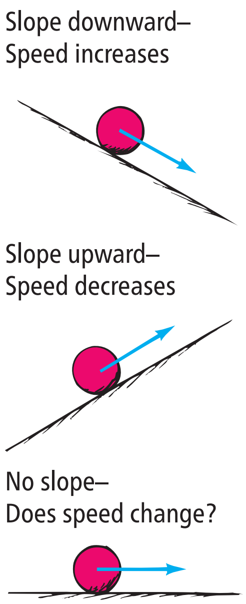


FIGURE 2.3
The motion of balls on various planes.

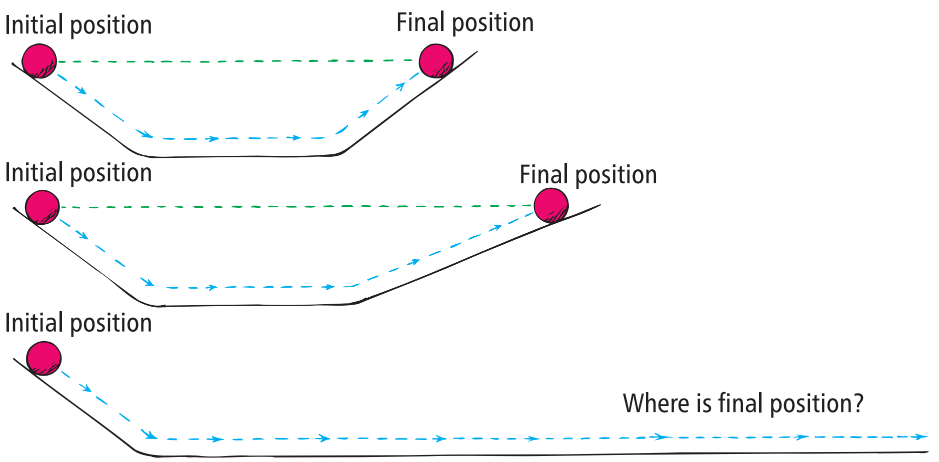


FIGURE 2.4
A ball rolling down an incline tends to roll up to its initial height. The ball must roll a greater distance as the angle of incline on the right is reduced.

HISTORY OF SCIENCE

Galileo Galilei (1564–1642)

Galileo was born in Pisa, Italy, in the same year Shakespeare was born and Michelangelo died. He studied medicine at the University of Pisa and then changed to mathematics. He developed an early interest in motion and was soon at odds with others around him, who held to Aristotelian ideas on falling bodies. He left Pisa to teach at the University of Padua and became an advocate of the new theory of the solar system advanced by the Polish astronomer Copernicus. Galileo was one of the first to build a telescope, and the first to direct it to the nighttime sky and discover mountains on the Moon and the moons of Jupiter. Because he published his findings in Italian instead of in Latin, which was expected of so reputable a scholar, and because of the recent invention of the printing press, his ideas reached many people. He soon ran afoul of the Church and was warned not to teach and not to hold to Copernican views. He restrained himself publicly for nearly 15 years. Then he defiantly published his observations and conclusions, which were counter to Church doctrine. The outcome was a trial in which he was found guilty, and he was forced to renounce his discoveries. By then an old man broken in health and spirit, he was sentenced to perpetual house arrest. Nevertheless, he completed his studies on motion, and his writings were smuggled out of Italy and published in Holland. His eyes had been damaged earlier by viewing the Sun through a telescope, which led to blindness at age 74. He died four years later.

CHECK YOURSELF

A ball rolling along a level surface slowly comes to a stop. How would Aristotle explain this behavior? How would Galileo explain it? How would you explain it?

CHECK YOUR ANSWERS

As mentioned, think about the Check-Yourself questions throughout this textbook before reading the answers. When you first formulate your own answers, you'll find yourself learning more—much more!

Aristotle would probably say that, with no force keeping the ball moving, it stops because it seeks its natural state of rest. Galileo would probably say that the force of friction overcomes the ball's natural tendency to continue rolling—that friction overcomes the ball's inertia and brings it to a stop. Only you can answer the last question!

2.3 Mass—A Measure of Inertia

LEARNING OBJECTIVE

Describe and distinguish between mass and weight.

Every material object possesses inertia; how much depends on its amount of matter—the more matter, the more inertia. In speaking of how much matter something has, we use the term *mass*—the greater the mass of an object, the greater the amount of matter and the greater its inertia. **Mass** is a measure of the inertia of a material object.

Loosely speaking, mass corresponds to our intuitive notion of **weight**. We say something has a lot of matter if it is heavy. That's because we are accustomed to measuring matter by gravitational attraction to Earth. But mass is more fundamental than weight; it is a fundamental quantity that completely escapes the notice of most people. There are times, however, when weight corresponds to our unconscious notion of inertia. For example, if you are trying to determine which of two small objects is heavier, you might shake them back and forth in your hands or move them in some way instead of lifting them. In doing so, you are judging which of the two is more difficult to get moving, seeing which is the more resistant to a *change* in motion. You are really comparing the inertias of the objects.

It is easy to confuse the ideas of mass and weight. We define each as follows:

Mass: The quantity of matter in an object. It is also the measure of the inertia or sluggishness that an object exhibits in response to any effort made to start it, stop it, or change its state of motion in any way.

Weight: The force upon an object due to gravity.

The standard unit of mass is the **kilogram**, abbreviated kg. Weight is measured in units of force (such as pounds). The scientific unit of force is the **newton**, abbreviated N, which we'll use in this textbook. The abbreviation is written with a capital letter because the unit is named after a person.

Mass and weight are directly proportional to each other.* If the mass of an object is doubled, its weight is also doubled; if the mass is halved, the weight is halved. Because of this, mass and weight are often interchanged. Also, mass and weight are sometimes confused because it is customary to measure the quantity of matter in things (their mass) by their gravitational attraction to Earth (their weight). But mass

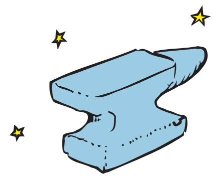


FIGURE 2.5
An anvil in outer space—beyond the Sun, for example—may be weightless, but it still has mass.

FIGURE 2.6
The astronaut in space finds it just as difficult to shake the "weightless" anvil as on Earth. If the anvil is more massive than the astronaut, which shakes more—the anvil or the astronaut?

* *Directly proportional* means that if you change one thing, the other thing changes proportionally. The constant of proportionality is g, the acceleration due to gravity. As we shall soon see, weight $= mg$ or (mass $\times$ acceleration due to gravity). So $9.8\text{ N} = (1\text{ kg})(9.8\text{ m/s}^2)$. In Chapter 5 we'll extend our definition of weight to be the force of a body pressing against a support (for example, against a weighing scale).

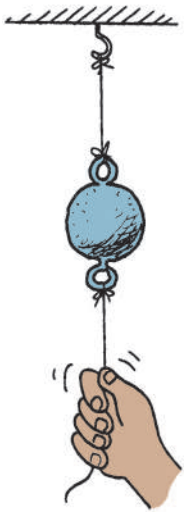


FIGURE 2.7
Why will a slow continuous increase in downward force break the string above the massive ball, whereas a sudden increase in downward force breaks the lower string?

doesn't depend on gravity. Gravity on the Moon, for example, is much less than it is on Earth. Whereas your weight on the surface of the Moon would be much less than it is on Earth, your mass would be the same in both locations.

Don't confuse mass and volume, the quantity of space an object occupies. When we think of a massive object, we often think of a big object. An object's size, however, is not necessarily a good way to judge its mass. Which is easier to get moving: a car battery or a king-size pillow? So we find that mass is neither weight nor volume.

A nice demonstration that distinguishes mass from weight is the massive ball suspended on the string shown in Figure 2.7. The top string breaks when the lower string is pulled with a gradual increase in force, but the bottom string breaks when the string is jerked. Which of these cases illustrates the weight of the ball, and which illustrates the mass of the ball? Note that only the top string bears the weight of the ball. So when the lower string is gradually pulled, the tension supplied by the pull is transmitted to the top string. Thus the total tension in the top string is pull plus the weight of the ball. The top string breaks when the breaking point is reached. But when the bottom string is jerked, the mass of the ball—its tendency to remain at rest—is responsible for breakage of the bottom string.

CHECK YOURSELF

1. **Does a 2-kg iron block have twice as much *inertia* as a 1-kg iron block? Twice as much *mass*? Twice as much *volume*? Twice as much *weight* when weighed in the same location?**
2. **Does a 2-kg iron block have twice as much *inertia* as a 1-kg bunch of bananas? Twice as much *mass*? Twice as much *volume*? Twice as much *weight* when weighed in the same location?**
3. **How does the mass of a bar of gold vary with location?**

CHECK YOUR ANSWERS

1. The answer is yes to all questions. A 2-kg block of iron has twice as many iron atoms, and therefore twice the amount of inertia, mass, and weight. The blocks consist of the same material, so the 2-kg block also has twice the volume.
2. Two kilograms of anything has twice the inertia and twice the mass of 1 kg of anything else. Because mass and weight are proportional in the same location, 2 kg of anything will weigh twice as much as 1 kg of anything. Except for volume, the answer to all the questions is yes. Volume and mass are proportional only when the materials are identical—when they have the same density. (More on density on the next page.) Iron is much more dense than bananas, so 2 kg of iron must occupy less volume than 1 kg of bananas.
3. Not at all! It consists of the same number of atoms no matter what the location. Although its weight may vary with location, it has the same mass everywhere. This is why mass is preferred to weight in scientific studies.

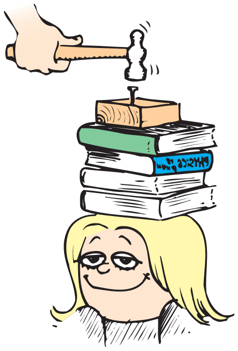


FIGURE 2.8
Why does the blow of the hammer not harm her?

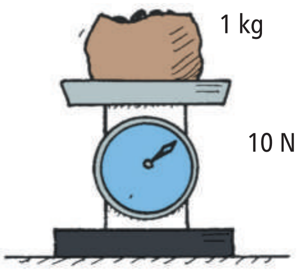


FIGURE 2.9
One kilogram of nails weighs about 10 N, which roughly equals 2.2 lb.

One Kilogram Weighs 10 N

A 1-kg bag of any material at Earth's surface has a weight of 9.8 N. Away from Earth's surface, where the force of gravity is less (on the Moon, for example), the bag would weigh less.

Except in cases where precision is needed, we round off 9.8 and call it 10. So 1 kg of something on Earth's surface weighs about 10 N. If you know the mass in kilograms and want the weight in newtons, multiply the number of kilograms by 10. Or, if you know the weight in newtons, divide by 10 and you'll have the mass in kilograms. As previously mentioned, weight and mass are proportional to each other.

Density

An important property of a material, whether solid, liquid, or gas, is the measure of its compactness: *density*. **Density** is a measure of how much mass is squeezed into a given space; it is the amount of matter per unit volume:

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

Like mass and weight, density has to do with the "lightness" or "heaviness" of materials. But the distinction is that density also involves the volume of an object, the space it occupies. For example, a kilogram of lead has the same mass as a kilogram of feathers, and, at the surface of Earth, both of them have the same weight—2.2 lb. But their densities are very different. A kilogram of lead is very dense and would fit into a tennis ball, while the same mass of feathers has a very low density and could adequately stuff the shell of a down-filled sleeping bag. Volume is often measured in cubic centimeters (cm^3) or cubic meters (m^3), so density is most typically expressed in units of g/cm^3, or kg/m^3. Water has a density of 1 g/cm^3. Mercury's density of 13.6 g/cm^3 means that it has 13.6 times as much mass as an equal volume of water. Although different masses of the same material have different volumes, the given materials have the same density.

UNIFYING CONCEPT

Density

A pillow is bigger than a car battery, but which has more matter? Which has more inertia? Which has more mass? Greater density?

CHECK YOURSELF

1. **Would 1 kg of gold have the same density on the Moon as on Earth?**
2. **Which has the greater density: an entire candy bar or half a candy bar?**

CHECK YOUR ANSWERS

1. Yes. Since mass and volume remain the same despite gravitational variations, the ratio of mass to volume remains constant as well.
2. Both half a candy bar and an entire candy bar have the same density.

2.4 Net Force

LEARNING OBJECTIVE

Distinguish between force and net force, and give examples.

In simplest terms, a force is a push or a pull. An object doesn't speed up, slow down, or change direction unless a force acts on it. When we say "force," we imply the total force, or **net force**, acting on the object. Often more than one force may be acting on an object. For example, when you throw a softball, the force of gravity and the pushing force you apply with your muscles both act on the ball. When the ball is sailing through the air, the force of gravity and air resistance both act on it. The net force on the ball is the combination of forces. It is the net force that changes an object's state of motion.

Another example; suppose you pull on a shoebox with a force of 5 N (slightly more than 1 lb). If your friend also pulls with 5 N in the same direction, the net force on the box is 10 N. If your friend pulls on the box with the same force as you but in the opposite direction, the net force on the box is zero. Now if you increase your pull to 10 N and your friend pulls oppositely with a force of 5 N, the net force is 5 N in the direction of your pull. You can see these examples in Figure 2.10.

The forces in Figure 2.10 are shown by arrows. Forces are *vector quantities*. A **vector quantity** has both magnitude (how much) and direction (which way). When an arrow represents a vector quantity, the arrow's length represents magnitude and its direction shows the direction of the quantity. Such an arrow is called a *vector*.

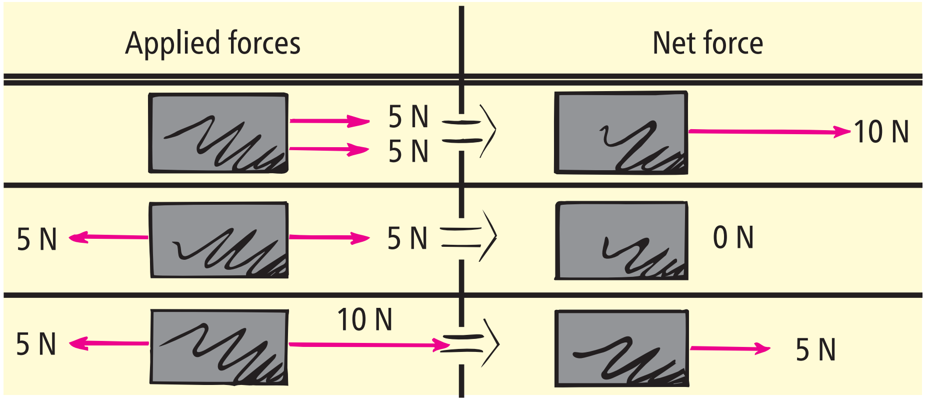


FIGURE 2.10
Net force.

LEARNING OBJECTIVE
Describe the rule $\Sigma F = 0$, and give examples.

2.5 The Equilibrium Rule

If you tie a string around a 2-lb bag of flour and suspend it on a weighing scale, a spring in the scale stretches until the scale reads 2 lb. The stretched spring is under a "stretching force" called *tension*. A scale in a science lab (Figure 2.11) is likely calibrated to read the same force as 9 N. Both pounds and newtons are units of weight, which, in turn, are units of force. The bag of flour is attracted to Earth with a gravitational force of 2 lb—or, equivalently, 9 N. Suspend twice as much flour from the scale and the reading will be about 18 N.

Two forces are acting on a bag of flour—tension force acting upward and weight acting downward. The two forces on the bag are equal and opposite, and they cancel to zero. Hence, the bag remains at rest.

When the net force on something is zero, we say that something is in mechanical equilibrium.* Anything in mechanical equilibrium obeys an interesting rule: In mathematical notation, the **equilibrium rule** is

$$\Sigma F = 0$$

The symbol Σ is the capital Greek letter sigma, which stands for "the vector sum of"; F stands for "forces." For a suspended body at rest, like the bag of flour, the equilibrium rule states that the forces acting upward on the body must be balanced by other forces acting downward to make the vector sum equal zero. (Vector quantities take direction into account, so, if upward forces are positive, downward forces are negative, and when summed they equal zero. See Figure 2.12.)

FIGURE 2.11
Burl Grey, who taught the author about tension forces, suspends a 2-lb bag of flour from a spring scale, showing the weight and tension in the string of about 9 N.

Everything that isn't undergoing a change in motion is in mechanical equilibrium.
That's because $\Sigma F = 0$.

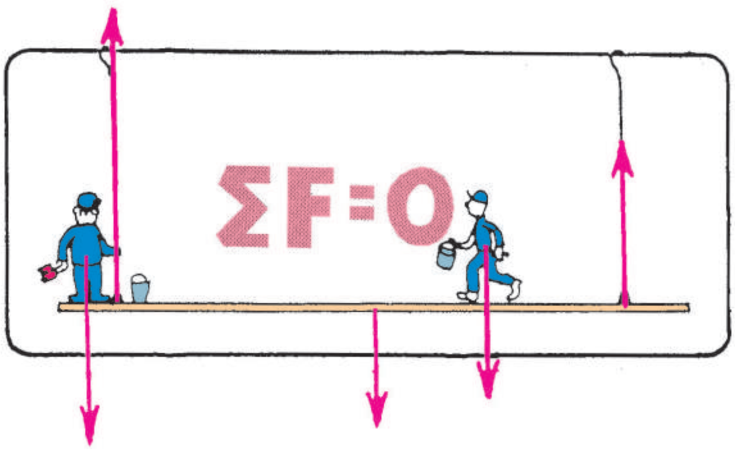


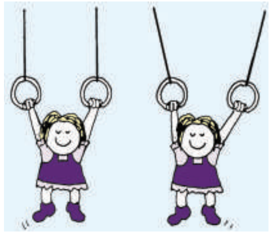
FIGURE 2.12
The sum of the upward vectors equals the sum of the downward vectors. $\Sigma F = 0$, and the scaffold is in equilibrium.

* We'll see in Appendix B that another condition for equilibrium is that the net torque is zero. Other forms of equilibrium include thermal and electrical equilibrium.

CHECK YOURSELF

Consider the gymnast Nellie Newton hanging from the rings.

1. **If Nellie hangs with her weight evenly divided between the two rings, how would scale readings in both supporting ropes compare with her weight?**
2. **Suppose Nellie hangs with slightly more of her weight supported by the left ring. What would the scale on the right read?**



CHECK YOUR ANSWERS

1. The reading on each scale would be half her weight. The sum of the readings on both scales would then equal her weight.
2. When more of her weight is supported by the left ring, the reading on the right is less than half her weight. No matter how she hangs, the sum of the scale readings equals her weight. For example, if one scale reads two-thirds her weight, the other scale will read one-third her weight. Get it?

LEARNING OBJECTIVE

Distinguish between equilibrium at rest and when moving.

Equilibrium of Moving Things

Equilibrium is a state of no change. Rest is only one form of equilibrium. An object moving at a constant speed in a straight-line path is also in equilibrium. A bowling ball rolling at a constant speed in a straight line is also in equilibrium—until it hits the pins. Whether at rest or steadily rolling in a straight-line path, $\Sigma F = 0$.

An object under the influence of only one force cannot be in equilibrium. The net force couldn't be zero. Only when two or more forces act on it can the object be in equilibrium. We can test whether or not something is in equilibrium by noting whether or not it undergoes changes in its state of motion.

Consider a table being pushed across a floor. If it moves at a steady speed in a straight-line path, it is in equilibrium. This indicates that more than one force is acting on the table. Another force exists—likely the force of friction between the table and the floor. The fact that the net force on the table equals zero tells us that the force of friction must be equal to, and opposite to, the pushing force (Figure 2.13).

FIGURE 2.13

When Marie's push is as great as the force of friction between the table and the floor, the net force on the table is zero and it slides at an unchanging speed.

2.6 The Support Force

LEARNING OBJECTIVE

Define the support force, and describe its relationship to weight.

Consider a book lying at rest on a table. It is in equilibrium. What forces act on the book? One is the force due to gravity—the weight of the book. Since the book is in equilibrium, there must be another force acting on it to produce a net force of zero—an upward force opposite to the force of gravity. The table exerts this upward force, called the **support force**. This upward support force, often called the *normal force*, must equal the weight of the book.* If we designate the upward force as positive, then the downward force (weight) is negative, and the sum of the two is zero. The net force on the book is zero. Stated another way, $\Sigma F = 0$.

To understand better that the table pushes up on the book, compare the case of compressing a spring (Figure 2.14). If you push the spring down, you can feel the spring pushing up on your hand. Similarly, the book lying on the table compresses the atoms in the table, which behave like microscopic springs. The weight of the book squeezes downward on the atoms, and they squeeze upward on the book. In this way, the compressed atoms produce the support force.

When you step on a bathroom scale, two forces act on the scale. One is the downward pull of gravity (your weight) and the other is the upward support force of the floor. These forces compress a spring that is calibrated to show your weight (Figure 2.15). In effect, the scale shows the support force. When you weigh yourself on a bathroom scale at rest, the support force and your weight have the same magnitude.

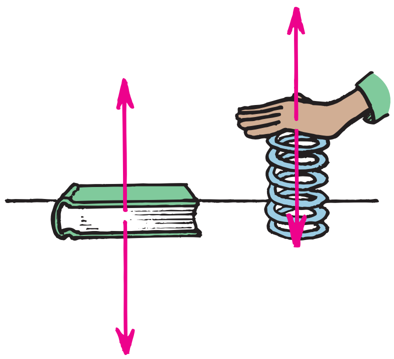


FIGURE 2.14

The table pushes up on the book with as much force as the downward force of gravity on the book. The spring pushes up on your hand with as much force as you exert to push down on the spring.

* This force acts at right angles to the surface. When we say "normal to," we are saying "at right angles to," which is why this force is called a normal force.

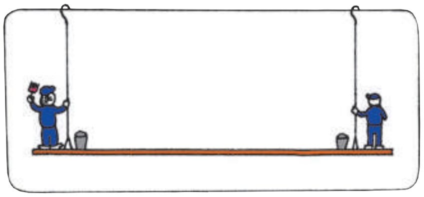
SCIENCE AND SOCIETY

Paul Hewitt and the Origin of Conceptual Integrated Science

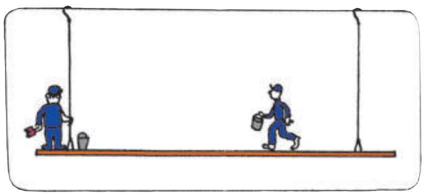
Paul Hewitt, the founding author of this book, wrote the physics textbook *Conceptual Physics* when he was a young instructor at City College of San Francisco. *Conceptual Physics* has been the leading physics book for nonscience majors in several countries for more than 45 years, and it's had a major impact on how science is taught—concepts first, with computations and technical details later. The following is Paul's personal story about how he discovered the fascination of science by observing physics principles at work in everyday life:

When I was in high school, my counselor advised me not to enroll in science and math classes but instead to focus on my interest in art. I took this advice. For a while, my major interests were drawing comic strips and boxing, but neither of these earned me much success. After a stint in the army, I tried my luck at sign painting, and the cold Boston winters drove me south to Miami, Florida. There, at age 26, I got a job painting billboards and met a new friend who became a great intellectual influence for me, Burl Grey. Like me, Burl had never studied physics in high school. But he was passionate about science in general, and he shared his passion with many questions as we painted together.

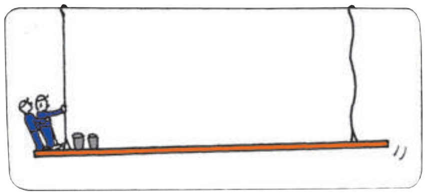
I remember Burl asking me about the tensions in the ropes that held up the scaffold we were standing on. The scaffold was simply a heavy horizontal plank suspended by a pair of ropes. Burl twanged the rope nearest his end of the scaffold and asked me to do the same with mine. He was comparing the tensions in both ropes—to determine which was greater. Like a more tightly stretched guitar string, the rope with greater tension twangs at a higher pitch. The finding that Burl's rope had a higher pitch seemed reasonable because he was heavier and his rope supported more of the load.



When I walked toward Burl to borrow one of his brushes, he asked if the tensions in the ropes had changed. Did the tension in his rope change as I moved closer? We agreed that it should have, because even more of the load was supported by Burl's rope. How about my rope? Did its tension decrease? We agreed that it would, for it would be supporting less of the total load. I was unaware at the time that I was discussing physics.

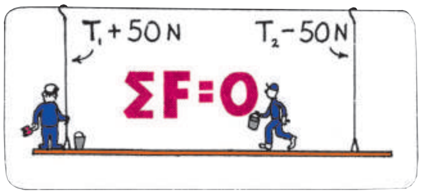


Burl and I used exaggeration to bolster our reasoning (just as physicists do). If we both stood at an extreme end of the scaffold and leaned outward, it was easy to imagine the opposite end of the scaffold rising like the end of a seesaw, with the opposite rope going limp. Then there would be no tension in that rope. We reasoned that the tension in my rope would gradually decrease as I walked toward Burl. It was fun posing such questions and seeing if we could answer them.



A question we couldn't answer was whether or not the decrease in tension in my rope when I walked away from it would be exactly compensated by a tension increase in Burl's rope. For example, if my rope underwent a decrease of 50 N, would Burl's rope gain 50 N? (We talked about pounds back then, but here we use the scientific unit of force, the *newton*—abbreviated N.) Would the gain be exactly 50 N? And, if so, would this be a grand coincidence? I didn't know the answer until more than a year later, when Burl's stimulation resulted in my leaving full-time painting and going first to prep school, and then college to learn more about science.

There I learned that any object at rest, such as the sign-painting scaffold I had worked on with Burl, is said to be in equilibrium. That is, all the forces that act on it balance to zero $(\Sigma F = 0)$. So the upward forces supplied by the supporting ropes indeed do add up to our weights plus the weight of the scaffold. A 50-N loss in one would be offset by a 50-N gain in the other.



I tell this story to make the point that one's thinking is very different when there is a rule to guide it. Now, when I look at any motionless object, I know immediately that all the forces acting on it cancel out. We see nature differently when we know its rules. Nature becomes simpler and easier to understand. Without the rules of physics, we tend to be superstitious and to see magic where there is none. Quite wonderfully, everything is beautifully connected to everything else by a surprisingly small number of rules. Physics is a study of nature's rules.

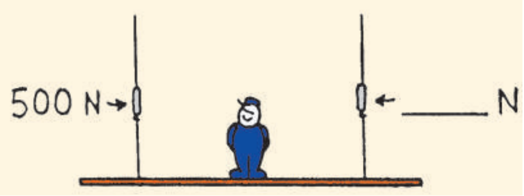
MATH CONNECTION

Applying the Equilibrium Rule

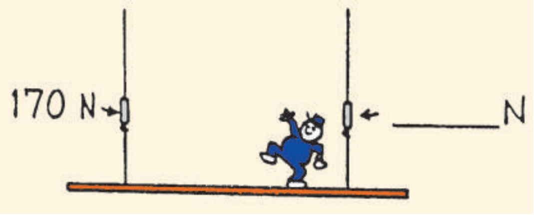
Use the physics you've learned so far to solve these practice problems.

Problems

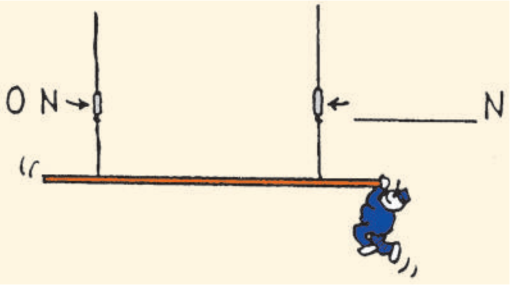
1. When Burl stands alone in the exact middle of his scaffold, the reading on the left scale is 500 N. Fill in the reading on the right scale. The total weight of Burl and the scaffold is ________ N.



2. Burl moves farther from the left side. Fill in the reading on the right scale.



3. In a silly mood, Burl dangles from the right end. Fill in the reading on the right scale.



Solutions

1. The total weight is 1000 N. The right rope must be under 500 N of tension because Burl is in the middle and both ropes support his weight equally. Since the sum of the tensions is 1000 N, the total weight of Burl and the scaffold must be 1000 N. Let's call the upward tension forces +1000 N. Then the downward weights are −1000 N. What happens when you add +1000 and −1000? The answer is that they equal zero. So we see that $\Sigma F = 0$.
2. Did you get the correct answer of 830 N? Reasoning: We know from question 1 that the sum of the rope tensions equals 1000 N, and since the left rope has a tension of 170 N, the other rope must make up the difference—that is, 1000 N − 170 N = 830 N. Get it? If so, great. If not, discuss it with your friends until you do. Then read further.
3. The answer is 1000 N. Do you see that this illustrates $\Sigma F = 0$?

CHECK YOURSELF

1. What is the net force on a bathroom scale when a 150-lb person stands on it?

2. Suppose you stand on two bathroom scales with your weight evenly distributed between the scales. What is the reading on each of the scales? What happens when you stand with more of your weight on one foot than on the other?

CHECK YOUR ANSWERS

1. Zero, because the scale remains at rest. The scale reads the support force (which has the same magnitude as weight), not the net force.
2. The reading on each scale is half your weight, because the sum of the scale readings must balance your weight, so that the net force on you will be zero. If you lean more on one scale than on the other, more than half your weight will be read on that scale, but less on the other, so they will still add up to your weight. Like the example of the gymnast hanging by the rings, if one scale reads two-thirds of your weight, the other scale will read one-third of your weight.

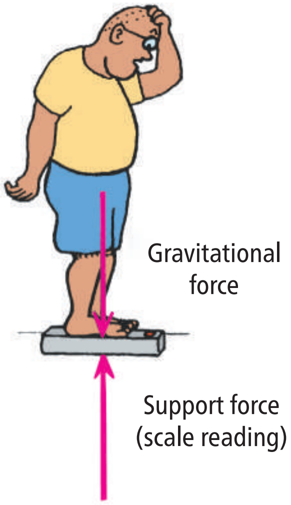


FIGURE 2.15
The upward support force is as much as the downward force of gravity, your weight.

LEARNING OBJECTIVE
Describe friction and its direction when an object slides.

UNIFYING CONCEPT
Friction

2.7 The Force of Friction

Friction is a force that opposes motion or attempted motion. It can occur when one object rubs against something else.* Friction occurs for solids, liquids, and gases. An important rule of friction is that it always acts in a direction to oppose motion. If you pull a solid block along a floor to the left, the force of friction on the block will be toward the right. A boat propelled to the east by its motor experiences water friction to the west. When an object falls downward through the air, the force of friction, **air resistance**, acts upward. Friction always acts in a direction to oppose motion.

CHECK YOURSELF
An airplane flies through the air at a constant velocity. In other words, it is in equilibrium. Two horizontal forces act on the plane. One is the thrust of the propeller that pushes it forward. The other is the force of air resistance that acts in the opposite direction. Which force is greater?

CHECK YOUR ANSWER
Both horizontal forces have the same magnitude. If you call the forward force exerted by the propeller positive, then the air resistance is negative. Since the plane is in equilibrium, can you see that the two forces combine to zero?

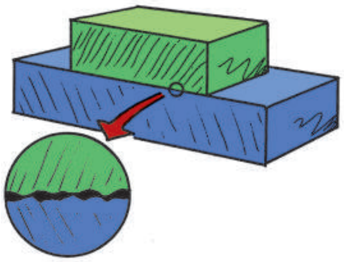


FIGURE 2.16
Friction results from the mutual contact of irregularities in the surfaces of sliding objects. Even surfaces that appear to be smooth have irregular surfaces when viewed at the microscopic level.

Friction is due to surface bumps and also to the "stickiness" of the atoms on the surfaces of the two materials (Figure 2.16). The amount of friction between two surfaces depends on the kinds of material and how much they are pressed together. The friction between a crate and a smooth wooden floor is less than the friction between the same crate and a rough floor. And, if the crate is full, the friction is more than it would be if the crate were empty because the crate presses down harder on the floor.

When you push horizontally on a crate and it slides across a factory floor, both your force and the opposite force of friction affect the crate's motion. When you push hard enough on the crate to match the friction, the net force on the crate is zero, and it slides at a constant velocity. Notice that we are talking about what we recently learned—that no change in motion occurs when $\Sigma F = 0$.

CHECK YOURSELF
1. **Suppose you exert a 100-N horizontal force on a heavy crate resting motionless on a factory floor. The fact that it remains at rest indicates that 100 N isn't great enough to make it slide. How does the force of friction between the crate and the floor compare with your push?**
2. **You push harder—say, 110 N—and the crate still doesn't slide. How much friction acts on the crate?**
3. **You push still harder, and the crate moves. Once the crate is in motion, you push with 115 N, which is just sufficient to keep it sliding at a constant velocity. How much friction acts on the crate?**

* Even though it may not seem so yet, most of the concepts in physics are not really complicated. But friction is different; it is a very complicated phenomenon. The findings are empirical (gained from a wide range of experiments), and the predictions are approximate (also based on experiments).

4. What net force does a sliding crate experience when you exert a force of 125 N and the friction between the crate and floor is 115 N?

CHECK YOUR ANSWERS

1. The force of friction is 100 N in the opposite direction. Friction opposes the motion that would occur otherwise. The fact that the crate is at rest is evidence that $\Sigma F = 0$.
2. The friction increases to 110 N; again $\Sigma F = 0$.
3. 115 N, because when the crate is moving at a constant velocity, $\Sigma F = 0$.
4. 10 N, because $\Sigma F = 125\text{ N} - 115\text{ N}$. In this case, the crate accelerates.

VIDEO: Friction

Integrated Science 2A:

BIOLOGY, ASTRONOMY, CHEMISTRY, AND EARTH SCIENCE

LEARNING OBJECTIVE
Relate friction to different areas of scientific study.

Friction Is Universal

Friction is the opponent of all motion. If an object moves upward, friction pushes it downward. Whenever two objects are in contact, friction acts in such a way as to prevent or slow their relative motion.

Your body is well adapted to a friction-filled environment. The fingerprint ridges in your palms and fingers increase surface roughness and so enhance friction between your hands and the things they touch. When your hands are wet and water partially fills in the troughs between the ridges, friction is reduced—and it's easy for a glass or plate to slip from your grip. Your toes and the soles of your feet are similarly patterned with grooves and ridges that help you grip the surface of the ground. If not for the friction between your feet and the ground, your feet would slip out from under you like smooth-soled shoes on ice when you try to walk. It's friction between her hands and the rock that holds the climber to the nearly vertical mountain face (Figure 2.17). Can you see the reason why rock climbers often rub chalk on their hands to absorb hand perspiration before a climb?

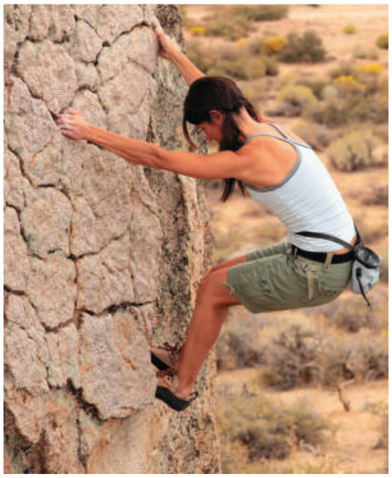


FIGURE 2.17
The rock climber grips the sheer rock face with her hands. Why is it important that her hands are dry?

Astronomy has its share of interesting friction effects as well. Shooting stars or *meteors* are bits of material falling through Earth's atmosphere. They are heated to incandescence by friction with the gas particles that make up the atmosphere. For some tiny dust grains, *micrometeoroids*, air resistance is enough to slow them sufficiently so that they do not burn up. Instead, they fall gently to Earth and accumulate, adding hundreds or thousands of tons to Earth's mass every day!

Although friction is often useful, there are many situations in which it reduces efficiency, and minimizing it would save energy—for example, inside most machines. So industry employs chemists to develop lubricants that minimize friction. Lubricants reduce friction by separating two contacting surfaces with an intermediate layer of more slippery material. Then, instead of rubbing against each other, the surfaces rub against the lubricant. Most lubricants are oils or greases. Currently, chemists are trying to develop lubricants that won't evaporate at high temperatures or freeze at low temperatures, won't lock when called upon to carry heavy loads, and won't leak through gaskets and seals when spun at high speeds.

Earthquakes are an Earth-science phenomenon that depends in an obvious way on friction. Earthquakes happen when adjoining, massive blocks of rock are pushed or pulled in different directions. The blocks of rock, locked together by friction, resist motion until the stress becomes too great. At that point, friction is overcome, the blocks of rock let go, and they slip into new positions, releasing energy that vibrates the Earth.

CHECK YOURSELF

1. **Tristan holds a brick, as shown, by pressing his hands inward on the brick to supply the contact force. In what direction does gravity act? In what direction does friction act? What is the net force on the brick? What does the texture of Tristan's hands have to do with the amount of friction acting on the brick?**
2. **What causes some lubricants to fail?**

CHECK YOUR ANSWERS

1. Gravity pulls the brick downward. Friction opposes gravity, so it acts upward. The net force on the brick is zero, as evidenced by no change in its state of motion. Tristan's hands are covered with grooves and ridges that, like treads on a tire, increase friction and improve his grip.
2. Lubricants fail when they too readily evaporate at high temperatures, or freeze at low temperatures, or leak through gaskets and seals when spun at high speeds.

TECHNOLOGY

Reducing Fluid Friction

Have you experienced frustration with ketchup that resists flowing from a bottle? Or with mayonnaise that stubbornly remains behind in a jar? Or paint that sticks to the inside of a pail when the pail is "empty"? The culprit is unwanted friction. In 2012, a new product called LiquiGlide was invented at Massachusetts Institute of Technology (MIT) that greatly reduces friction and enhances slipperiness.

LiquiGlide is a transparent thin film that adheres to the inner surfaces of the smooth walls of glass, plastic, ceramic, or metal containers. The film surface is impregnated with nano-sized grooves. At this point, LiquiGlide is not yet slippery; not until a specially customized liquid is introduced that nestles in the grooves to form a coating held in place by capillary forces. This liquid coating creates a slippery surface fixed to the interior surface that enables the liquid product, ketchup for example, to easily slide from the bottle. The ketchup is not in contact with the glass or plastic bottle, but with the customized film coating. Hence the near frictionless flow of the ketchup, which pours out of the bottle leaving nothing behind. What works for ketchup, however, won't work for mayonnaise. Each specific liquid coating in the grooves of the LiquiGlide works with the product liquid. One customized coating for ketchup, another for spaghetti sauce, and another for mayonnaise.

LiquiGlide is without flavor, odor, and is composed of non-toxic FDA-approved materials. Furthermore, the coating does not interfere with recycling. A container completely clean of the once-held product improves recycling and decreases waste. Watch for this amazing new reducer of friction—not only in bottles in your kitchen or bathroom, but in medical devices, oil pipelines, and in yet unexpected places.

LEARNING OBJECTIVE
Distinguish between different kinds of speed and velocity.

2.8 Speed and Velocity

Speed

Before the time of Galileo, people described moving things as "slow" or "fast." Such descriptions were vague. Galileo was the first to measure speed by comparing the distance covered with the time it takes to move that distance. He defined **speed** as the distance covered per amount of travel time:

$$\textbf{Speed} = \frac{\textbf{Distance covered}}{\textbf{Travel time}}$$

Speed is a measure of "how fast." For example, if a bicyclist covers 20 km in 1 h, her speed is 20 km/h. Or, if she runs 6 m in 1 s, her speed is 6 m/s.

Any combination of units for distance and time can be used for speed—kilometers per hour (km/h), centimeters per day (the speed of a sick snail). The slash (/) is read as "per" and means "divided by." In science, the preferred unit of speed is meters per second (m/s). Table 2.1 compares some speeds in different units.

TABLE 2.1 APPROXIMATE SPEEDS IN DIFFERENT UNITS

12 mi/h	= 20 km/h	= 6 m/s	(bowling ball)
25 mi/h	= 40 km/h	= 11 m/s	(very good sprinter)
37 mi/h	= 60 km/h	= 17 m/s	(sprinting rabbit)
50 mi/h	= 80 km/h	= 22 m/s	(tsunami)
62 mi/h	= 100 km/h	= 28 m/s	(sprinting cheetah)
75 mi/h	= 120 km/h	= 33 m/s	(batted softball)
100 mi/h	= 160 km/h	= 44 m/s	(batted baseball)

FIGURE 2.18
The greater the distance traveled each second, the faster Joan's horse gallops.

Instantaneous Speed

Moving things often have variations in speed. A car, for example, may travel along a street at 50 km/h, slow to 0 km/h at a red light, and then speed up to only 30 km/h because of traffic. At any instant, you can tell the speed of the car by looking at its speedometer. The speed at any given instant is the *instantaneous speed*.

Average Speed

In planning a trip by car, the driver wants to know the travel time. The driver is concerned with the *average speed* for the trip. How is average speed defined?

$$\textbf{Average speed} = \frac{\textbf{Total Distance covered}}{\textbf{Travel time}}$$

If you get a traffic ticket for speeding, is it because of your instantaneous speed or your average speed?

Average speed can be calculated rather easily. For example, if you drive a distance of 80 km in 1 h, your average speed is 80 km/h. Likewise, if you travel 320 km in 4 h,

$$\text{Average speed} = \frac{\text{Total Distance covered}}{\text{Travel time}} = \frac{320\text{ km}}{4\text{ h}} = 80\text{ km/h}$$

Note that when a distance in kilometers (km) is divided by a time in hours (h), the answer is in kilometers per hour (km/h).

Since average speed is the entire distance covered divided by the total time of travel, it doesn't indicate the various instantaneous speeds that may have occurred along the way. At any moment on most trips, the instantaneous speed is often quite different from the average speed.

If we know average speed and travel time, the distance traveled is easy to find. A simple rearrangement of the definition above gives

$$\textbf{Total Distance covered} = \textbf{Average speed} \times \textbf{Travel time}$$

For example, if your average speed on a 4-h trip is 80 km/h, then the total distance covered = 80 km/h × 4 h = 320 km.

FIGURE 2.19
A common automobile speedometer. Note that speed is shown both in km/h and in mi/h.

CHECK YOURSELF

1. **What is the average speed of a cheetah that sprints 100 m in 4 s? How about if it sprints 50 m in 2 s?**
2. **If a car travels at an average speed of 60 km/h for 1 h, it will cover a distance of 60 km. (a) What total distance is traveled for 4 h? (b) For 10 h?**
3. **In addition to the speedometer on the dashboard of every car, there is an odometer, which records the distance traveled. If the initial reading**

Pearson eText

VIDEO: Definition of Speed
VIDEO: Average Speed

is set at zero at the beginning of a trip and the reading is 40 km after 0.5 h, what was the average speed?**

4. **Would it be possible to attain the average speed in question 3 and never go faster than 80 km/h?**

CHECK YOUR ANSWERS

(Are you reading this before you have thought about the answers in your mind? As mentioned earlier, think before you read the answers. You'll not only learn more, but you'll enjoy learning more.)

1. In both cases, the answer is 25 m/s:

$$\text{Average speed} = \frac{\text{Total Distance covered}}{\text{Travel time}} = \frac{100\ \text{m}}{4\ \text{s}} = \frac{50\ \text{m}}{2\ \text{s}} = 25\ \text{m/s}$$

2. The distance traveled is average speed $\times$ time of travel, so:
   (a) Distance $= 60\ \text{km/h} \times 4\ \text{h} = 240\ \text{km}$.
   (b) Distance $= 60\ \text{km/h} \times 10\ \text{h} = 600\ \text{km}$.

3. $$\text{Average speed} = \frac{\text{Total Distance covered}}{\text{Travel time}} = \frac{40\ \text{km}}{0.5\ \text{h}} = 80\ \text{km/h}$$

4. No, not if the trip starts from rest and ends at rest. During the trip, there are times when the instantaneous speeds are less than 80 km/h, so the driver must at some time drive faster than 80 km/h in order to average 80 km/h. In practice, average speeds are usually much less than high instantaneous speeds.

FIGURE 2.20
Although Mike Jukes in his 1935 Ford Sprint can maintain a constant speed while rounding the curved part of the track, he cannot maintain a constant velocity on the curve. Why?

Velocity

When we know both the speed and direction of an object, we know its **velocity**. For example, if a vehicle travels at 60 km/h, we know its speed. But, if we say how fast it moves at 60 km/h to the north, we specify its *velocity*. Speed is a description of how fast; velocity is a description of how fast and in what direction. Velocity is a vector quantity.

Constant speed means steady speed, neither speeding up nor slowing down. Constant velocity, on the other hand, means both constant speed and constant direction. Constant direction is a straight line—the object's path doesn't curve. So constant velocity means motion in a straight line at a constant speed—motion, as we shall soon see, with no acceleration.

CHECK YOURSELF

"She moves at a constant speed in a constant direction." Restate this sentence in just a few words.

CHECK YOUR ANSWER

"She moves at a constant velocity."

Pearson eText

VIDEO: Velocity
VIDEO: Changing Velocity

Motion Is Relative

Everything is always moving. Even when you think you're standing still, you're actually speeding through space. You're moving relative to the Sun and stars, although you are at rest relative to Earth. At this moment, your speed relative to the Sun is about 100,000 km/h, and it is even faster relative to the center of our galaxy.

When we discuss the speed or velocity of something, we mean the speed or velocity relative to something else. For example, when we say that a space vehicle travels at 30,000 km/h, we mean relative to Earth. Unless stated otherwise, all speeds discussed in this book are relative to the surface of Earth. Motion is relative (Figure 2.21).

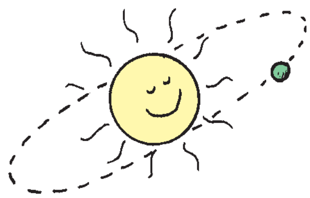


FIGURE 2.21
When you are sitting on a chair, your speed is zero relative to Earth but 30 km/s relative to the Sun.

2.9 Acceleration

LEARNING OBJECTIVE
Define acceleration, and distinguish it from velocity and speed.

Most moving things usually experience variations in their motion. We say they undergo **acceleration**. The first to formulate the concept of acceleration was Galileo, who developed the idea in his experiments with inclined planes. He found that balls rolling down inclined planes rolled faster and faster. Their velocities changed as they rolled. Further, the balls gained the same amount of speed in equal time intervals (Figure 2.22).

Galileo defined the rate of change of velocity, or acceleration, as:*

$$\textbf{Acceleration} = \frac{\textbf{Change of velocity}}{\textbf{Time interval}}$$

Pearson eText
VIDEO: Definition of Acceleration
VIDEO: Force Causes Acceleration

You experience acceleration when you're in a moving bus. When the driver steps on the gas pedal, the bus picks up speed. We say that the bus accelerates. We can see why the gas pedal is called the "accelerator." When the bus driver applies the brakes, the vehicle slows down. This is also acceleration because the velocity of the vehicle is changing. When something slows down, we often call this *deceleration*.

Consider driving a car that steadily increases in speed. Suppose that, in 1 s, you steadily increase your velocity from 30 km/h to 35 km/h. In the next second, you steadily go from 35 km/h to 40 km/h, and so on. You change your velocity by 5 km/h each second. Thus we can see that

$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Time interval}} = \frac{5\text{ km/h}}{1\text{ s}} = 5\text{ km/h}\cdot\text{s}$$

In this example, the acceleration is described as "5 kilometers per hour-second" (abbreviated as $5\text{ km/h}\cdot\text{s}$). Note that a unit for time enters twice: once for the unit of velocity and again for the interval of time in which the velocity is changing. Also note that acceleration is not just the change in velocity; it is the change in velocity per second. If either speed or direction changes, or if both change, then velocity changes.

Can you see that a car has three controls that change velocity—the gas pedal (accelerator), the brakes, and the steering wheel?

When a car or motorcycle makes a turn, even if its speed does not change, it is accelerating. Can you see why? Acceleration often occurs because the motorcycle's direction is changing. Acceleration refers to a change in velocity. So acceleration involves a change in speed, a change in direction, or changes in both speed and direction. Figure 2.23 illustrates this.

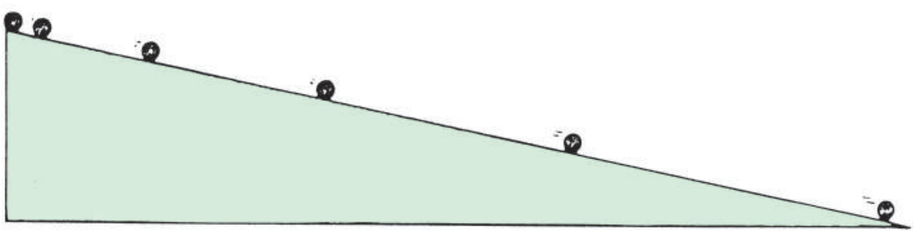


FIGURE 2.22
A ball gains the same amount of speed in equal intervals of time. It undergoes acceleration.

* The capital Greek letter Δ (delta) is often used as a symbol for "change in" or "difference in." In "delta" notation, $a = \Delta v/\Delta t$, where Δv is the change in velocity and Δt is the change in time (the time interval). From this we can see that $\Delta v = a\Delta t$. See the further development of linear motion in Appendix B.

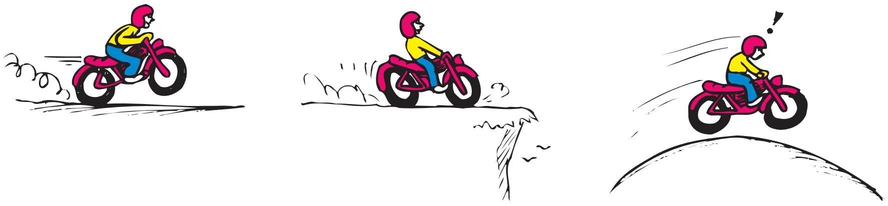


FIGURE 2.23
We say that a body undergoes acceleration when there is a change in its state of motion.

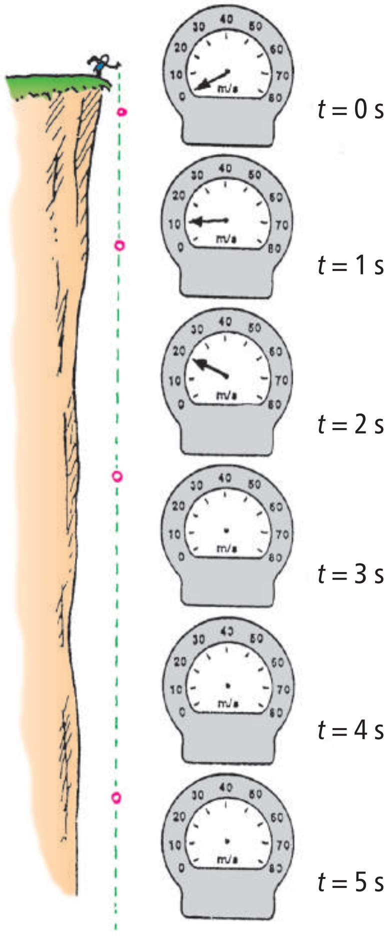


FIGURE 2.24
Imagine that a falling boulder is equipped with a speedometer. In each succeeding second of fall, you'd find the boulder's speed increasing by the same amount: 10 m/s. Sketch in the missing speedometer needle at $t = 3s$, $t = 4s$, and $t = 5s$.

CHECK YOURSELF

In 2.0 s, a car increases its speed from 60 km/h to 65 km/h while a bicycle goes from rest to 5 km/h. Which has the greater acceleration?

CHECK YOUR ANSWER

Both have the same acceleration, since both gain the same amount of speed (5 km/h) in the same time. Both accelerate at 2.5 km/h · s.

Hold a stone at a height above your head and drop it. It accelerates during its fall. When the only force that acts on a falling object is that due to gravity, when air resistance doesn't affect its motion, we say that the object is in **free fall**. All freely falling objects in the same vicinity undergo the same acceleration. At Earth's surface, a freely falling object gains speed at the rate of 10 m/s each second, as shown in Table 2.2.

$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Time interval}} = \frac{10 \text{ m/s}}{1 \text{ s}} = 10 \text{ m/s}^2$$

We read the acceleration of free fall as "10 meters per second squared" (more precisely, 9.8 m/s^2). This is the same as saying that acceleration is "10 meters per second × second." As stated before, the unit of time, the second, appears twice–once in the unit of velocity and again for the time during which the velocity changes.

In Figure 2.24, we imagine a freely falling boulder with a speedometer attached. As the boulder falls, the speedometer shows that the boulder goes 10 m/s faster each second. This 10-m/s gain each second is the boulder's acceleration. (The acceleration of free fall is further developed in Appendix B.)

Why do all freely falling objects fall with equal acceleration? The answer to this question awaits you in Chapter 3.

TABLE 2.2 FREE FALL

Time of Fall(s)	Speed of Fall (m/s)	Distance of Fall (m)
0	0	0
1	10	5
2	20	20
3	30	45
4	40	80
5	50	125
.	.	.
.	.	.
.	.	.
t	$10t$	$^1/_2 10t^2$

Pearson eText

VIDEO: Free Fall: How Far?

Up-and-down motion is shown in Figure 2.25. The ball leaves the thrower's hand at 30 m/s. Call this the initial velocity. The figure uses the convention of up as positive and down as negative, indicated by a minus sign (−). Notice that the 1-s interval positions correspond to changes in velocity of 10 m/s.

Aristotle used logic to establish his ideas of motion. Galileo used experiment. Galileo showed that experiments are superior to logic in testing knowledge. Galileo was concerned with how things move rather than why they move. The path was paved for Isaac Newton to make further connections of concepts in motion.

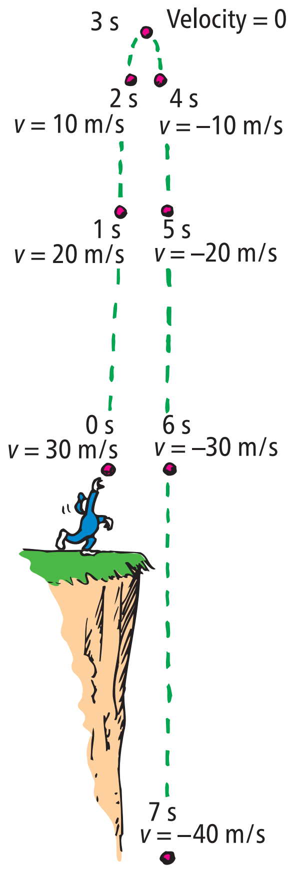


FIGURE 2.25
INTERACTIVE FIGURE
The rate at which velocity changes each second is the same.

Integrated Science 2B
BIOLOGY

Hang Time

LEARNING OBJECTIVE
Apply the equations of motion to the act of jumping.

Some athletes and dancers have great jumping ability. Leaping straight up, they seem to defy gravity, hanging in the air for what feels like at least 2 or 3 s. In reality, however, the "hang time" of even the best jumpers is almost always less than 1 s. What determines hang time? Just what you'd expect—how high you jump.

It is common to overestimate how long the best jumpers stay in the air and to overestimate how high people jump. You can test your own jumping ability by performing what's called a standing vertical jump: Stand facing a wall with your feet flat on the floor and your arms extended upward. Make a mark on the wall at the top of your reach. Then jump, arms outstretched, and make another mark on the wall at your peak. The distance between the two marks measures your vertical jump. If it's more than 0.6 m (2 ft), you're exceptional.

A standing vertical jump of 1.25 m is a record breaker. The best basketball stars can't top this. At the top of a jump, right when you stop going up and are about to start coming down, your speed is zero and you are at rest. As we show in Appendix B, the relationship between the time it takes to reach the ground and the vertical height for a uniformly accelerating object starting from rest is

$$d = \tfrac{1}{2}gt^2$$

We can rearrange this equation to calculate time:

$$t = \sqrt{\frac{2d}{g}}$$

For a record-breaking jump, we use 1.25 m for d and 10 m/s^2 for g and see that:

$$t = \sqrt{\frac{2d}{g}} = \sqrt{\frac{2(1.25\text{ m})}{10\text{ m/s}^2}} = 0.50\text{ s}$$

The hang time is actually double this, since t is the time for only one way of an up-and-down round trip—so the total hang time would be an impressive 1 s. It's safe to say you're not acquainted with anybody who can do a 1-s standing jump! (You can win bets on this!)

What determines jumping ability? Your jumping ability increases with the length of your legs and with the strength of your leg muscles. If you look at the bodies of animals that specialize in jumping—frogs, kangaroos, and rabbits, for example—you'll see that they all have elongated and very muscular hind legs.

CHECK YOURSELF

The red kangaroo has a standing vertical jump height of about 1.8 m (6 ft). What is the kangaroo's hang time?

CHECK YOUR ANSWER

The time it takes for the kangaroo to reach the ground from a height of 1.8 m is

$$t = \sqrt{\frac{2d}{g}} = \sqrt{\frac{2(1.8\text{ m})}{10\text{ m/s}^2}} = 0.60\text{ s}$$

The hang time is double this, or 1.2 s.

For instructor-assigned homework, go to https://mlm.pearson.com

SUMMARY OF TERMS (KNOWLEDGE)

Acceleration The rate at which velocity changes with time; the change in velocity may be in magnitude, or in direction, or in both. It is usually measured in m/s^2.

Air resistance The force of friction acting on an object due to its motion through air.

Density A measure of mass per volume for a substance.

Equilibrium rule The vector sum of forces acting on a nonaccelerating object equals zero: $\Sigma F = 0$.

Force Simply stated, a push or a pull.

Free fall Motion under the influence of gravity alone. Falling without air resistance.

Friction The resistive force that opposes the motion or attempted motion of an object through a fluid or past another object with which it is in contact.

Inertia The property of things to resist changes in motion.

Kilogram The unit of mass. One kilogram (symbol kg) is the mass of 1 liter (symbol L) of water at 4°C.

Mass The quantity of matter in an object. More specifically, mass is a measure of the inertia or sluggishness that an object exhibits in response to any effort made to start it, stop it, deflect it, or change its state of motion in any way.

Net force The combination of all forces that act on an object.

Newton The scientific unit of force.

Speed The distance traveled per unit of time, or how fast.

Support force The force that supports an object against gravity; often called the normal force.

Vector quantity A quantity whose description requires both magnitude and direction.

Velocity A vector quantity that specifies both the speed of an object and its direction of motion.

Weight Simply stated, the force upon an object due to gravity. More specifically, the force with which a body presses against a supporting surface.

READING CHECK QUESTIONS (COMPREHENSION)

Each chapter in this book concludes with a set of questions and exercises, and for some chapters there are problems. The ***Reading Check Questions*** *and the* ***Think Integrated Science*** *questions are designed to help you comprehend ideas and catch the essentials of the chapter material. You'll notice that answers to the questions can be found within the chapters. The* ***Think and Do*** *activities provide hands-on applications, and can be done in or out of class. In Part 1 of this book are* ***Plug and Chug*** *problems, very simple "plug-ins" to familiarize you with the formulas of the chapter. Regretfully, these too often require "overtime" in less conceptual courses and should be minimized in this course. Emphasis on number crunching kills the spirit of a conceptual course.* ***Think and Compare*** *tasks involve analysis and ranking of the magnitudes of various quantities.* ***Think and Solve*** *problems are standard math problems that apply math applications to chapter material.* ***Think and Explain*** *exercises are grouped by chapter sections (new to this edition) and synthesize chapter material with emphasis on thinking rather than mere recall of information.* ***Discussion Questions*** *are written to elicit group discussions of the chapter material. Unless you cover only a few chapters in your course, you will likely be expected to tackle only a few of these items for each chapter. Every chapter concludes with a* ***Readiness Assurance Test****, a bank of 10 multiple-choice questions with answers at the bottom of the page.*

2.1 Aristotle on Motion

1. What were Aristotle's two main classifications of motion?
2. Did Aristotle believe that forces are necessary to keep moving objects moving, or did he believe that, once moving, they would move by themselves?

2.2 Galileo's Concept of Inertia

3. What two main ideas of Aristotle did Galileo discredit?
4. Which dominated Galileo's way of extending knowledge: philosophical discussion or experiment?
5. What is the name of the property of objects to maintain their states of motion?

2.3 Mass—A Measure of Inertia

6. Which depends on gravity: weight or mass?
7. Where would your weight be greater: on Earth or on the Moon? Where would your mass be greater?
8. What are the units of measurement for weight and mass?
9. One kg weighs 10 N on Earth. Would it weigh more or less on the Moon?
10. Which has the greater density: 1 kg of water or 10 kg of water?

2.4 Net Force

11. What is the net force on a block that is pulled to the right with 50 pounds of force and to the left with 60 pounds of force?
12. What two quantities are necessary to determine a vector quantity?

2.5 The Equilibrium Rule

13. What is the name given to a force that occurs in a rope when both ends are pulled in opposite directions?
14. How much rope tension holds a 20-N bag of apples at rest?
15. What is the meaning of $\Sigma F = 0$?
16. What test tells us whether or not a moving object is in equilibrium?
17. A bowling ball at rest is in equilibrium. Is the ball in equilibrium when it moves at a constant speed along a curved path?

2.6 The Support Force

18. Why is the support force on an object often called the normal force?
19. When you weigh yourself, how does the support force of the scale acting on you compare with the gravitational force between you and Earth?

2.7 The Force of Friction

20. How does the direction of a friction force compare with the direction of motion of a sliding object?
21. If you push on a heavy crate to the right and it slides, what is the direction of friction on the crate?
22. Suppose you push on a heavy crate, but not hard enough to make it slide. Does a friction force act on the crate?

2.8 Speed and Velocity

23. What equation shows the relationship among speed, distance, and time?
24. Why do we say that velocity is a vector and speed is not a vector?
25. Is a fine for speeding based on one's average speed or instantaneous speed?
26. How can you be at rest and also moving at 100,000 km/h at the same time?

2.9 Acceleration

27. What equation shows the relationship among velocity, time, and acceleration?
28. What is the acceleration of an object in free fall at Earth's surface?
29. Why does the unit of time appear twice in the definition of acceleration?
30. When you toss a ball upward, by how much does its upward speed decrease each second?

THINK INTEGRATED SCIENCE

2A—Friction Is Universal

31. *Joints* are places where bones meet. Many of them, such as the ball-and-socket joints in your shoulders and hips, are bathed with *synovial fluid*, a viscous substance resembling the white of an egg. Speculate about the purpose of the synovial fluid.
32. How would speed of travel and fuel efficiency of ships be affected if a surface coating were developed that reduces friction between the hull of the ship and ocean water?
33. In what way does friction affect an earthquake?

2B—Hang Time

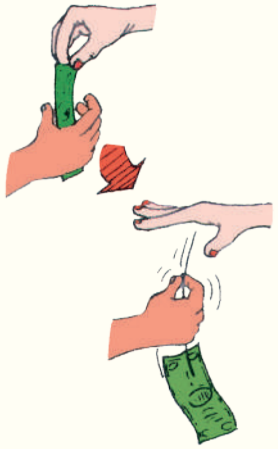
34. When during a standing jump is your speed zero?
35. What is the record-breaking height for a standing jump?
36. Standing at rest, the best jumper in your school makes a mark high on a wall. He then jumps as high as possible, making a second mark on the wall. How likely is it that the vertical distance between the marks will exceed 1.25 m?
37. What are some anatomical features that affect an animal's jumping ability?

THINK AND DO (HANDS-ON APPLICATION)

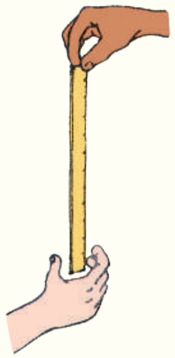
38. Place your smartphone on top of a sheet of paper on a desk or table. Pull the paper horizontally with a quick snap. What concept of physics does this illustrate?

39. By any method you choose, determine both your walking speed and your running speed.

40. Try this with your friends: Hold a dollar bill so that the midpoint hangs between a friend's fingers and challenge your friend to catch it by snapping her fingers shut when you release it. She won't be able to catch it! Explanation: From $d = \frac{1}{2}gt^2$, the bill will fall a distance of 8 centimeters (half the length of the bill) in a time of 1/8 second, but the time required for the necessary impulses to travel from her eyes to her brain is at least 1/7 second.



41. Drop a ruler between a friend's fingers as shown. The number of centimeters that pass through his fingers relates to his reaction time. You can express the result in fractions of a second by rearranging $d = \frac{1}{2}gt^2$. Expressed for time it is $t = \sqrt{2d/g} = 0.045\sqrt{d}$, where d is in centimeters.



42. Stand flat-footed next to a wall and make a mark at the highest point you can reach. Then jump vertically and make another mark at the highest possible point. The distance between these two marks is your vertical jumping distance. Use this distance to calculate your personal hang time.

PLUG AND CHUG (FORMULA FAMILIARIZATION)

These are "plug-in-the-number" tasks to familiarize you with the main formulas that link the physics concepts of this chapter. They are one-step substitutions, much less challenging than the Think and Solve problems that follow.

$$\textbf{Average speed} = \frac{\textbf{Total distance covered}}{\textbf{Time interval}}$$

43. Show that the average speed of a tortoise that covers a distance of 10 cm in 10 s is 0.01 m/s.

$$\textbf{Speed} = \frac{\textbf{Distance}}{\textbf{Time}}$$

44. A man walks 3.0 m in 1.2 s. Calculate the speed at which he is walking.

$$\textbf{Acceleration} = \frac{\textbf{Change of velocity}}{\textbf{Time interval}} = \frac{\Delta \boldsymbol{v}}{\Delta \boldsymbol{t}}$$

45. Calculate the acceleration of a mongoose when it increases its velocity from rest to 21 m/s in 3 s.

46. Calculate the acceleration of a car that starts from rest and reaches 120 km/h in 15 s.

47. Show that the acceleration of a rock that reaches a speed of 40 m/s in 4 s is 10 m/s^2.

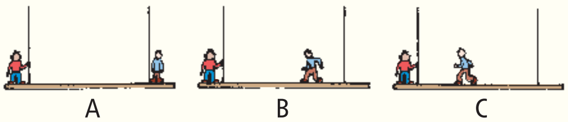
Free-fall distance from rest; $\boldsymbol{d = \frac{1}{2}gt^2}$

48. Show that Careless Cary who slips from the rung of a ship ladder falls slightly more than 11 meters to the water below in 1.5 seconds.

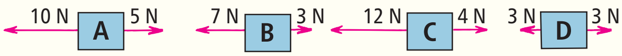
49. Show that a basketball player who jumps vertically for $\frac{1}{2}$ second increases her reach by 1.2 meters. Calculate her hang time. Why is such an athlete exceptional?

THINK AND COMPARE (ANALYSIS)

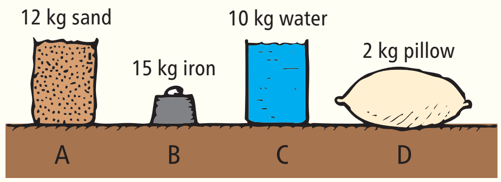
50. The weights of Burl, Paul, and the scaffold produce tensions in the supporting ropes. Rank the tensions in the left rope, from greatest to least, in the three situations A, B, and C.



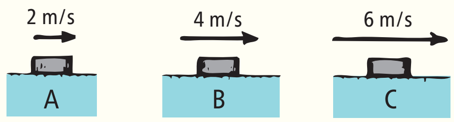
51. Rank the net forces on the block from greatest to least in the four situations A, B, C, and D.



52. Different materials, A, B, C, and D, rest on a table.
    (a) From greatest to least, rank them by how much they resist being set in motion.
    (b) From greatest to least, rank them by the support (normal) force the table exerts on them.

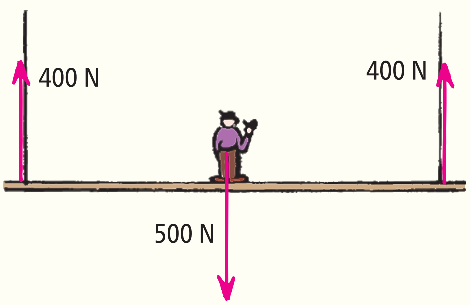


53. Three pucks, A, B, and C, are sliding across ice at the given speeds. The forces of air and ice friction are negligible.
    (a) From greatest to least, rank the pucks by the force needed to keep them moving.
    (b) From greatest to least, rank the pucks by the force needed to stop them in the same time interval.

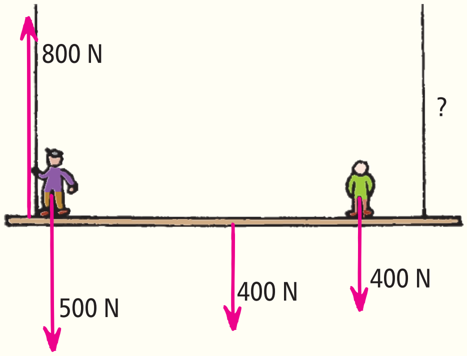


THINK AND SOLVE (MATHEMATICAL APPLICATION)

54. Consider two forces, 30 N and 40 N, applied to an object. Calculate the magnitude of the net force when: (a) the two forces have the same direction and (b) the two forces are perpendicular to each other.
55. A person carrying a 10-kg box stands on a bathroom scale that reads 588 N. What are the person's weight and mass?
56. You toss a ball straight up with an initial speed of 20 m/s. How much time does it take to reach its maximum height (ignoring air resistance)?
57. The sketch shows a painter's scaffold in mechanical equilibrium. The person in the middle weighs 500 N, and the tensions in each rope are 400 N. What is the weight of the scaffold?



58. A different scaffold that weighs 400 N supports two painters, one 500 N and the other 400 N. The reading in the left scale is 800 N. What is the reading in the right-hand scale?



59. A vehicle changes its velocity from 90 km/h to a dead stop in 10 s. Show that its acceleration in doing so is $-2.5\ \text{m/s}^2$.
60. Extend Table 2.2 (which gives values from 0 to 5 s) from 6 to 10 s, assuming no air resistance.
61. An airplane starting from rest on a runway accelerates uniformly at $2.0\ \text{m/s}^2$ for 15 s before takeoff.
    (a) What is its takeoff speed?
    (b) Show that the plane travels along the runway a distance of 225 m before takeoff.

THINK AND EXPLAIN (SYNTHESIS)

2.1 Aristotle on Motion

62. Knowledge can be gained by philosophical logic and also by experimentation. Which of these did Aristotle favor, and which did Galileo favor?
63. Which of Aristotle's ideas did Galileo discredit with his inclined plane experiments?

2.2 Galileo's Concept of Inertia

64. Your friend says that a ball rolling down a flat inclined plane increases both its speed and its acceleration. Why do you disagree?
65. A ball at the end of a string makes a pendulum. If you raise the ball a given distance and release it, how high will it swing on the other side?
66. A ball on the inside surface of a circular track is raised a certain height. If released, how far up the other side will it roll according to Galileo?

2.3 Mass–A Measure of Inertia

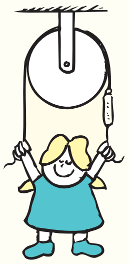
67. Which has more mass, a 2-kg fluffy pillow or a 3-kg small piece of iron? Which has more volume? Why are your answers different?
68. Gravitational force on the Moon is merely 1/6 that of gravitational force on Earth. What would be the weight of a 10-kg object on the Moon and on Earth? What would its mass be on the Moon and on Earth?

2.4 Net Force

69. A monkey hangs stationary at the end of a vertical vine. What two forces act on the monkey? Which force, if either, is greater?
70. Suppose the monkey weighs 100 N and the vine supporting her pulls upward with a force of 120 N. What is the net force on the monkey? Describe her motion.

2.5 The Equilibrium Rule

71. Nellie hangs suspended at rest from the ends of the rope as shown. How does the reading on the scale compare with her weight?



72. Nellie Newton stands at rest on a bathroom scale. How does the reading on the scale compare with her weight?
73. Can a basketball player halfway through a jump in midair be in equilibrium? Why or why not?
74. Little Hudson as shown in the opening photo of this chapter is being tossed upward by his dad. When Hudson reaches the top of his trajectory where his speed is zero, is he momentarily in equilibrium? Why or why not?

2.6 The Support Force

75. An empty 50-N jug rests on a table. What is the support force exerted by the table on the jug? What is the support force when 5 N of water is poured into the jug?
76. A 500-g book lays at rest on top of your head. How much support force does your head provide to the book? What is the net force on the book?

2.7 The Force of Friction

77. The falling speedometer of Figure 2.24 shows readings of speed as it falls. How would the readings of speed differ if air drag were taken into account?
78. In Figure 2.13, we see Marie pushing horizontally on a table that slides across the floor at constant velocity. If she pushed with the same amount of force but directed downward a bit, how would the amount of friction of the table legs with the floor be affected? Defend your answer.

2.8 Speed and Velocity

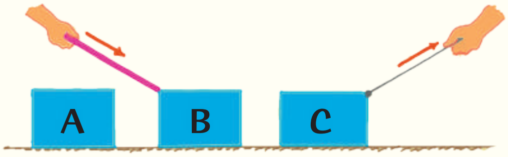
79. Suppose that a free-falling object were somehow equipped with a speedometer. By how much would its speed readings increase with each second of fall?
80. What is the speed acquired by a freely falling object 2 seconds after being dropped from a rest position? Will your answer change if the object was not at rest?

2.9 Acceleration

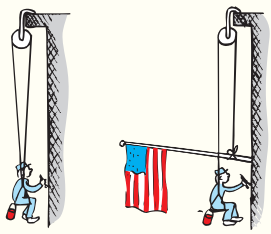
81. A car's velocity increases from 40 to 50 km/h in 10 s when it is moving along a straight path. What is its acceleration?
82. Correct your friend who says, "Japan's bullet trains can easily round a curve at a constant velocity of 160 kilometers per hour."
83. An airplane flies horizontally at a constant velocity of 200 m/s for 10 seconds. A friend says its acceleration during that time is 20 m/s^2. Why do you disagree with your friend's assessment?
84. You toss a coin vertically upward in the air. Assuming no air resistance, (a) will it return to your hand with its initial speed? (b) Will its acceleration be the same in its up and down motion?

THINK AND DISCUSS (EVALUATION)

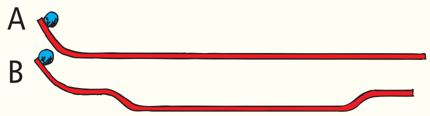
85. Is changing your mass the only way to change your weight?
86. Gracie says acceleration is how fast you go. Alex says acceleration is how fast you get fast. They look to you for confirmation. Who's correct?
87. For an object in free fall, how does its acceleration vary with the distance it travels?
88. We see a box in three cases: In A it is at rest; in B it is being pushed with a stick; in C it is being pulled by a rope. Discuss with your classmates and decide in which position the friction between the box and supporting surface is zero? Least, but greater than zero? Greatest?



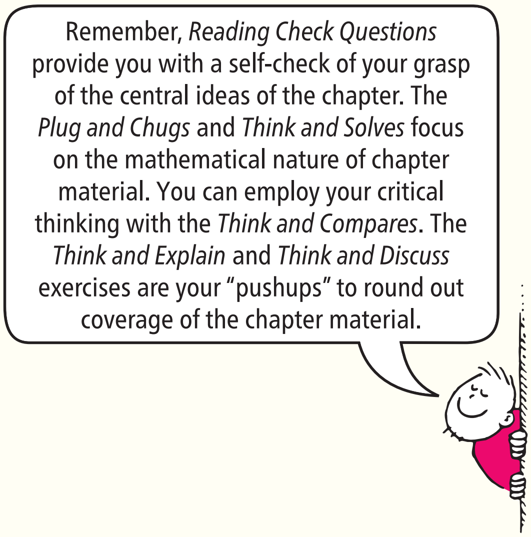
89. Harry the painter swings year after year from his bosun's chair. His weight is 500 N, and the rope, unknown to him, has a breaking point of 300 N. Why doesn't the rope break when he is supported as shown on the left? One day, Harry was painting near a flagpole, and, for a change, he tied the free end of the rope to the flagpole instead of to his chair, as shown on the right. Discuss why Harry ended up taking his vacation early.



90. When a ballplayer throws a ball straight up, by how much does the speed of the ball decrease each second while it is ascending? In the absence of air resistance, by how much does the ball's speed increase each second while it is descending? How much time elapses during the ball's ascent compared with its descent?
91. Someone standing on the edge of a cliff (as in Figure 2.25) throws a ball straight up at a certain speed. Another ball is thrown straight down with the same initial speed. If air resistance is negligible, which ball has the greater speed when it strikes the ground below?
92. A metallic bob is made to fall freely from the top of the Eiffel Tower (300 m). Compute its acceleration: (a) after it falls 100 m from the starting point and (b) 100 m before it reaches the ground.
93. Two balls, A and B, are released simultaneously from rest at the left end of the equal-length tracks, as shown.



(a) Which ball will reach the end of its track first?
(b) Does ball B roll faster along the lower part of track B than ball A rolls along track A?
(c) Is the speed gained by ball B going down the extra dip the same as the speed it loses going up near the right-hand end? Does this mean that the speeds of balls A and B will be the same at the ends of the tracks?
(d) So, overall, does ball A or ball B have the greater average speed? (Do you wish to change your answer to (a)?



READINESS ASSURANCE TEST (RAT)

If you have a good handle on this chapter, you should be able to score at least 7 out of 10 on this RAT. If you score less than 7, you need to study further before moving on.

Choose the BEST answer to each of the following:

1. According to Galileo, inertia is a
   (a) force like any other force.
   (b) special kind of force.
   (c) property of all matter.
   (d) concept opposite to force.
2. An object with a very small mass must also have a very small
   (a) weight.
   (b) volume.
   (c) size.
   (d) all of these
3. The equilibrium rule $\Sigma F = 0$ applies to
   (a) objects or systems at rest.
   (b) objects or systems in uniform motion in a straight line.
   (c) both.
   (d) neither.
4. A man weighing 800 N stands at rest on two bathroom scales so that one scale shows a reading of 500 N. The reading on the other scale is
   (a) 200 N.
   (b) 300 N.
   (c) 400 N.
   (d) 800 N.
5. If an object moves along a straight-line path at constant speed, then it must be
   (a) accelerating.
   (b) acted on by a force.
   (c) both of these
   (d) neither of these.
6. What is the net force on a box of chocolates when pushed across a table with a horizontal force of 10 N while friction between it and the surface is 6 N?
   (a) 16 N.
   (b) 10 N.
   (c) 6 N.
   (d) 4 N.
7. Neglecting air resistance, when you toss a rock upward, by about how much does its upward speed decrease each second?
   (a) 10 m/s.
   (b) 10 m/s^2.
   (c) The answer depends on the initial speed.
   (d) None of these
8. During each second of free fall, the speed of an object
   (a) increases by the same amount.
   (b) changes by increasing amounts.
   (c) remains constant.
   (d) doubles.
9. A freely falling object has a speed of 40 m/s at one instant. Exactly 1 s later its speed will be
   (a) the same.
   (b) 10 m/s.
   (c) 45 m/s.
   (d) greater than 45 m/s.
10. The vertical height attained by a basketball player who achieves a hang time of a full 1 s is about
    (a) 0.8 m.
    (b) 1 m.
    (c) 1.2 m.
    (d) 2.5 m.

Answers to RAT

1. c, 2. a, 3. c, 4. b, 5. d, 6. d, 7. a, 8. a, 9. d, 10. c

CHAPTER THREE

3 Newton's Laws of Motion

THINGS TEND to stay put—to remain as they are. Unless we intervene, something at rest will remain at rest; something moving will remain moving. As we learned from Galileo, things have inertia—the tendency to resist changes in motion. This curious property of matter became the crux of Newton's first law of motion, nicely demonstrated in the above photo. The large mass of the anvil on the author's chest provides sufficient inertia to shield the blow of the hammer wielded by assistant Will Maynez. The anvil accelerates very little. Newton's second law of motion relates acceleration to its cause—force. Newton's third law, the law of action and reaction, tells us that forces exist only in pairs, that you can never change only one thing. You can't even touch without being touched.

Newton's three laws of motion are the foundation of present-day mechanics. Quite significantly, it was Newton's laws that got humans to the Moon and back.

LEARNING OBJECTIVE
Define Newton's first law of motion and relate it to inertia.

Pearson eText

VIDEO: Newton's Law of Inertia

UNIFYING CONCEPT
Newton's First Law

FIGURE 3.1
Inertia in action.

FIGURE 3.2
Rapid deceleration is sensed by the driver, who lurches forward—inertia in action!

3.1 Newton's First Law of Motion

Galileo's work on inertia set the stage for Isaac Newton, who was born shortly after Galileo's death in 1642. By the time Newton was 23 years old, he had developed his famous three laws of motion, which completed the overthrow of Aristotelian ideas about motion. These three laws first appeared in one of the most famous books of all time, Newton's *Philosophiae Naturalis Principia Mathematica*,* often known as simply the *Principia*. The first law is a restatement of Galileo's concept of inertia, the second law relates acceleration to its cause—force, and the third is the law of action and reaction. **Newton's first law** of motion states:

Every object continues in its state of rest, or a uniform speed in a straight line, unless acted on by a nonzero force.

The key word in this law is *continues*; an object continues to do whatever it happens to be doing unless a force is exerted on it. If the object is at rest, it continues in a state of rest. This is nicely demonstrated when a tablecloth is skillfully whipped out from beneath dinnerware resting on a tabletop, leaving the objects in their initial state of rest (Figure 3.1).** On the other hand, if an object is moving, it continues to move without changing its speed or direction, as evidenced by space probes that continuously move in outer space. As stated in Chapter 2, this property of objects to resist changes in motion is called *inertia* (Figures 3.1 and Figure 3.2).

CHECK YOURSELF

When a space vehicle travels in a nearly circular orbit around Earth, is a force required to maintain its high speed? If the force of gravity were suddenly cut off, what type of path would the space vehicle follow?

CHECK YOUR ANSWERS

There is no force in the direction of the vehicle's motion, which is why it coasts at a constant speed by its own inertia. The only force acting on it is the force of gravity, which acts at right angles to its motion (toward Earth's center). We'll see later that this right-angled force holds the vehicle in a circular path. If the force of gravity were cut off, the vehicle would fly off in a straight line at a constant velocity.

LEARNING OBJECTIVE
Relate the three concepts acceleration, force, and mass.

UNIFYING CONCEPT
Newton's Second Law

3.2 Newton's Second Law of Motion

Isaac Newton was the first to recognize the connection between force and mass in producing acceleration, which is one of the central rules of nature, as expressed in his second law of motion.

Newton's second law of motion states:

The acceleration produced by a net force on an object is directly proportional to the net force, is in the same direction as the net force, and is inversely proportional to the mass of the object.

* The Latin title means "mathematical principles of natural philosophy."

** Close inspection reveals that brief friction between the dinnerware and the fast-moving tablecloth starts the objects moving, but then friction between the dishes and the tabletop stops the dishes before they slide very far. If you try this, use unbreakable dinnerware!

Or, in shorter notation,

$$\textbf{Acceleration} \sim \frac{\textbf{net force}}{\textbf{mass}}$$

We use the wiggly line ~ as a symbol meaning "is proportional to." Recall from Chapter 2 that acceleration is the rate at which velocity changes with time. We add to this and say that acceleration a is directly proportional to the overall net force F and inversely proportional to the mass m. By this we mean that, if F increases, a increases by the same factor (if F doubles, a doubles), and if m increases, a decreases by the same factor (if m doubles, a is cut in half). If both the net force and the mass are doubled (or are halved, or change in the same way), then the acceleration will be unchanged.

By using consistent units such as newtons (N) for force, kilograms (kg) for mass, and meters per second squared (m/s^2) for acceleration, the proportionality may be expressed as an exact equation:

$$\textbf{Acceleration} = \frac{\textbf{net force}}{\textbf{mass}}$$

In its briefest form, where a is acceleration, F is net force, and m is mass, the equation becomes

$$a = \frac{F}{m}$$

The acceleration of an object is equal to the net force acting on the object divided by its mass. Notice how this equation connects three separate concepts: acceleration, force, and mass, all of which were quite familiar to Galileo. Historians have to wonder how Galileo, who is credited for defining acceleration, inertia, and was knowledgeable about force, failed to connect these three concepts together. Newton made the connection.

In Figure 3.4 we see how force affects acceleration. Figure 3.5 shows how mass affects acceleration for the same applied force.

An object accelerates in the direction of the net force acting on it. Speed changes when the net force acts in the direction of the object's motion. When the net force acts at right angles to the object's motion, the direction of the object changes. A net force acting in any other direction results in a combination of speed change and deflection (Figure 3.6).

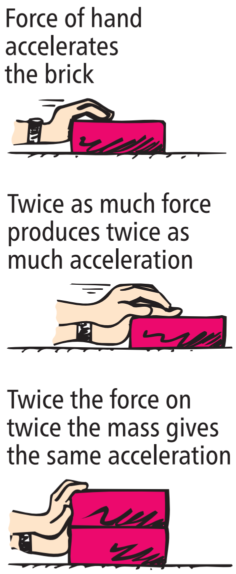


FIGURE 3.4
Acceleration is directly proportional to force.

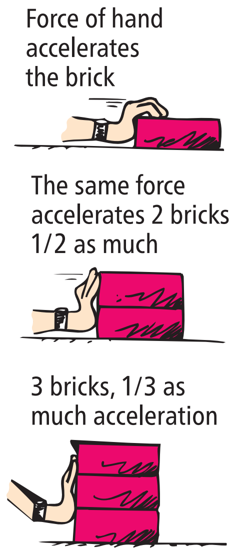
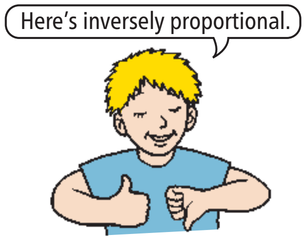


FIGURE 3.5
Acceleration is inversely proportional to mass.



If one thing is inversely proportional to another, then, as one gets bigger, the other gets smaller.

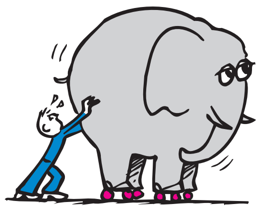


FIGURE 3.3
INTERACTIVE FIGURE
The greater the mass, the greater a force must be for a given acceleration.

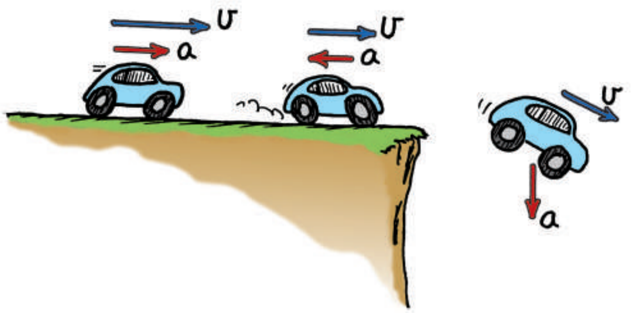
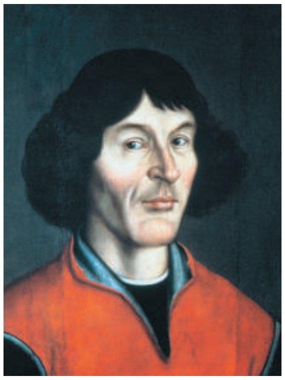


FIGURE 3.6
When you accelerate in the direction of your velocity, you speed up; when you accelerate against your velocity, you slow down; when you accelerate at an angle to your velocity, your direction changes.

HISTORY OF SCIENCE

The Moving Earth

In 1543, the Polish astronomer Nicolaus Copernicus caused a great controversy when he published a book proposing that the Earth revolved around the Sun.* This idea conflicted with the popular view that the Earth was the center of the universe. Copernicus's concept of a Sun-centered solar system was the result of years of studying the planets. He had kept his theory from the public for two reasons. First, he feared persecution: A theory so completely different from common opinion would surely be taken as an attack on the established order. Second, he had reservations about it himself: He could not reconcile the idea of a moving Earth with the prevailing ideas of motion. The concept of inertia was unknown to him and to others of his time. In the final days of his life, at the urging of close friends, Copernicus sent his manuscript, *De Revolutionibus Orbium Coelestium*,† to the printer. The final copy of his famous exposition reached him on the day he died—May 21, 1543.



Nicolaus Copernicus, 1473–1543

The idea of a moving Earth was much debated. Europeans thought about the universe much as Aristotle had, and the existence of a force big enough to keep Earth moving was beyond their imagination. They had no concept of inertia. One of the arguments against a moving Earth was the following:

Consider a bird sitting at rest on a branch of a tall tree. On the ground below is a fat, juicy worm. The bird sees the worm and drops vertically below and catches it. It was argued that this would be impossible if Earth were moving. A moving Earth would have to travel at an enormous speed to circle the Sun in one year. While the bird would be in the air, descending from its branch to the ground below, the worm would be swept far away along with the moving Earth. It seemed that catching a worm on a moving Earth would be an impossible task. The fact that birds do catch worms from tree branches seemed to be clear evidence that Earth must be at rest.

Can the bird drop down and catch the worm if Earth moves at 30 km/s?

Can you see the mistake in this argument? You can if you use the concept of inertia. You see, not only is Earth moving at a great speed, but so are the tree, the branch of the tree, the bird that sits on it, the worm below, and even the air in between. Things in motion remain in motion if no unbalanced forces are acting on them. So when the bird drops from the branch, its initial sideways motion remains unchanged. It catches the worm quite unaffected by the motion of its total environment.

We live on a moving Earth. If you stand next to a wall and jump up so that your feet are no longer in contact with the floor, does the moving wall slam into you? Why not? It doesn't because you are also traveling at the same horizontal speed—before, during, and after your jump. The speed of Earth relative to the Sun is not the speed of the wall relative to you.

Four hundred years ago, people had difficulty with ideas like these. One reason is that they didn't yet travel in high-speed vehicles. Rather, they experienced slow, bumpy rides in horse-drawn carts. People were less aware of the effects of inertia. Today, we can flip a coin in a high-speed car, bus, or plane and catch the vertically moving coin as easily as we could if the vehicle were at rest. We see evidence of Newton's first law when the horizontal motion of the coin before, during, and after the catch is the same. The coin always keeps up with us.

When you flip a coin in a high-speed airplane, it behaves as if the airplane were at rest. The coin keeps up with you–inertia in action!

* Copernicus was certainly not the first to think of a Sun-centered solar system. In the fifth century, for example, the Indian astronomer Aryabhatta taught that Earth circles the Sun, not the other way around (as the rest of the world believed).

† The Latin title means "On the Revolution of Heavenly Spheres."

VIDEO: Newton's Second Law

CHECK YOURSELF

1. **In Chapter 2, we defined acceleration as the time rate of change of velocity—that is, a = (change in v)/time. Are we now saying that acceleration is instead the ratio of force to mass—that is, $a = F/m$? Which is it?**

2. **A jumbo jet cruises at a constant velocity of 1000 km/h when the thrusting force of its engines is a constant 100,000 N. What is the acceleration of the jet? What is the force of air resistance on the jet?**
3. **Suppose you apply the same amount of force to two separate carts, one cart of mass 1 kg and the other of mass 2 kg. Which cart will accelerate more, and with how much greater acceleration?**

CHECK YOUR ANSWERS

1. Acceleration is *defined* as the time rate of change of velocity, and it is *produced* by a force. The magnitude of force/mass (often the cause) determines the rate change in velocity/time (often the effect).
2. The acceleration is zero, as evidenced by a constant velocity. Newton's second law tells us that zero acceleration means that the net force is zero, which tells us that the force of air resistance must just equal the thrusting force of 100,000 N and that it must act in the opposite direction. So the air resistance on the jet is 100,000 N. This is in accord with $\Sigma F = 0$. (Note that we don't need to know the velocity of the jet to answer this question, only that the velocity is *constant*. In a nutshell, zero acceleration means that the net force is also zero.)
3. The 1-kg cart will have greater acceleration—twice as much, in fact—because it has half as much mass, which means it has half as much resistance to a change in motion.

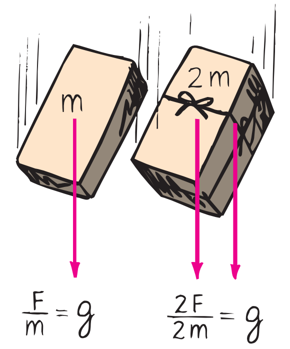


FIGURE 3.7
INTERACTIVE FIGURE
The ratio of weight (F) to mass (m) is the same for all objects in the same locality; hence, their accelerations are the same in the absence of air resistance.

Only a single force acts on something in free fall—the force of gravity.

When Acceleration Is g—Free Fall

Although Galileo articulated both concepts of inertia and acceleration and was the first to measure the acceleration of falling objects, he was unable to explain why objects of different masses fall with equal accelerations. Newton's second law provides the explanation.

We know that a falling object accelerates toward Earth because of the gravitational force of attraction between the object and Earth. As discussed in Chapter 2, when the force of gravity is the only force—that is, when air resistance is negligible—we say that the object is in a state of **free fall**. An object in free fall accelerates toward Earth at 10 m/s^2 (or, more precisely, at 9.8 m/s^2).

The greater the mass of an object, the stronger the gravitational pull between it and Earth. The double brick in Figure 3.7, for example, has twice the gravitational attraction to Earth as the single brick. Why, then, doesn't the double brick fall twice as fast, as Aristotle supposed it would? The answer is evident in Newton's second law: The acceleration of an object depends not only on the force (weight, in this case) but also on the object's resistance to motion—its inertia (mass). A force produces an acceleration, whereas inertia is a *resistance* to acceleration. So twice the force exerted on twice the inertia produces the same acceleration as half the force exerted on half the inertia. Both accelerate equally. The acceleration due to gravity is symbolized by g. We use the symbol g, rather than a, to denote that acceleration is due to gravity alone.

So the ratio of weight to mass for freely falling objects equals a constant, g. This is similar to the ratio of a circle's circumference to its diameter, which equals the constant π. The ratio of weight to mass is identical for both heavy objects and light objects, just as the ratio of circumference to diameter is the same for both large and small circles (Figure 3.8).

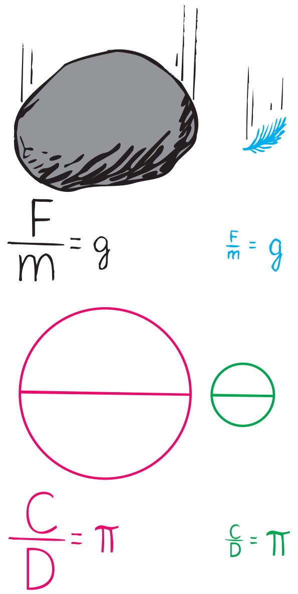


FIGURE 3.8
The ratio of weight (F) to mass (m) is the same for the large rock and the small feather; similarly, the ratio of the circumference (C) to the diameter (D) is the same for the large and small circles.

MATH CONNECTION

Equations as Guides to Thinking: $a = \frac{F}{m}$

Newton's second law is not only simple in form but also widely applicable, so it's a highly useful tool in many problem-solving situations—it is well worth your while to become adept at using it.

For example, if we know the mass of an object in kilograms (kg) and its acceleration in meters per second squared (m/s^2), then the force will be expressed in newtons (N). One newton is the force needed to give a mass of 1 kilogram an acceleration of 1 meter per second squared. We can rearrange Newton's law to read

$$\text{Force} = \text{mass} \times \text{acceleration}$$
$$1\ \text{N} = (1\ \text{kg}) \times (1\ \text{m/s}^2)$$

We can see that

$$1\ \text{N} = 1\ \text{kg} \cdot \text{m/s}^2$$

The centered dot between "1 kg" and "m/s^2" means that one expression is multiplied by the other.

If we know two of the quantities in Newton's second law, we can calculate the third. For example, how much force, or thrust, must a 20,000-kg jet plane develop to achieve an acceleration of 1.5 m/s^2? Using the equation, we can calculate

$$\begin{aligned} F &= ma \\ &= (20{,}000\ \text{kg}) \times (1.5\ \text{m/s}^2) \\ &= 30{,}000\ \text{kg} \cdot \text{m/s}^2 \\ &= 30{,}000\ \text{N} \end{aligned}$$

Suppose we know the force and the mass and we want to find the acceleration. For example, what acceleration is produced by applying a force of 2000 N to a 1000-kg car? Using Newton's second law, we find that

$$\begin{aligned} a &= \frac{F}{m} = \frac{2000\ \text{N}}{1000\ \text{kg}} \\ &= \frac{2000\ \text{kg} \cdot \text{m/s}^2}{1000\ \text{kg}} = 2\ \text{m/s}^2 \end{aligned}$$

If the force is 4000 N, the acceleration is

$$\begin{aligned} a &= \frac{F}{m} = \frac{4000\ \text{N}}{1000\ \text{kg}} \\ &= \frac{4000\ \text{kg} \cdot \text{m/s}^2}{1000\ \text{kg}} = 4\ \text{m/s}^2 \end{aligned}$$

Doubling the force on the same mass simply doubles the acceleration.

Physics problems are often more complicated than these. We don't focus on solving complicated problems in this book; instead, we emphasize equations, such as Newton's second law, in which the relationships among physical quantities are clear. Such equations serve as guides to thinking, rather than recipes for mathematical problem solving. Remember, mastering concepts first makes problem solving later more meaningful.

We now understand that the acceleration of free fall is independent of an object's mass. A boulder 100 times more massive than a pebble falls at the same acceleration as the pebble because, although the force on the boulder (its weight) is 100 times that of the pebble, the greater force offsets the equally greater mass.

FIGURE 3.9
In a vacuum, a feather and a coin fall with equal accelerations.

CHECK YOURSELF

In a vacuum, a coin and a feather fall at an equal rate, side by side. Would it be correct to say that equal forces of gravity act on both the coin and feather in the vacuum?

CHECK YOUR ANSWER

No, no, no–a thousand times no! Gravity is much greater for the coin, though the coin has more mass. The coin and feather accelerate equally because the ratio *F*/*m* for each is the same. Although air resistance is not present in a vacuum, gravity is. (You'd know this if you placed your hand in a vacuum chamber and a cement truck rolled over it.) If you answered yes to this question, let it be a signal for you to be more careful when you think physics.

When Acceleration Is Less Than g—Non–Free Fall

Most often, air resistance is not negligible for falling objects. Then the acceleration of the object's fall is less. Air resistance, which is the force of friction acting between an object and the surrounding air, depends on two quantities: speed and surface area. When a skydiver steps from a high-flying plane, the air resistance on the skydiver's body builds up as the falling speed increases. The result is reduced acceleration. The acceleration can be reduced further by increasing the surface area. A skydiver does this by orienting his or her body so that more air is encountered by its surface—by spreading out like a flying squirrel. So air resistance depends both on speed and on the surface area encountered by the air.

For free fall, the downward net force is weight—only weight. But, when air is present, the downward net force = weight − air resistance. Can you see that the presence of air resistance reduces the net force? And that less force means less acceleration? So, as a skydiver falls faster and faster, the acceleration of the fall decreases.* What happens to the net force if air resistance builds up to equal the weight of the skydiver? The answer is that the net force becomes zero. Does this mean the skydiver comes to a stop? No! What it means is that the skydiver no longer gains speed. Acceleration terminates—it no longer occurs. We say that the skydiver has reached **terminal speed**. If we are concerned with direction—down, for falling objects—we say that the skydiver has reached *terminal velocity*.

Terminal speed for a human skydiver varies from about 150 km/h to 200 km/h, depending on the weight, size, and orientation of the body. A heavier person has to fall faster for air resistance to balance weight.** The greater weight is more effective in "plowing through" the air, resulting in a higher terminal speed for a heavier person. Increasing the frontal area reduces the terminal speed. That's where a parachute is useful. A parachute increases the frontal area, which greatly increases the air resistance, reducing the terminal speed to a safe 15 km/h to 25 km/h.

Consider the interesting demonstration of the falling coin and the feather in the glass tube. When air is inside the tube, the feather falls more slowly because of air resistance. The feather's weight is very small, so the feather reaches terminal speed very quickly because it doesn't have to fall very far or very fast before air resistance builds up to equal its small weight. The coin, on the other hand, doesn't have a chance to fall fast enough for air resistance to build up to equal its weight. If you were to drop a coin from a very high location, such as from the top of a tall building, its terminal speed would be reached when the speed of the coin is greater than 100 km/h. This is a much, much higher terminal speed than that of a falling feather.

When Galileo allegedly dropped objects of different weights from the Leaning Tower of Pisa, the objects didn't actually hit the ground at the same time. They almost did, but, because of air resistance, the heavier one hit slightly before the lighter one. But this still contradicted the much longer time difference expected by the followers of Aristotle. The behavior of falling objects was never really understood until Newton announced his second law of motion.

UNIFYING CONCEPT
Friction
Section 2.8

When Galileo tried to explain why all objects fall with equal accelerations, wouldn't he have loved to know the rule $a = \frac{F}{m}$?

When the force of gravity and air resistance act on a falling object, the object is not in free fall.

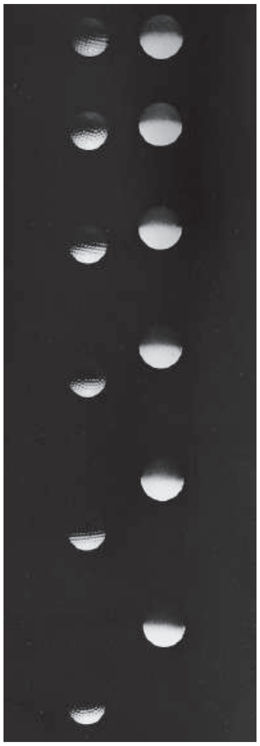


FIGURE 3.10
A stroboscopic study of a golf ball (left) and a Styrofoam ball (right) falling in air. The air resistance is negligible for the heavier golf ball, and its acceleration is nearly equal to *g*. Air resistance is not negligible for the lighter Styrofoam ball, however, and it reaches its terminal speed sooner.

* In mathematical notation, $a = \frac{F_{net}}{m} = \frac{mg - R}{m}$, where mg is the weight and R is the air resistance. Note that, when $R = mg$, $a = 0$; then, with no acceleration, the object falls at a constant velocity. With elementary algebra, we can proceed another step and get $a = \frac{F_{net}}{m} = \frac{mg - R}{m} = g - \frac{R}{m}$.

We see that the acceleration a will always be less than g if air resistance R impedes falling. Only when $R = 0$ does $a = g$.

** A skydiver's air resistance is proportional to speed squared.

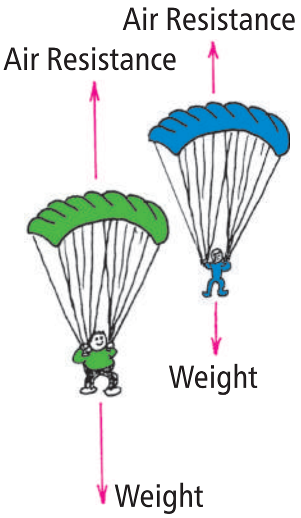


FIGURE 3.11
The heavier parachutist must fall faster than the lighter parachutist for air resistance to cancel her greater weight.

CHECK YOURSELF

Two parachutists, a heavy person and a light person, jump from the same altitude with parachutes of the same size.

1. **Which person reaches terminal speed first?**
2. **Which person has the higher terminal speed?**
3. **Which person reaches the ground first?**
4. **If there were no air resistance, like on the Moon, how would your answers to the questions differ?**

CHECK YOUR ANSWERS

To answer these questions correctly, think of a coin and a feather falling in air.

1. Just as a feather reaches terminal speed very quickly, the light person reaches terminal speed first.
2. Just as a coin falls faster than a feather through air, the heavy person falls faster and reaches a higher terminal speed.
3. Just as in the race between a falling coin and a falling feather, the heavy person falls faster and reaches the ground first.
4. If there were no air resistance, there would be no terminal speed at all. Both parachutists would be in free fall, and both would hit the ground at the same time.

LEARNING OBJECTIVE
Relate how living creatures are able to glide.

Integrated Science 3A
BIOLOGY

Gliding

Only three groups of living organisms—birds, bats, and insects—can truly fly. Gliding, however, has evolved many times in the biological world. Gliding is a mode of locomotion in which animals move through the air in a controlled fall. There are gliding squirrels, gliding lizards, gliding snakes, gliding frogs, even gliding ants. Although gliders cannot generate the forward thrust that enables fliers to power through the air, many gliders nevertheless have remarkable control—many, for example, are able to execute sharp turns in midair.

How does gliding work? When an animal jumps out of a tree, it falls toward the ground due to the downward force of gravity. Air resistance slows the animal's fall, just as it slows the motion of any object moving through air. The more air resistance an animal encounters, the slower and more controllable its fall. Since the amount of air resistance a falling object encounters depends on the object's surface area, all gliding animals have evolved special structures that increase their surface area. "Flying" squirrels have large flaps of skin between their front and hind legs. We now see humans emulating flying squirrels (see Figure 3.12). "Flying dragons" (gliding lizards of the genus *Draco*) have long extendable ribs that support large gliding membranes. "Flying" frogs have very long toes with extensive webbing between them. Gliding geckos have skin flaps along their sides and tails in addition to webbed toes. Gliding tree snakes spread out their ribs and suck in their stomachs when they leap off a branch, creating a concave parachute to slow their descent.

VIDEO: Free Fall: Acceleration Explained

VIDEO: Air Resistance and Falling Objects

MATH CONNECTION

When Air Resistance Slows Acceleration

The effect of air resistance on acceleration can be made clearer with some problem-solving practice. Examine the problems and solutions. You'll have more opportunities for practice at the end of the chapter.

Problems

1. A skydiver jumps from a high-flying helicopter. As she falls faster and faster through the air, does her *acceleration* increase, decrease, or remain the same?
2. What will be her acceleration if her weight is mg and air resistance builds up to be equal to half her weight?

Solutions

1. Acceleration decreases because the net force on her decreases. Net force is equal to her weight minus her air resistance and, because air resistance increases with increasing speed, net force and therefore acceleration also decrease. According to Newton's second law,

$$a = \frac{F_{\text{net}}}{m} = \frac{mg - R}{m}$$

where mg is her weight and R is the air resistance she encounters. As R increases, a decreases. Note that if she falls fast enough so that $R = mg$, $a = 0$, then, with no acceleration, she falls at terminal speed.

2. We find the acceleration from

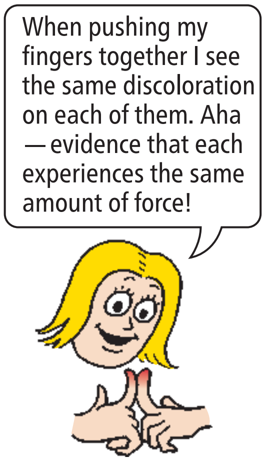
$$a = \frac{F_{\text{net}}}{m} = \frac{mg - R}{m} = \frac{(mg - mg/2)}{m} = \frac{(mg/2)}{m} = \frac{g}{2}$$

Gliding locomotion is particularly common in certain types of habitat. For example, the presence of tall trees without much "clutter" between them has resulted in the evolution of many gliding species in the rainforests of Southeast Asia. Gliding offers a number of advantages. First, it allows rapid, energetically efficient descent, which is useful in many contexts, such as escaping from predators. Second, gliding allows animals to move from one tree to another without descending all the way to the ground and climbing back up. This is, again, energy efficient. And gliding allows gliders to avoid potentially dangerous forest understories.

(a) (b)

FIGURE 3.12
(a) A flying squirrel increases its frontal area by spreading out. The result is greater air resistance and a slower fall. (b) Likewise for a wingsuit flyer.

LEARNING OBJECTIVE
Identify forces in pairs.



3.3 Forces and Interactions

So far, we've treated force in its simplest sense—as a push or a pull. In a broader sense, a force is not a thing in itself but an **interaction** between one thing and another. If you push a wall with your fingers, more is happening than you pushing on the wall. You're interacting with the wall, and the wall is simultaneously pushing on you. Your push on the wall and the wall's push on you are equal in magnitude (amount) and opposite in direction. The pair of forces constitutes a single interaction. In fact, you can't push on the wall unless the wall pushes back (Figure 3.13).*

In Figure 3.14, we see a boxer's fist hitting a massive punching bag. The fist hits the bag (and dents it) while the bag hits back on the fist (and stops its motion). This force pair is fairly large. But what if the boxer were hitting a piece of tissue paper? The boxer's fist can exert only as much force on the tissue paper as the tissue paper can exert on the boxer's fist. Furthermore, the fist can't exert any force at all unless what is being hit exerts the same amount of reaction force. An interaction requires a pair of forces acting on two different objects.

When a hammer hits a stake and drives it into the ground, the stake exerts an equal amount of force on the hammer, and that force brings the hammer to an abrupt halt (Figure 3.15). And when you pull on a cart, the cart pulls back on you, as evidenced, perhaps, by the tightening of the rope wrapped around your hand. One thing interacts with another: The hammer interacts with the stake, and you interact with the cart.

For emphasis: Forces occur *only* in pairs. A single force without a corresponding reaction does not exist in the world of physics.

FIGURE 3.13
When Kara Mae exerts a force on the wall, the wall simultaneously exerts an equal and opposite force on her. That's the law!

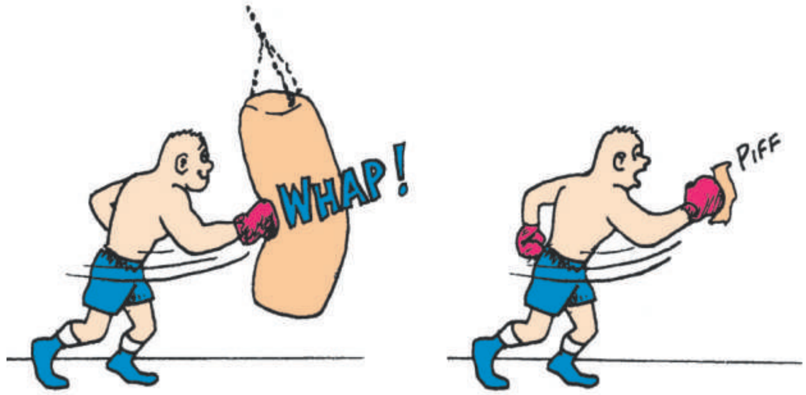


FIGURE 3.14
The boxer can hit the massive bag with considerable force. But, with the same punch, he can exert only a tiny force on the tissue paper in midair.

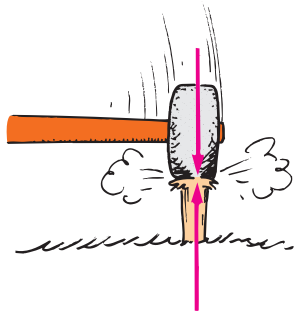


FIGURE 3.15
In the interaction between the hammer and the stake, each exerts the same amount of force on the other.

Pearson eText

VIDEO: Forces and Interactions

*We tend to think of only living things pushing and pulling, but inanimate things can also push and pull. So please don't be troubled by the idea of the inanimate wall pushing back on you. It does push back, just as another person pushing back on you would.

3.4 Newton's Third Law of Motion

LEARNING OBJECTIVE
Define Newton's third law of motion, and give examples.

Newton's third law of motion states:

> **When one object exerts a force on a second object, the second object exerts an equal and opposite force on the first.**

We can call one force the action force, and we can call the other the reaction force. The important thing is that they are coequal parts of a single interaction and that neither force exists without the other. Action and reaction forces are equal in strength and opposite in direction. They occur in pairs, and they make up a single interaction between two things (Figure 3.16).

The key word in Newton's third law is *when*, which implies "at the same time." When you walk, you interact with the floor. Your push against the floor is simultaneously paired with the floor's opposite push against you. Likewise, when the tires of a car push against the road, the road pushes back on the tires—the tires and the road push simultaneously against each other. When swimming, you interact with the water that you push backward, while the water pushes you forward—you and the water push against each other. The reaction forces are what account for our motion in these cases. These simultaneous forces depend on friction; a person or a car on ice, for example, may not be able to exert the action force necessary to produce the desired reaction force. Investigate the four interactions shown in Figure 3.17.

UNIFYING CONCEPT
Newton's Third Law

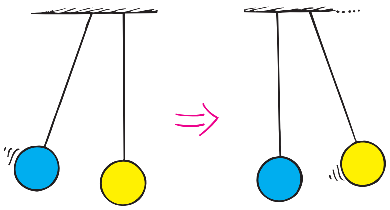


FIGURE 3.16
The impact forces between the blue and yellow balls move the yellow ball and stop the blue ball.

Simple Rule to Identify Action and Reaction

There is a simple rule for identifying action and reaction forces. First, identify the interaction—one thing (object A) interacts with another (object B). Then, action and reaction forces can be stated in the following form:

> **Action: Object A exerts a force on object B.**
> **Reaction: Object B exerts a force on object A.**

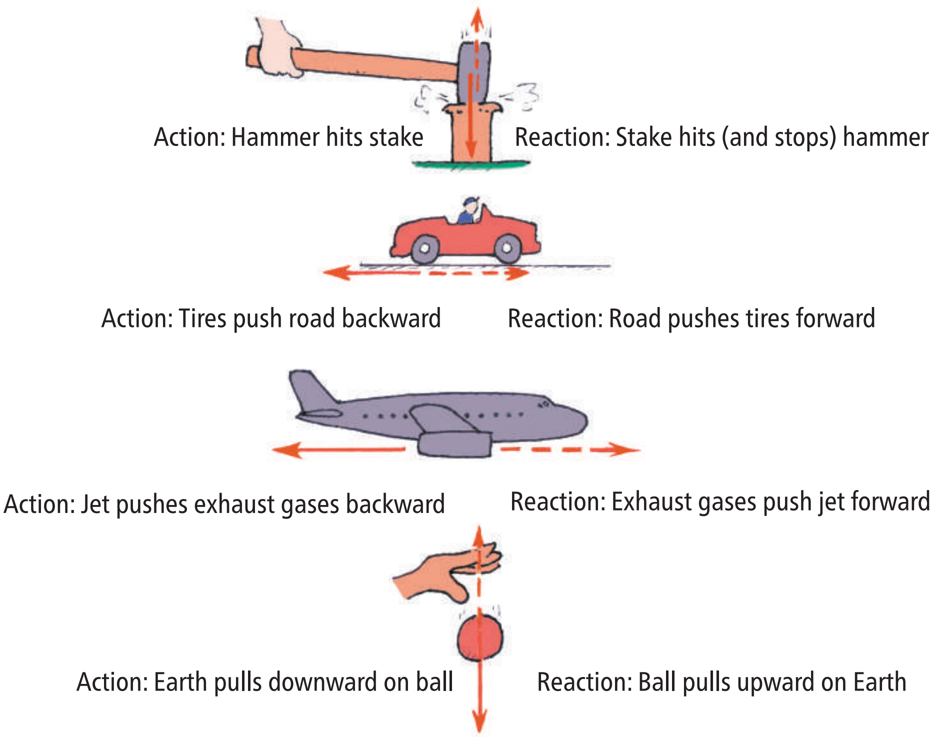


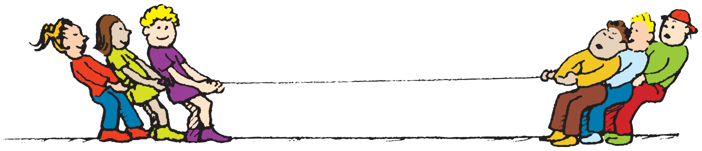
FIGURE 3.17
Action forces (solid red vectors) and reaction forces (dashed vectors). When "A exerts force on B," the reaction force is simply "B exerts force on A."

You can't pull on something unless that something simultaneously pulls back on you. That's the law!

PRACTICING PHYSICS

Tug-of-War

Perform a tug-of-war between guys and gals. Do it on a polished floor that's somewhat slippery, with guys wearing socks and gals wearing rubber-soled shoes. Who will surely win, and why? (*Hint*: Who wins a tug-of-war: those who pull harder on the rope or those who push harder against the floor?)



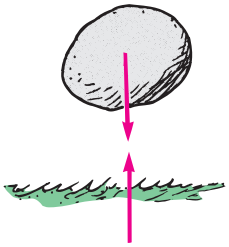


FIGURE 3.18
By way of gravity, the Earth pulls the boulder downward (action). At the same time, the boulder pulls the Earth upward (reaction).

The rule is easy to remember. If action is A acting on B, then reaction is B acting on A. We see that A and B are simply switched around. Consider the case of a boulder pulled downward by Earth's gravity (Figure 3.18). The interaction is between Earth and the boulder. We'll say the action is Earth (object A) pulling downward on the boulder (object B). Then the reaction is the boulder pulling up on Earth.

CHECK YOURSELF

1. **A car accelerates along a road. Identify the force that moves the car.**
2. **Identify the action and reaction forces for the case of an object in free fall (with no air resistance).**

CHECK YOUR ANSWERS

1. The force is the road that pushes the car along. Except for air resistance, only the road provides a horizontal force on the car. How does the road do this? The rotating tires of the car push back on the road (action). The road simultaneously pushes forward on the tires (reaction). How about that?
2. To identify a pair of action–reaction forces in any situation, first identify the pair of interacting objects. In this case, Earth interacts with the falling object via the force of gravity. So Earth pulls the falling object downward (call it action). Then the reaction is the falling object pulling Earth upward. It is only because of Earth's enormous mass that you don't notice its upward acceleration.

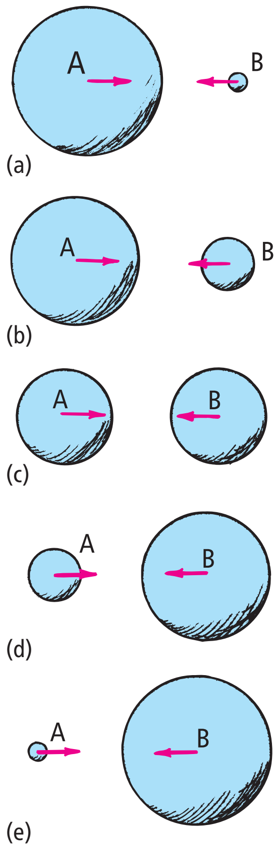


FIGURE 3.19
Which planet falls toward the other, A or B? Although the magnitudes of the forces are the same, how do the accelerations of each planet relate to their relative masses?

Action and Reaction on Different Masses

Quite interestingly, a falling object pulls upward on Earth with as much force as Earth pulls downward on the object. The resulting acceleration of the falling object is evident, while the upward acceleration of Earth is too small to detect (Figure 3.18).

Consider the exaggerated examples of the two planetary bodies shown in Figure 3.19. The forces between bodies A and B are equal in magnitude and oppositely directed in each case. If the acceleration of Planet A is unnoticeable in (a), then it is more noticeable in (b), where the difference between the masses is less extreme. In (c), where both bodies have equal mass, the acceleration of Planet A is as evident as it is for Planet B. Continuing, we see that the acceleration of Planet A becomes even more evident in (d) and even more so in (e). So, strictly speaking, when you step off the curb, the street rises ever so slightly to meet you.

When a cannon is fired, there is an interaction between the cannon and the cannonball (Figure 3.20). The sudden force that the cannon exerts on the cannonball is exactly equal and opposite to the force the cannonball exerts on the cannon. This is why the cannon recoils (kicks). But the effects of these equal forces are very different because the forces act on different masses. The different accelerations are evident in Newton's second law,

$$a = \frac{F}{m}$$

Let F represent both the action and reaction forces, $\Large m$ the mass of the cannon, and m the mass of the cannonball. Different-size symbols are used here to indicate the relative masses and the resulting accelerations. Then the acceleration of the cannonball and cannon can be represented in the following way:

$$\text{cannonball: } \frac{F}{m} = \Large a$$

$$\text{cannon: } \frac{F}{\Large m} = a$$

Thus we see why the change in velocity of the cannonball is so large compared with the change in velocity of the cannon. A given force exerted on a small mass produces a large acceleration, while the same force exerted on a large mass produces a small acceleration.

We can extend the idea of a cannon recoiling from the cannonball it fires to understanding rocket propulsion. When a rocket is fired, an enormous amount of high-velocity gas is ejected. It continually recoils from the ejected gas like a cannon recoiling from a succession of fired cannonballs (Figure 3.21).

A common misconception is that a rocket is propelled by the impact of exhaust gases against the atmosphere. In fact, before the advent of rockets, it was commonly thought that sending a rocket to the Moon was impossible. Why? Because there is no air above Earth's atmosphere for the rocket to push against. But this is like saying a cannon wouldn't recoil unless the cannonball had air to push against. Not true! Both the rocket and the recoiling cannon accelerate because of the reaction forces by the material they fire, not because of any pushes on the air. In fact, a rocket operates better above the atmosphere, where there is no air resistance.

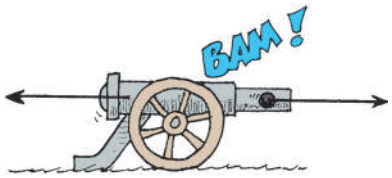


FIGURE 3.20

INTERACTIVE FIGURE

The force exerted against the recoiling cannon is just as great as the force that drives the cannonball along the barrel. Why, then, does the cannonball undergo more acceleration than the cannon?

FIGURE 3.21

The rocket recoils from the "molecular cannonballs" it fires, and it rises.

Pearson eText

VIDEO: Action and Reaction on Different Masses

CHECK YOURSELF

1. **We know that Earth pulls on the Moon. Does it follow that the Moon also pulls on Earth?**
2. **Which pulls harder—Earth on the Moon or the Moon on Earth?**
3. **A high-speed bus and an unfortunate bug have a head-on collision. The force of the bus on the bug splatters it all over the windshield. Is the corresponding force of the bug on the bus greater than, less than, or the same as the force of the bus on the bug? How do the resulting accelerations for each compare?**

CHECK YOUR ANSWERS

1. Yes, both pulls make up an action–reaction pair of forces associated with the gravitational interaction between Earth and the Moon. We can say that (a) Earth pulls on the Moon and (b) the Moon likewise pulls on Earth; however, it is more insightful to think of this as a single interaction—Earth and Moon simultaneously pulling on each other, each with the *same* amount of force.
2. Both pull with the same strength. This is like asking which distance is greater—from San Francisco to New York, or from New York to San Francisco? Both distances, like both forces in the Moon–Earth pulls, are the same.

Action and reaction are two equal and oppositely directed forces that are coequal parts of a single interaction between two different things.

3. The magnitudes of the forces are the same because they constitute an action–reaction force pair that makes up the interaction between the bus and the bug. The accelerations, however, are very different because the masses are different. The bug undergoes an enormous and lethal deceleration, while the bus undergoes a very tiny deceleration—so tiny that the very slight slowing of the bus is unnoticed by its passengers. But, if the bug were more massive—as massive as another bus, for example—its deceleration would be very apparent.

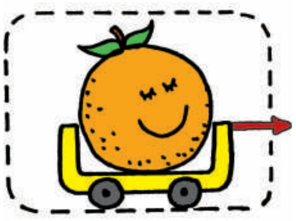


FIGURE 3.22

INTERACTIVE FIGURE

A force acts on the orange, and the orange accelerates to the right.

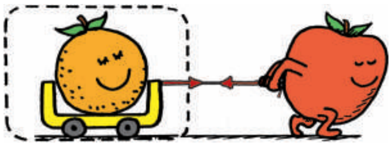


FIGURE 3.23

INTERACTIVE FIGURE

The force on the orange, provided by the apple, is not canceled by the reaction force on the apple. The orange still accelerates.

A system may be as tiny as an atom or as large as the universe.

Defining Your System

An interesting question often arises: Since action and reaction forces are equal and opposite, why don't they cancel to zero? To answer this question, we must consider the system. For example, think of a system consisting of the single orange shown in Figure 3.22. The dashed line surrounding the orange encloses and defines the system. The vector that pokes outside the dashed line represents an external force on the system. The system accelerates in accord with Newton's second law. In Figure 3.23, we see that this force is provided by the apple, which doesn't change our analysis. The apple is outside the system. The fact that the orange simultaneously exerts a force on the apple, which is external to the system, may affect the apple (another system) but not the orange. You can't cancel a force on the orange with a force on the apple. So, in this case, the action–reaction forces don't cancel and the orange accelerates to the right.

Now let's consider a larger system, enclosing both the orange and the apple bounded by the dashed line in Figure 3.24. Notice that the force pair is internal to the orange–apple system. These forces do cancel each other. They play no role in accelerating the system. A force external to the system is needed for acceleration. That's where friction with the floor comes in (Figure 3.25). When the apple pushes against the floor, the floor simultaneously pushes on the apple—an external force on the system. The system accelerates to the right.

Inside a baseball are trillions and trillions of interatomic forces at play. They hold the ball together, but they play no role in accelerating the ball. Although every one of the interatomic forces is part of an action–reaction pair inside the ball, they combine to zero, no matter how many of them there are. A force external to the ball, such as that which a swinging bat provides, is needed to accelerate the ball.

If this is confusing, it may be well to note that Newton had difficulties with the third law himself.

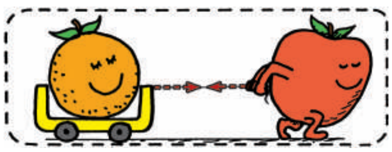


FIGURE 3.24

INTERACTIVE FIGURE

In the larger system of orange + apple, action and reaction forces are internal and cancel. If these are the only horizontal forces, with no external force, then no acceleration of the system occurs.

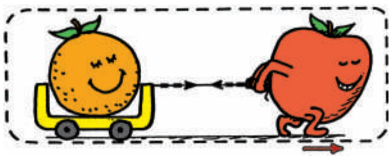


FIGURE 3.25

INTERACTIVE FIGURE

An external horizontal force occurs when the floor pushes on the apple (reaction to the apple's push on the floor). The orange + apple system accelerates.

CHECK YOURSELF

1. **On a cold, rainy day, your car battery is dead, and you must push the car to move it and get it started. Why can't you move the car by remaining comfortably inside and pushing against the dashboard?**
2. **Does a fast-moving softball possess force?**

CHECK YOUR ANSWERS

1. In this case, the system to be accelerated is the car. If you remain inside and push on the dashboard, the force pair you produce acts and reacts within the system. These forces cancel out, as far as any motion of the car is concerned. To accelerate the car, there must be an interaction between the car and something external—for example, you on the outside pushing against the road.
2. No, a force is not something an object has, like mass; a force is an interaction between one object and another. A speeding softball may possess the capability of exerting a force on another object when interaction occurs, but it does not possess force as a thing in itself. As we will see in the next chapter, moving things possess momentum and kinetic energy.

We see Newton's third law in action everywhere. A fish propels water backward with its fins, and the water propels the fish forward. The wind caresses the branches of a tree, and the branches caress back on the wind to produce whistling sounds. Forces are interactions between different things. Every contact requires at least a twoness; there is no way that an object can exert a force on nothing. Forces, whether large shoves or slight nudges, always occur in pairs, each opposite to the other. Thus, we cannot touch without being touched (Figure 3.26).

FIGURE 3.26
You cannot touch without being touched—Newton's third law.

Integrated Science 3B
BIOLOGY

LEARNING OBJECTIVE
Relate the physics of motion to living creatures.

Animal Locomotion

The study of how animals move, *animal locomotion*, is a branch of *biophysics*. Biophysics draws both on physics and on biology and is one of many crossover science disciplines thriving today.

Much of the study of animal locomotion is based on Newton's third law. To move forward, an animal pushes back on something else; the reaction force pushes the animal forward. For example, birds fly by pushing against air. When they flap their wings, birds push the air downward. The air, in turn, pushes the bird upward. When a bird is soaring, its wing is shaped so that moving air particles are deflected downward; the upward reaction force is lift. A fish swims by pushing against water—the fish propels water backward with its fins, and the water propels the fish forward. Likewise, land animals such as humans push against the ground, and the ground in turn pushes them forward.

Let's consider an example of animal locomotion on land in more detail. Specifically, how does Newton's third law come into play when you walk? First, note that when you are standing still, you are not accelerating. The forces that act on you, gravity and the normal force, balance as shown in Figure 3.27a. To walk, you must accelerate horizontally—the vertical forces of gravity and the normal force don't help. The forces involved in walking are horizontal *frictional* forces (Figure 3.27b). Because your feet press the floor, there is friction when you push your foot horizontally

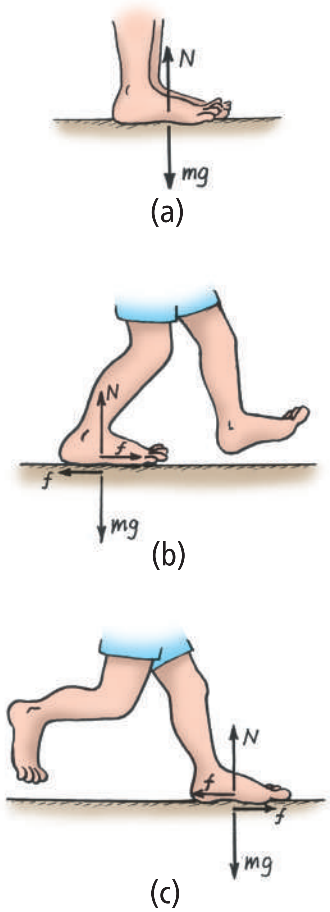


FIGURE 3.27
(a) Standing still, you push against the floor with a force equal to your weight; the normal force pushes you back equally—action and reaction. (b) When you lift your left foot, only the reaction to the friction force on the floor by your right foot moves you forward. (c) When your left foot lands, friction acts again but in the opposite direction. Friction stops your foot from slipping forward as the rest of your body catches up.

against the floor. By Newton's third law, the floor pushes back on you in the opposite direction—forward. So the reaction force that allows you to walk is the friction force that the floor applies to your foot and thereby to your mass as a whole. (Don't be confused by all the internal forces within your body that are involved in walking, such as the rotation of your bones and the stretching of your muscles and tendons. An *external* force must act on your body to accelerate it; friction is that force.)

After friction nudges you forward from a standstill, your step is like a controlled fall. You step forward, and your body drops a short distance until your front foot becomes planted in front of you. Friction, as shown in Figure 3.27c, acts in the opposite direction as it prevents your front foot from sliding forward.

Locomotion is important for many life functions (eating, finding mates, escaping predators, and so on). Biophysical research in this area, therefore, has beneficial applications for countless animals—human and otherwise—in locomotion.

CHECK YOURSELF

1. **In what way is the study of animal locomotion an integrated science?**
2. **Why is Newton's third law such a necessary piece of information for understanding animal locomotion?**
3. **Why don't the force interactions among your muscles, bones, and other internal organs—or, for that matter, the forces among the atoms and molecules in your body—move your body as a whole?**
4. **Why is walking in a puddle of grease so much more difficult than walking on carpet?**

CHECK YOUR ANSWERS

1. It combines biology and physics.
2. Generally speaking, animals move by pushing back on some medium, and the reaction force pushes them forward.
3. Forces internal to a system cannot accelerate a system.
4. Grease is so smooth that it offers little friction to your feet and therefore insufficient reaction force to get you walking.

3.5 Vectors

LEARNING OBJECTIVE
Differentiate among vectors, their components, and their resultants.

We have learned that quantities such as velocity, force, and acceleration require both magnitude and direction for a complete description. Such a quantity is a **vector quantity**. By contrast, a quantity that can be described by magnitude only, a quantity not involving direction, is called a **scalar quantity**. Mass, volume, and speed are scalar quantities.

A vector quantity is nicely represented by an arrow. When the length of the arrow is scaled to represent the quantity's magnitude, and the direction of the arrow indicates the direction of the quantity, we refer to the arrow as a **vector** (Figure 3.28).

FIGURE 3.28
This vector, scaled so that 1 cm equals 20 N, represents a force of 60 N to the right.

Adding vectors is quite simple when they act along parallel directions: If they are in the same direction, they add; if they are in opposite directions, they subtract. The sum of two or more vectors is called their **resultant**. To find the resultant of nonparallel vectors, we use the parallelogram rule.* Construct a parallelogram in which the two vectors are adjacent sides—the diagonal of the parallelogram shows the resultant. In Figure 3.29, the parallelograms are rectangles.

* A parallelogram is a four-sided figure with opposite sides equal in length and parallel to each other. You can determine the length of the diagonal by measuring, but, in the special case in which the two vectors **V** and **H** are perpendicular, forming a square or rectangle, you can apply the Pythagorean theorem, $\mathbf{R}^2 = \mathbf{V}^2 + \mathbf{H}^2$, to give the resultant: $\mathbf{R} = \sqrt{(\mathbf{V}^2 + \mathbf{H}^2)}$.

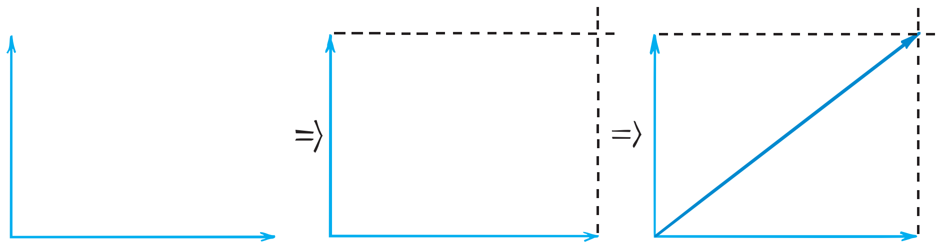
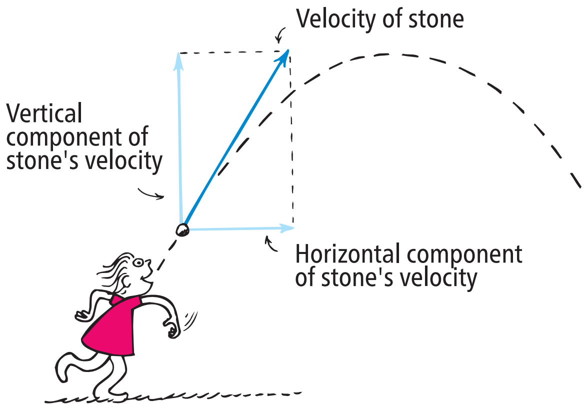


FIGURE 3.29
The pair of vectors at right angles to each other form two sides of a rectangle; the diagonal is their resultant.

MATH CONNECTION

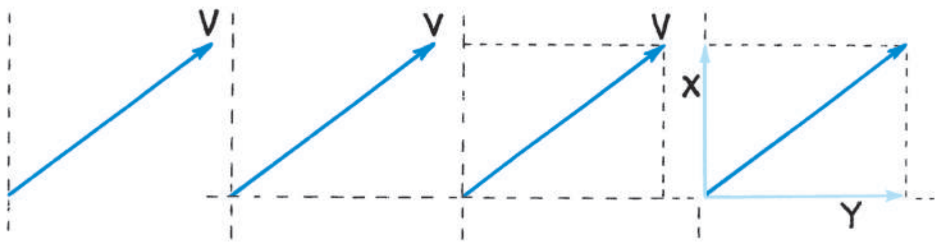
Vector Components

Just as two vectors at right angles can be resolved into one resultant vector, any vector can be "resolved" into two component vectors perpendicular to each other. These two vectors are known as the **components** of the given vector they replace. The process of determining the components of a vector is called *resolution*. Any vector drawn on a piece of paper can be resolved into vertical and horizontal components.



The horizontal and vertical components of a ball's velocity.

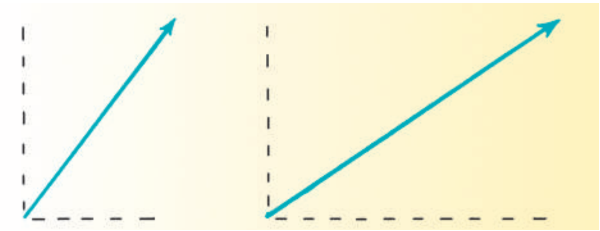
Vector resolution is illustrated in the accompanying figure. A vector **V** is drawn in the proper direction to represent a vector quantity. Then vertical and horizontal lines (axes) are drawn at the tail of the vector. Next, a rectangle is drawn that has **V** as its diagonal. The sides of this rectangle are the desired components, vectors **X** and **Y**. In reverse, note that the vector sum of vectors **X** and **Y** is **V**. We'll return to vector components when we treat projectile motion in Chapter 5.



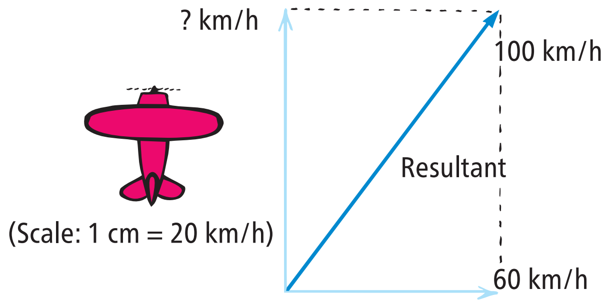
Construction of the vertical and horizontal components of a vector.

Problems

1. With a ruler, draw the horizontal and vertical components of the two vectors below. Measure the components.



2. Consider an airplane that sets its course north but is blown off course by a crosswind blowing eastward at 60 km/h. The resultant velocity of the plane is 100 km/h relative to the ground in a direction between north and northeast. Find the plane's airspeed (its speed if there were no wind).



Solutions

1. Left vector: The horizontal component is 2 cm; the vertical component is 2.6 cm. Right vector: The horizontal component is 3.9 cm; the vertical component is 2.6 cm.
2. The plane's airspeed is 80 km/h.

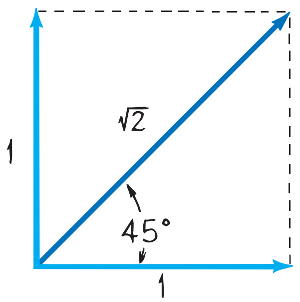


FIGURE 3.30
When a pair of equal-length vectors at right angles to each other are added, they form a square. The diagonal of the square is $\sqrt{2}$ times the length of the other side.

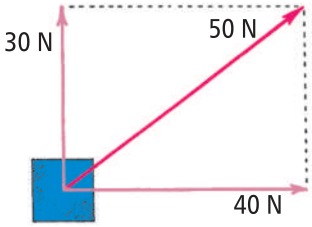
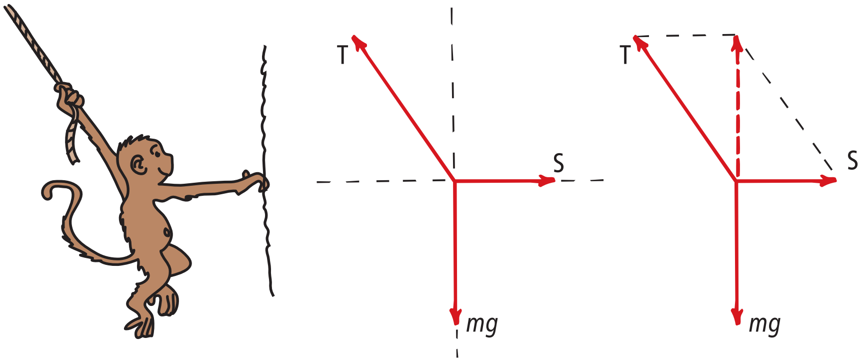


FIGURE 3.31
INTERACTIVE FIGURE
The resultant of the 30-N and 40-N forces is 50 N.

In the special case of two perpendicular vectors that are equal in magnitude, the parallelogram is a square (Figure 3.30). Since, for any square, the length of a diagonal is $\sqrt{2}$, or 1.41 times the length of one of the sides, the resultant is $\sqrt{2}$ times one of the vectors. So, the resultant of two equal vectors of magnitude 100 acting at a right angle to each other is 141. Consider the **force vectors** shown in Figure 3.31. The figure shows the top view of a pair of horizontal forces acting on the box. One force is 30 N and the other is 40 N. Simple measurement shows that the resultant is 50 N. (Vectors are developed in more detail in Appendix C.)

FIGURE 3.32
Monkey Mo and the three forces that provide equilibrium.



LEARNING OBJECTIVE
Summarize and contrast Newton's three laws of motion.

3.6 Summary of Newton's Three Laws

Newton's first law, the law of inertia: An object at rest tends to remain at rest; an object in motion tends to remain in motion at constant speed along a straight-line path. This property of objects to resist change in motion is called inertia. Objects will undergo changes in motion only in the presence of a net force.

FIGURE 3.33
What is Hudson's acceleration at the top of his trajectory? (Why do those who don't distinguish between velocity and acceleration get this wrong? And why do more students who use $a = F/m$ to guide their thinking get it right?)

Newton's second law, the law of acceleration: When a net force acts on an object, the object will accelerate. The acceleration is directly proportional to the net force and inversely proportional to the mass. Symbolically, $a \sim F/m$. Acceleration is always in the direction of the net force. When an object falls in a vacuum, the net force is simply the weight and the acceleration is g (the symbol g denotes that acceleration is due to gravity alone). When an object falls in air, the net force is equal to the weight minus the force of air resistance, and the acceleration is less than g. If and when the force of air resistance equals the weight of a falling object, acceleration terminates and the object falls at a constant speed (called the *terminal speed*).

Newton's third law, the law of action–reaction: Whenever one object exerts a force on

HISTORY OF SCIENCE

Isaac Newton (1642–1727)

Isaac Newton was born prematurely (and barely survived) on Christmas Day, 1642, at his mother's farmhouse in Woolsthorpe, England, the same year that Galileo died. Newton's father had died several months before his birth, and Isaac grew up under the care of his mother and grandmother. As a child, he showed no particular signs of brightness, and, at the age of $14\frac{1}{2}$, he was removed from school to work on his mother's farm. As a farmer, he was a failure, preferring to read books he borrowed from a neighborhood druggist. An uncle sensed the potential in young Isaac and prompted him to study at Cambridge University, which he did for five years, graduating without distinction.

A plague swept through London, and Newton retreated to his mother's farm—this time to continue his studies. While on the farm, at age 23, he laid the foundations for the work that was to make him immortal. Seeing an apple fall to the ground led him to consider the force of gravity extending to the Moon and beyond. He formulated the law of universal gravitation (which he later proved). He invented the calculus, a very important mathematical tool in science. He extended Galileo's work and formulated the three fundamental laws of motion. He also formulated a theory of the nature of light and demonstrated with prisms that white light is composed of all colors of the rainbow. It was his experiments with prisms that initially brought him fame.

When the plague subsided, Newton returned to Cambridge and soon established a reputation for himself as a first-rate mathematician. His mathematics teacher resigned in his favor, and Newton was appointed the Lucasian Professor of Mathematics, a post he held for 28 years. In 1672, he was elected to the Royal Society, where he exhibited the world's first reflector telescope. It can still be seen, preserved at the library of the Royal Society in London, with this inscription: "The first reflecting telescope, invented by Sir Isaac Newton, and made with his own hands."

It wasn't until Newton was 42 that he began to write what is generally acknowledged as the greatest scientific book ever written, the *Philosophiae Mathematica Principia Naturalis*. He wrote the work in Latin and completed it in 18 months. It appeared in print in 1687, but an English translation wasn't printed until 1729, two years after his death. When asked how he was able to make so many discoveries, Newton replied that he solved his problems by continually thinking very long and hard about them—and not by sudden insight.

At the age of 46, Newton was elected a member of Parliament for two years and never gave a speech. One day he rose and the House fell silent to hear the great man speak. Newton's "speech" was very brief; he simply requested that a window be closed because of a draft.

A further turn from his work in science was his appointment as warden, and then as master, of the mint. Newton resigned his professorship and directed his efforts toward greatly improving the workings of the mint, to the dismay of counterfeiters who flourished at that time. He maintained his membership in the Royal Society and was elected president, then was reelected each year for the rest of his life. At the age of 62, he wrote *Opticks*, which summarized his work on light. Nine years later, he wrote a second edition of his *Principia*.

Although Newton's hair turned gray when he was 30, it remained full, long, and wavy all his life. Unlike others of his time, he did not wear a wig. He was a modest man, very sensitive to criticism, and never married. He remained healthy in body and mind into old age. At 80, he still had all his teeth, his eyesight and hearing were sharp, and his mind was alert. In his lifetime, he was regarded by his countrymen as the greatest scientist who ever lived. In 1705, he was knighted by Queen Anne. Newton died at the age of 85, and he was buried in Westminster Abbey, along with England's kings and heroes.

Newton showed that the universe ran according to natural laws—a knowledge that provided hope and inspiration to people of all walks of life and that ushered in the Age of Reason. The ideas and insights of Isaac Newton truly changed the world and elevated the human condition.

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a second object, the second object simultaneously exerts an equal and opposite force on the first. Forces occur in pairs: One is an action and the other is a reaction, and together they constitute the interaction between one object and the other. Action and reaction always act on different objects. Neither force exists without the other.

Are Newton's laws *always* accurate? From falling apples to rising smoke to the orbits of planets, Newton's laws seem to explain all motion. However, there are limitations to these laws. Modern experiments show that Newton's laws are valid over the range of phenomena we normally observe; however, they are *not* valid for:

1. Objects moving near the speed of light: To understand the motion of very fast moving objects, we must use Einstein's principles of special relativity.
2. Objects that are very small—on the scale of an atom: Objects that consist of just a few atoms move according to the principles of *quantum mechanics* rather than Newtonian physics.

3. Objects under the influence of very strong gravitational forces: To understand the motions of such astronomical objects, we invoke Einstein's theory of *general relativity,* which appears valid for all gravitational forces.

Though they have limitations, Newton's laws remain the major tools of scientists working today. Most objects are slow enough, big enough, and not subject to extraordinary gravitational forces, so Newton's laws work just fine to describe their motion. Also, the mathematics of special relativity, quantum mechanics, and general relativity are so much more complicated than the mathematics of Newtonian physics that these modern theories are usually reserved for extreme situations where Newton's laws do not apply. After all, it was primarily Newton's laws that got us to the Moon!

For instructor-assigned homework, go to https://mlm.pearson.com

SUMMARY OF TERMS (KNOWLEDGE)

Components Mutually perpendicular vectors, usually horizontal and vertical, whose vector sum is a given vector.

Force vector An arrow drawn to scale so that its length represents the magnitude of a force and its direction represents the direction of the force.

Free fall Motion under the influence of gravitational pull only.

Interaction Mutual action between objects during which one object exerts an equal and opposite force on the other object.

Newton's first law Every object continues in a state of rest, or of uniform speed in a straight line, unless acted on by a nonzero force.

Newton's second law The acceleration produced by a net force on an object is directly proportional to the net force, is in the same direction as the net force, and is inversely proportional to the mass of the object.

Newton's third law Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first object.

Resultant The net result of a combination of two or more vectors.

Scalar quantity A quantity, such as mass, volume, speed, and time, that can be completely specified by its magnitude.

Terminal speed The speed at which the acceleration of a falling object terminates when air resistance balances weight.

Vector An arrow whose length represents the magnitude of a quantity and whose direction represents the direction of the quantity.

Vector quantity A quantity whose description requires both magnitude and direction.

READING CHECK QUESTIONS (COMPREHENSION)

3.1 Newton's First Law of Motion

1. What is Newton's first law of motion?
2. What kind of path would the planets follow if suddenly their attraction to the Sun no longer existed?

3.2 Newton's Second Law of Motion

3. (a) Express Newton's second law of motion in words.
   (b) Then express it abbreviated with symbols.
4. (a) Is acceleration *directly* proportional to force, or is it *inversely* proportional to force? Give an example.
   (b) Is acceleration *directly* proportional to mass, or is it *inversely* proportional to mass? Give an example.
5. If the mass of a sliding block is tripled at the same time the net force on it is tripled, how does the resulting acceleration compare with the original acceleration?
6. What is the acceleration of a 10-N freely falling object?
7. Why do objects with different masses fall at the same rate during free fall?
8. What is the acceleration of a falling object that has reached its terminal velocity?
9. What two quantities affect air resistance?
10. Who falls faster when wearing the same-size parachute—a heavy person or a light person—or do both fall at the same speed?

3.3 Forces and Interactions

11. Identify the pair of forces involved when you push on an object with your fingers.
12. When you push against a wall with your fingers, they bend because they experience a force. What is this force?
13. A boxer can hit a heavy bag with a great force. Why can't he hit a sheet of newspaper in midair with the same amount of force?

3.4 Newton's Third Law of Motion

14. What is Newton's third law of motion?
15. If we call the force of a bat hitting a ball the action force, what is the reaction force?
16. Do action and reaction forces act in succession or simultaneously?
17. If the forces that act on a cannonball and the recoiling cannon from which it is fired are equal in magnitude, why do the cannonball and cannon have very different accelerations?
18. What is needed to accelerate a system?

3.5 Vectors

19. Cite three examples of a vector quantity. Then cite three examples of a scalar quantity.
20. What is the resultant of two equal-magnitude vectors at right angles to each other?
21. According to the parallelogram rule, what does the diagonal of a constructed parallelogram represent?
22. Can it be said that, when two vectors are at right angles to each other, the resultant is greater than either of the vectors separately?
23. What change in magnitude occurs for the vertical component of velocity for a ball tossed at an upward angle? For the horizontal component when air resistance can be neglected?

3.6 Summary of Newton's Three Laws

24. Newton's laws of motion are valid for most of our experiences. When are they invalid?
25. Does Hudson's speed undergo a change when tossed upward by his dad (Figure 3.33)? Does his acceleration undergo a change while airborne?

THINK INTEGRATED SCIENCE

3A—Gliding

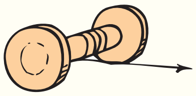
26. What is gliding locomotion?
27. Why is having a large surface area important for effective gliding?
28. Describe some of the physical characteristics that gliding organisms have evolved to increase their surface area.

3B—Animal Locomotion

29. Explain how Newton's third law underlies many forms of animal locomotion—from fish, to birds, to humans.
30. A squid propels itself forward by pushing water backward. Why does this occur?
31. When you walk, what is the force that pushes you forward?
32. Why does a duck in an oil spill find it difficult to walk?

THINK AND DO (HANDS-ON APPLICATION)

33. The net force acting on an object and the resulting acceleration are always in the same direction. You can demonstrate this with a spool. If the spool is pulled horizontally to the right, in which direction will it roll? (Some of your classmates may be surprised.)



34. Hold your hand with the palm down like a flat wing outside the window of a moving automobile. Then slightly tilt the front edge of your hand upward and notice the lifting effect as air bounces from the bottom of your hand. Which of Newton's laws is illustrated here?
35. Drop a sheet of paper and a coin at the same time. Which reaches the ground first? Why? Now crumple the paper into a small, tight wad and again drop it with the coin. Explain the difference observed. Will they fall together if dropped from a second-, third-, or fourth-story window? Try it and explain your observations.
36. Drop a book and a sheet of paper, and you'll see that the book has a greater acceleration *g*. Repeat, but place the paper *beneath* the book so that it is forced against the book as both fall, so both fall equally at *g*. How do the accelerations compare if you place the paper on top of the raised book and then drop both? You may be surprised, so try it and see. Then explain your observation.

PLUG AND CHUG (FORMULA FAMILIARIZATION)

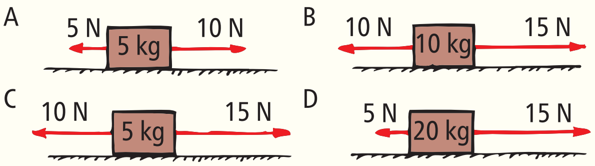
Do these simple one-step calculations and familiarize yourself with the equation that connects the concepts of force, mass, and acceleration.

$$\textbf{Acceleration} = \frac{\textbf{net force}}{\textbf{mass}} = \frac{F_{net}}{m}$$

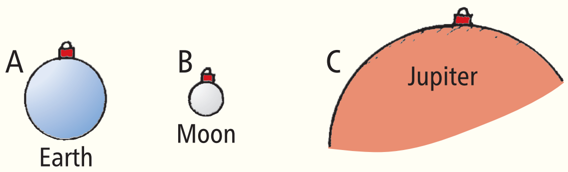
37. In Chapter 2, acceleration is defined as $a = \frac{\Delta v}{\Delta t}$. Use this formula to show that the acceleration of a cart on an inclined plane that gains 6.0 m/s each 1.2 s is 5.0 m/s^2.
38. In this chapter, we learned that the cause of acceleration is given by Newton's second law: $a = F_{net}/m$. Show that the 5.0-m/s^2 acceleration in Exercise 37 can result when a 15-N net force is exerted on a 3.0-kg cart. (Note: The unit N/kg is equivalent to m/s^2.)
39. If you know that a 1-kg object weighs 10 N, confirm that the acceleration of a 1-kg stone in free fall is 10 m/s^2.
40. A simple rearrangement of Newton's second law gives $F_{net} = ma$. Show that a net force of 84 N is needed to give a 12-kg package an acceleration of 7.0 m/s^2. (Note: The units $kg \cdot m/s^2$ and N are equivalent.)

THINK AND COMPARE (ANALYSIS)

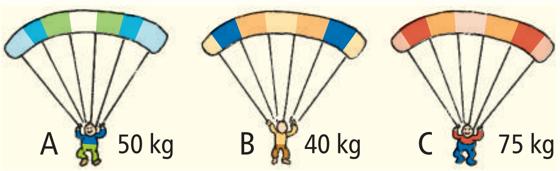
41. Four boxes of different masses are on a friction-free, level table. From greatest to least, rank the (a) net forces on the boxes and (b) accelerations of the boxes.



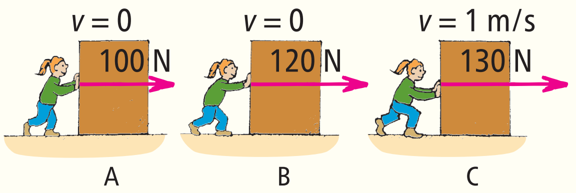
42. Consider a 100-kg box of tools in locations A, B, and C. Rank from greatest to least the (a) masses of the 100-kg box of tools and (b) weights of the 100-kg box of tools.



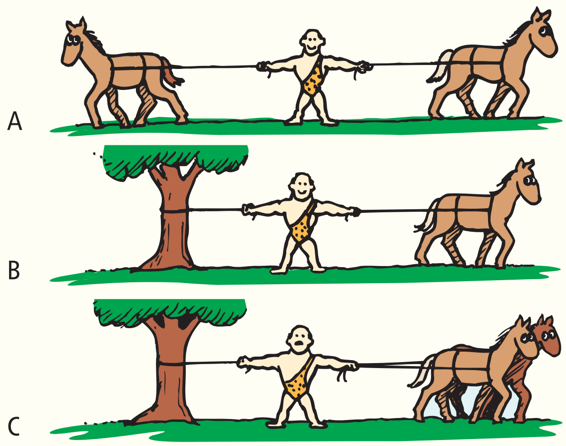
43. Three parachutists, A, B, and C, each have reached terminal velocity at the same altitude. (a) From fastest to slowest, rank their terminal velocities. (b) From longest to shortest times, rank their order in reaching the ground.



44. In cases A, B, and C, the crate is in equilibrium (no acceleration). From greatest to least, rank the amounts of friction between the crate and the floor.



45. The strong man is pulled in the three situations shown. Rank the amounts of tension in the rope in his right hand (the one attached to the tree in B and C) from least to greatest.



THINK AND SOLVE (MATHEMATICAL APPLICATION)

46. The British system of units includes the slug as a unit of mass, where one slug is the same as 14.6 kg. What is the mass in slugs of a person who weighs 60 kg?
47. If Lillian weighs 500 N, what is her weight in pounds?
48. Consider a mass of 1 kg accelerated 1 m/s^2 by a force of 1 N. Show that the acceleration would be the same for a force of 2 N acting on 2 kg.
49. Consider a business jet of mass 30,000 kg in takeoff when the thrust for each of its two engines is 30,000 N. Show that its acceleration is 2 m/s^2.
50. Alex, who has a mass of 100 kg, is skateboarding at 9.0 m/s when he smacks into a brick wall and comes to a dead stop in 0.2 s.
    (a) Show that his deceleration is 45 m/s^2.
    (b) Show that the force of impact is 4500 N. (Ouch!)
51. A boxer punches a sheet of paper in midair, bringing it from rest to a speed of 25 m/s in 0.05 s. If the mass of the paper is 0.003 kg, show that the force the boxer exerts on it is only 1.5 N.
52. Suppose that you are standing on a skateboard near a wall and you push on the wall with a force of 30 N. (a) How hard does the wall push on you? (b) Show that if your mass is 60 kg, your acceleration while pushing will be 0.5 m/s^2.
53. If raindrops fall vertically at a speed of 5 m/s, and you are riding a bike along a straight, level road at 12 m/s, then at what speed will the raindrops hit your face?
54. Horizontal forces of 3 N and 4 N act at right angles on a block of mass 5 kg. Show that the resulting acceleration is 1 m/s^2.
55. A fighter jet flying at an airspeed of 400 km/h encounters an intense crosswind of speed 300 km/h. What would be the speed of the fighter jet as measured by an observer on the ground?

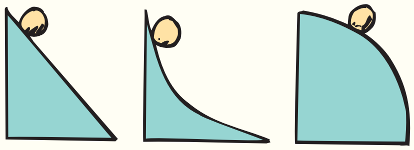
THINK AND EXPLAIN (SYNTHESIS)

3.1 Newton's First Law of Motion

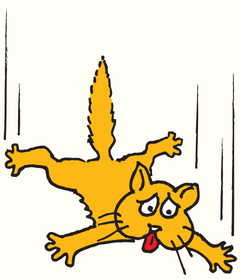
56. The weight of a bowling ball on the Moon is similar to the weight of a basketball on Earth. On Earth, you can comfortably kick a basketball hard enough that it travels 20 m along the ground. Could an astronaut on the Moon do the same with a bowling ball?
57. Your empty hand is not hurt when it bangs lightly against a wall. Why does it hurt if it is carrying a heavy load when it bangs against the wall? Which of Newton's laws is most applicable here?
58. On a long alley, a bowling ball slows down as it rolls. Is any horizontal force acting on the ball? How do you know?
59. If a motorcycle moves with a constant velocity, can you conclude that there is no net force acting on it? How about if it's moving with constant acceleration?
60. Since an object weighs less on the surface of the Moon than on Earth's surface, does it have less inertia on the Moon's surface?
61. Does the mass of an astronaut change when he or she is visiting the International Space Station? Defend your answer.
62. Two darts with different masses are thrown at a dartboard. If both arrive at the same speed which is more likely to stick into the dartboard, the lighter or the heavier dart? Explain your answer.

3.2 Newton's Second Law of Motion

63. Neglecting air resistance, if you drop an object, its acceleration toward the ground is 10 m/s^2. If you throw it down instead, will its acceleration after throwing be greater than 10 m/s^2? Why or why not?
64. Can you think of a reason why the acceleration of the object thrown downward through the air in Exercise 63 will actually be less than 10 m/s^2?
65. A feather and coin accelerate equally when dropped in a vacuum. If the feather were made of lead, and much heavier than the coin, would accelerations of both still be the same? Explain.
66. On which of these hills does the ball roll down with increasing speed and decreasing acceleration along the path? (Use this example if you wish to explain to someone the difference between speed and acceleration.)



67. At what stage in a parachute jump are velocity and acceleration in opposite directions? At what stage does acceleration become zero while falling continues?
68. What is the direction of the net force on a falling object just before it reaches terminal velocity? What about just after it reaches terminal velocity?
69. Free fall is motion in which gravity is the only force acting. (a) When a glider is released from its towing airplane, is it in free fall? (b) Is the Moon in free fall?
70. Why is it that a cat that falls from the top of a 50-story building will hit the safety net below no faster than if it fell from the 20th story?



71. You tell your friend that the acceleration of a skydiver before the chute opens decreases as falling progresses. Your friend then asks if this means the skydiver is slowing down. What is your response?

3.3 Forces and Interactions

72. First we say that force is a push or pull. Now we say a force is part of an interaction. Is a force a push or pull, or part of an interaction?
73. We know that the Sun pulls on the planets. Does it follow that the planets also pull on the Sun?

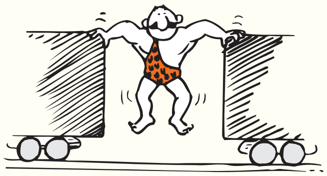
74. A friend says that Alé cannot push on the tree unless the tree pushes back on her. Another friend says that if Alé pushes quickly, the tree won't push as hard on her. What is your opinion on this?

75. When you stand at rest on a floor, does the floor exert an upward force on you? How much force does it exert? Why does this force not move you upward?

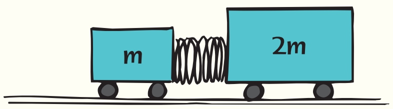
76. When you pull on a rope, what pulls on you? If the rope breaks, does it still pull on you?

3.4 Newton's Third Law of Motion

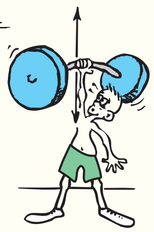
77. The strong man will push apart the two initially stationary freight cars of equal mass before he alone drops straight to the ground. Is it possible for him to give either of the cars a greater speed than the other? Defend your answer.



78. Consider that two carts, one twice as massive as the other, fly apart when the compressed spring is released. How fast does the heavier cart roll compared to the lighter cart?



79. When the athlete pushes upward to hold the barbell at rest, the reaction force is the weight of the barbell on his hand. How is this force different when the barbell is lifted at an increasing speed?



80. Note the two forces acting on the man standing at rest. One is due to the gravitational force of Earth pulling him down and the other is the support force by the floor. Are these forces equal and opposite? Do they make up an action-reaction pair of forces? Why or why not?

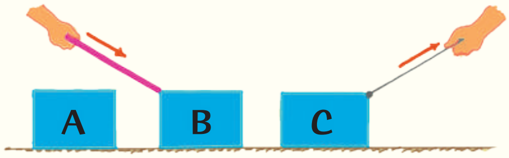
81. Regarding the orange-apple system discussed in the chapter, would the apple be able to exert the force on the floor shown in Figure 3.25 if the floor were perfectly slippery ice? Defend your answer.

82. The photo shows Steve Hewitt and his daughter Gretchen. Is Gretchen touching her dad or is he touching her? Explain.

3.5 Vectors

83. Nellie tosses a ball at an angle upward. What happens to the vertical component of the ball's velocity as it rises? The horizontal component? (Neglect air resistance.)

84. A block is at rest in positions A, B, and C. The push by the stick and pull by the string are almost, but not quite strong enough, to cause sliding. In which position is the normal force, not shown, greatest? Next greatest? Least?



85. Which is more likely to break—the ropes supporting a hammock stretched tightly between a pair of trees or the ropes supporting a hammock that sags more when you sit on it? Defend your answer.

86. Refer to Monkey Mo in Figure 3.32. If the rope makes an angle of 45° with the vertical, how will the magnitude of vectors S and mg compare?

87. Refer to Monkey Mo in Figure 3.32. What will be the magnitude of vector S if the rope that supports Mo is vertical?

3.6 Summary of Newton's Three Laws

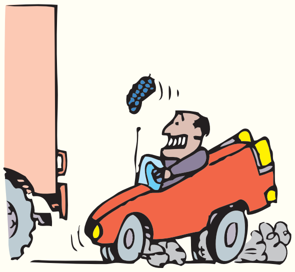
88. You are sitting across the table from a friend and skillfully pass a drink bottle to them by giving it just the right push so it slides across the table and comes to rest in front of them. Where in this situation is the force of friction on the bottle equal to zero? Where in this situation is the force on the bottle from you equal to zero?

89. Why does a rocket become progressively easier to accelerate as it travels through space? (Hint: About 90% of the mass of a newly fired rocket is fuel. Let $a = F/m$ guide your thinking.)

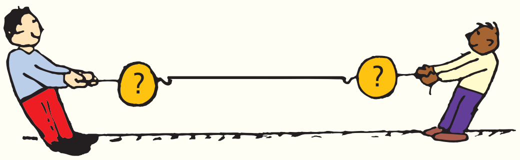
90. Which team wins in a tug-of-war: the team that pulls harder on the rope or the team that pushes harder against the floor?

THINK AND DISCUSS (EVALUATION)

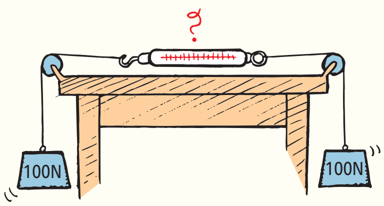
91. A boulder dropped from the roof of your school falls much more quickly than a Ping-Pong ball. Didn't Galileo say they would fall with equal accelerations? Explain.
92. Your friend says that when you step off a table, the Earth moves up to meet you. Discuss whether or not your friend is correct.
93. Is Newton's third law applied inappropriately by a friend who asserts that, when telling a lie, sooner or later it elicits another lie in reaction. Or that treating a friend harshly results in an equal harshness by that friend. What goes around comes around. Why or why not are these examples of Newton's third law?
94. The auto in the sketch moves forward as the brakes are applied. Your friend says that during this braking interval the auto's velocity and acceleration are in opposite directions. Do you agree or disagree?



95. Your instructor challenges you and your friend to each pull on a pair of scales attached to the ends of a horizontal rope, in tug-of-war fashion, so that the readings on the scales will differ. Can this be done? Explain.



96. Two 100-N weights are attached to a spring scale as shown. Does the scale read 0, 100, or 200 N, or does it give some other reading? (Hint: Would it read any differently if one of the ropes were tied to the wall instead of to the hanging 100-N weight?)



97. Each of the vertebrae forming your spine is separated from its neighbors by disks of elastic tissue. What happens, then, when you jump heavily on your feet from an elevated position? Can you think of a reason why you are a little taller in the morning than you are at the end of the day? (Hint: Think about how Newton's first law of motion applies in this case.)
98. A common saying is, "It's not the fall that hurts you; it's the sudden stop." Translate this statement into Newton's laws of motion.
99. Does a stick of dynamite contain force? Discuss and defend your answer.
100. Can a dog wag its tail without the tail in turn "wagging the dog"? (Consider a dog with a relatively massive tail.)
101. When air drag builds up to equal the combined weight of Dick and Jane in their tandem skydive, a terminal velocity of nearly 200 km/h is reached. How would this terminal velocity compare for each if they fell separately?

102. If you simultaneously drop a pair of tennis balls from the second story of a building, they will strike the ground at the same time. If one of the tennis balls is filled with lead pellets, will it fall faster and hit the ground first? Which of the two will encounter more air resistance? Defend your answers.
103. A friend says that if the acceleration of little Hudson (Figure 3.33) at the top of his path were zero, then Hudson would remain at rest there. Since Hudson doesn't remain at rest, acceleration cannot be zero. Do you agree with your friend? Defend your answer.
104. A boxer hits his equal-weight opponent with his most forceful punch. If the same punch is delivered to a lighter opponent, would the punch be more forceful, or less forceful? Defend your answer in terms of Figure 3.14.
105. Using Figure 3.14 as a guide, do you agree with a friend who reasons that a boxer should be able to deliver more forceful punches to a boxer heavier than himself? Defend your answer.

READINESS ASSURANCE TEST (RAT)

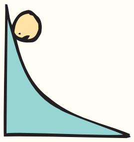
If you have a good handle on this chapter, you should be able to score at least 7 out of 10 on this RAT. If you score less than 7, you need to study further before moving on.

Choose the BEST answer to each of the following:

1. If an object moves along a curved path, then it must be
   (a) accelerating.
   (b) acted on by a force.
   (c) both of these
   (d) none of these

2. As mass is added to a cart pushed by a constant force, its acceleration
   (a) increases.
   (b) decreases.
   (c) remains constant.
   (d) gradually reaches zero.

3. A ball rolls down a curved ramp as shown. As its speed increases, its rate of gaining speed
   (a) increases.
   (b) decreases.
   (c) remains unchanged.
   (d) none of these



4. A heavy rock and a light rock in free fall (zero air resistance) have the same acceleration. The *reason* the heavy rock doesn't have a greater acceleration is that the
   (a) force due to gravity is the same on each.
   (b) air resistance is always zero in free fall.
   (c) inertia of both rocks is the same for both.
   (d) ratio of force to mass is the same for both.

5. You drop a pillow off the edge of the tallest building on your campus. While the pillow falls, its speed
   (a) and acceleration both increase.
   (b) increases and its acceleration decreases.
   (c) and acceleration both decrease.
   (d) decreases and its acceleration increases.

6. A karate chop delivers a force of 3000 N to a board that breaks. The force that the board exerts on the hand during this event is
   (a) less than 3000 N.
   (b) 3000 N.
   (c) greater than 3000 N.
   (d) More information is needed.

7. Two parachutists, a heavy person and a light person, jumping from the same altitude have the same size parachute. Who reaches the ground first?
   (a) The heavy person.
   (b) The light person.
   (c) They reach the ground at the same time.
   (d) More information is needed.

8. The amount of air resistance that acts on a wingsuit flyer (and a flying squirrel) depends on the flyer's
   (a) area.
   (b) speed.
   (c) area and speed.
   (d) acceleration.

9. When you push an ice cube with a 0.5-N force, the ice cube
   (a) accelerates at 10 m/s^2.
   (b) resists being pushed with its own 0.5-N force.
   (c) will likely not move.
   (d) pushes on you with a 0.5-N force.

10. The force that propels a rocket is provided by
   (a) gravity.
   (b) Newton's laws of motion.
   (c) its exhaust gases.
   (d) the atmosphere against which the rocket pushes.

Answers to RAT

1. c, 2. b, 3. b, 4. d, 5. b, 6. b, 7. a, 8. c, 9. d, 10. c

CHAPTER FOUR

4

Momentum and Energy

ANDREA IS intrigued with the swinging-balls apparatus, which is popular in physics classrooms when demonstrating momentum—a property of all moving things. She lifts and releases two balls and sees that two balls pop out the other side with the same speed. Aha! Momentum of the dropped balls nicely transfers equally to momentum of the popped balls. We say that momentum is conserved, but momentum would also be conserved if one ball popped out at twice the speed. Why this never happens involves another concept: energy. Moving things with momentum also have energy of motion: kinetic energy. Things at rest have another kind of energy: potential energy. And all objects, whether at rest or moving, have an energy of being: $E = mc^2$. This chapter is about two of the most central concepts in physics: momentum and energy.