McGraw-Hill Education

Physics

United Arab Emirates Edition

GRADE 9 ADVANCED

VOLUME 1

McGraw Hill Education

Project: McGraw-Hill Education United Arab Emirates Edition Advanced Science Grade 9 Year 3 Vol 1 Student Edition – Physics
All Chapters from Glencoe Physics: Principles & Problems, Student Edition ©2017

COVER: Vadym Andrushchenko/Shutterstock

mheducation.com/prek-12

Printed in the United Arab Emirates.

ISBN: 978-1-52-686753-7 *(Student Edition)*
MHID: 1-52-686753-2 *(Student Edition)*
ISBN: 978-1-52-686754-4 *(Teacher Edition)*
MHID: 1-52-686754-0 *(Teacher Edition)*

1 2 3 4 5 6 7 8 9 XXX 22 21 20 19 18 17

ePub Edition

ISBN: 978-1-52-686758-2 *(Student Edition)*
MHID: 1-52-686758-3 *(Student Edition)*
ISBN: 978-1-52-686759-9 *(Teacher Edition)*
MHID: 1-52-686759-1 *(Teacher Edition)*

"Extensive knowledge and modern science must be acquired. The educational process we see today is in an ongoing and escalating challenge which requires hard work.
We succeeded in entering the third millennium, while we are more confident in ourselves."

H.H. Sheikh Khalifa Bin Zayed Al Nahyan

President of the United Arab Emirates

CONTENTS IN BRIEF

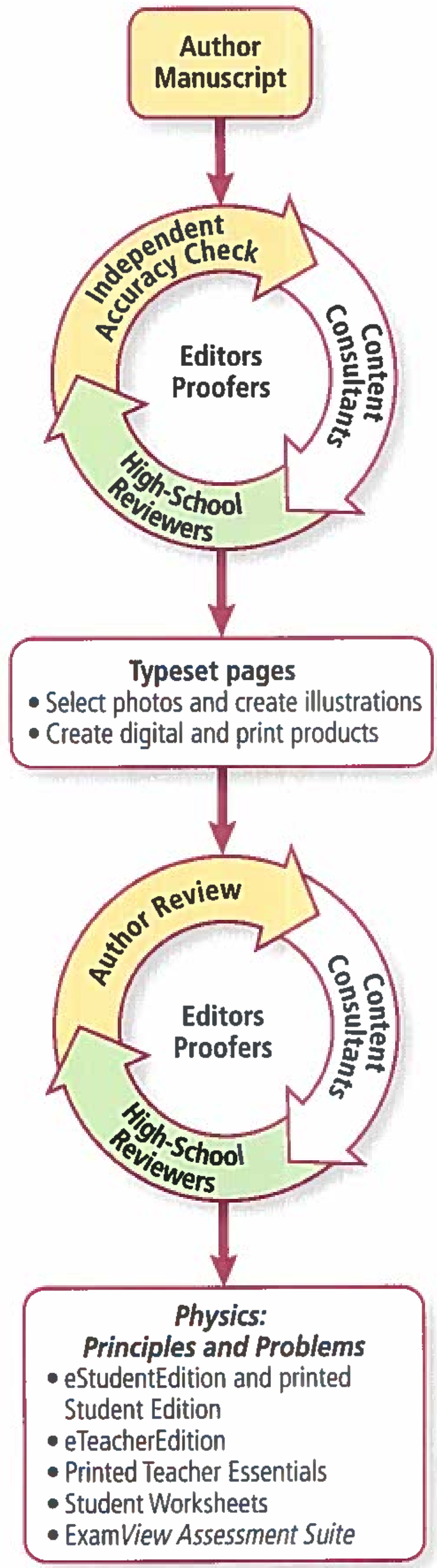
A² DEVELOPMENT PROCESS

Why A²?

Accuracy Assurance is central to McGraw-Hill's commitment to high-quality, learner-oriented, real-world, and error-free products. Also at the heart of our A² Development Process is a commitment to make the text **Accessible** and **Approachable** for both students and teachers. A collaboration among authors, content editors, academic advisors, and classroom teachers, the A² Development Process provides opportunities for continual improvement through customer feedback and thorough content review.

The A² Development Process begins with a review of the previous edition and a look forward to state and national standards. The authors for *Physics: Principles and Problems* combine expertise in teacher training and education with a mastery of physics content knowledge. As manuscript is created and edited, consultants review the accuracy of the content while our Teacher Advisory Board members examine the program from the points of view of both teacher and student. Student labs, technology resources, and teacher demonstrations are reviewed for both accuracy of content and safety. As design elements are applied, chapter text is again reviewed, as are photos and diagrams.

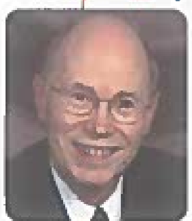
Throughout the life of the program, McGraw-Hill continues to troubleshoot and incorporate improvements. Our goal is to deliver to you a program that has been created, refined, tested, and validated as a successful tool for your continued **Academic Achievement.**



Authors

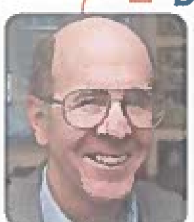
The authors of *Physics: Principles and Problems* used their physics content knowledge and teaching expertise to craft manuscript that is accessible, accurate, and geared toward student achievement.

Paul W. Zitzewitz, lead author



is an emeritus professor of physics and of science education at the University of Michigan–Dearborn. He received his BA from Carleton College and his MA and PhD from Harvard University, all in physics. Dr. Zitzewitz taught physics to undergraduates at the University of Michigan-Dearborn for 36 years and, as an active experimenter in the field of atomic physics, published more than 50 research papers. He was named a Fellow of the American Physical Society for his contributions to physics and science education for high school and middle school teachers and students. He is now treasurer of the American Association of Physics Teachers and has been the president of the Michigan Section of the American Association of Physics Teachers and chair of the American Physical Society's Forum on Education.

D. G. Haase



is an Alumni Distinguished Undergraduate Professor of Physics at North Carolina State University. He earned a BA in physics and mathematics at Rice University and an MA and a PhD in physics at Duke University, where he was a J.B. Duke Fellow. He has been an active researcher in experimental low-temperature and nuclear physics. He teaches undergraduate and graduate physics courses and has worked many years in K–12 teacher training. He was the founding director of The Science House at NC State, a science-math learning center that leads teacher training and student programs across North Carolina. He has co-authored over 100 papers in experimental physics and in science education. He is a Fellow of the American Physical Society. He received the Alexander Holladay Medal for Excellence, NC State University; was awarded the Pegram Medal for Physics Teaching Excellence; and was chosen 1990 Professor of the Year in the state of North Carolina by the Council for the Advancement and Support of Education (CASE).

Kathleen A. Harper

is an auxiliary faculty member in the Engineering Education Innovation Center at The Ohio State University. She received her MS in physics and BS in electrical engineering and applied physics from Case Western Reserve University and her PhD in physics from The Ohio State University. She has taught introductory physics, astronomy, and engineering courses to undergraduates for nearly 20 years and has been instrumental in offering Modeling Instruction workshops to in-service high school teachers, both in Ohio and nationwide. Her research interests include the teaching and learning of problem-solving skills and the development of alternative problem formats. She is active in AAPT, both on the local and national levels, often presenting talks and workshops on teaching problem solving. Additionally, she is co-editor of a selection of articles available through AAPT's Compadre portal entitled, "Getting Started in Physics Education Research."

Teacher Advisory Board

The Teacher Advisory Board gave the editorial staff and design team feedback on the content and design of both the Student Edition and the Teacher Essentials. They were instrumental in providing valuable input toward the development of the 2013 edition of *Physics: Principles and Problems.* We thank these teachers for their hard work and creative suggestions.

Janet Adams
Physics Teacher
Mars Area High School
Mars, PA

Craig Dowler
Physics Teacher
West Genesee High School
Camillus, NY

C. Foust, M.S.
Physics Teacher
Hermitage High School
Richmond, VA

Ryan Hall
Physics Teacher
Palatine High School
Palatine, IL

Stan Hutto
Physics Teacher
Alamo Heights High School
San Antonio, TX

Richard A. Lines, Jr.
Physics Teacher
Garland High School
Garland, TX

Nikki Malatin
Physics Teacher
West Caldwell High School
Lenoir, NC

Jennifer McDonnell
Coordinator of Math and Science
School District U-46
Elgin, IL

Jeremy Paschke
Physics Teacher
York High School
Elmhurst, IL

Don Pata
Physics Teacher
Grosse Pointe North High School
Grosse Pointe Woods, MI

Charles Payne
Physics Teacher
Northern High School
Durham, NC

Content Consultants

Content consultants each reviewed selected chapters of *Physics: Principles and Problems* for content accuracy and clarity.

Dr. Solomon Bililign, PhD
Professor of Physics
Director: NOAA-ISET Center
North Carolina A&T State University
Greensboro, NC

Ruth Howes
Professor Emerita of Physics and Astronomy
Ball State University
Muncie, IN

Dr. Keith H. Jackson
Professor and Chair of Department of Physics
Morgan State University
Baltimore, MD

Kathleen Johnston
Associate Professor of Physics
Louisiana Tech University
Ruston, LA

Dr. Monika Kress
Associate Professor
Department of Physics & Astronomy
San Jose State University
San Jose, CA

Jorge Lopez
Professor
University of Texas at El Paso
El Paso, TX

Dr. Ramon E. Lopez
Department of Physics
University of Texas at Arlington
Arlington, TX

Albert J. Osei
Professor of Physics
Oakwood University
Huntsville, AL

Charles Ruggiero
Visiting Assistant Professor
Allegheny College
Meadeville, PA

Toni Sauncy
Associate Professor of Physics
Angelo State University
San Angelo, TX

Sally Seidel
Professor of Physics
University of New Mexico
Albuquerque, NM

Contributing Writers

Additional science writers added feature content, teacher materials, assessment, and laboratory investigations.

Molly Wetterschneider
Austin, TX

Steve Whitt
Columbus, OH

Safety Consultant

The safety consultant reviewed labs and lab materials for safety and implementation.

Kenneth Russell Roy, PhD
Director of Science and Safety
Glastonbury Public Schools
Glastonbury, CT

Teacher Reviewers

Each teacher reviewed selected chapters of *Physics: Principles and Problems* and provided feedback and suggestions regarding the effectiveness of the instruction.

J. S. Bonanno
Physics Teacher
Red Creek Central School
Red Creek, NY

Beverly Trina Cannon
Physics Teacher
Highland Park High School
Dallas TX

Katharine Chole
Physics Teacher
Villa Duchesne School
St. Louis, MO

Cheryl Rawlins Cowley
Lead Physics Teacher
Sherman High School
Sherman, TX

B. Wayne Davis
Physics Teacher (retired)
Henrico County Public Schools
Richmond, VA

Nina Morley Daye
Physics Teacher
Orange High School
Hillsborough, NC

D. Eberst
Physics Teacher
Bishop Watterson High School
Columbus, OH

Terry Elmer
Physics Teacher
Red Creek Central School
Red Creek, NY

Michael Fetsko
Physics Teacher
Mills E. Godwin High School
Henrico, VA

C. Foust, M.S.
Physics Teacher
Hermitage High School
Richmond, VA

Elaine Gwinn
Physics Teacher
Shenandoah High School
Middletown, IN

Janie Head
Physics Teacher
Foster High School
Richmond, TX

Stan Hutto
Physics Teacher
Alamo Heights High School
San Antonio, TX

Emily James
Physics Teacher
Brewster Academy
Wolfeboro, NH

Dr. C. D. Jones
School of Applied and Engineering Physics
Cornell University
Ithaca, NY

Dr. Mike Papadimitriou
Headmaster
Academy for Science and Health Professions
Conroe, TX

Julia Quaintance
Physics Teacher
Morgan Local High School
McConnelsville, OH

Stephen Rea
University of Michigan, Dearborn
Plymouth, MI

Patricia Rollison
Physics Teacher
St. Gertrude High School
Richmond, VA

Patrick Slattery
Physics Teacher
South Elgin High School
South Elgin, IL

James Stankevitz
Physics Teacher
Wheaton Warrenville South High School
Wheaton, IL

Jason Sterlace
Physics Teacher
J.R. Tucker High School
Henrico, VA

C. White
Physics Teacher
Seneca High School
Seneca, SC

Michael Young, MS
ACT, Inc.
Iowa City, IA

Tom Young
Physics Teacher
Whitehouse High School
Whitehouse, TX

TABLE OF CONTENTS

Each chapter begins with a **LaunchLAB,** an introductory laboratory investigation designed to introduce the concepts in that chapter. **MiniLABs** are short investigations that can improve your understanding of physics content. You will also find one or more **PhysicsLABs** in each chapter, providing opportunities for more in-depth investigations.

CHAPTER
2

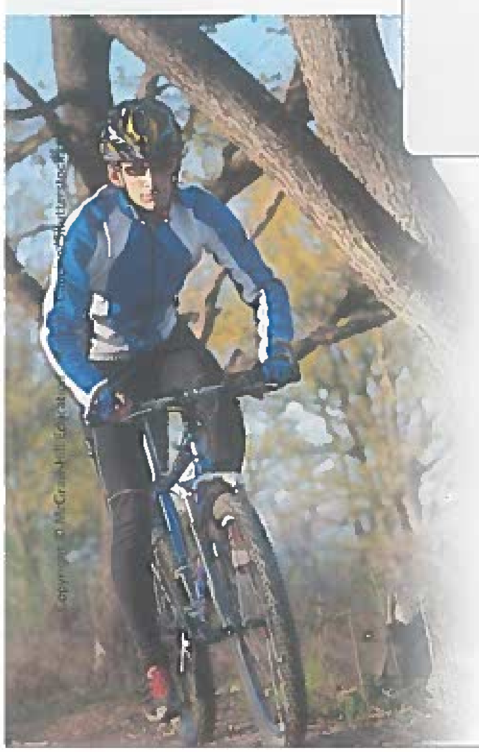
Representing Motion 32

LaunchLAB Toy Car Race
MiniLABs Vector Models
Velocity Vectors
PhysicsLABs Motion Diagrams
Constant Speed
Measure Velocity

CHAPTER
3

Accelerated Motion 58

LaunchLAB Graphing Motion
MiniLABs Steel Ball Race
Free Fall
PhysicsLABs Acceleration
Tossed-Ball Motion
Measuring Acceleration
Free-Fall Acceleration



CHAPTER 4

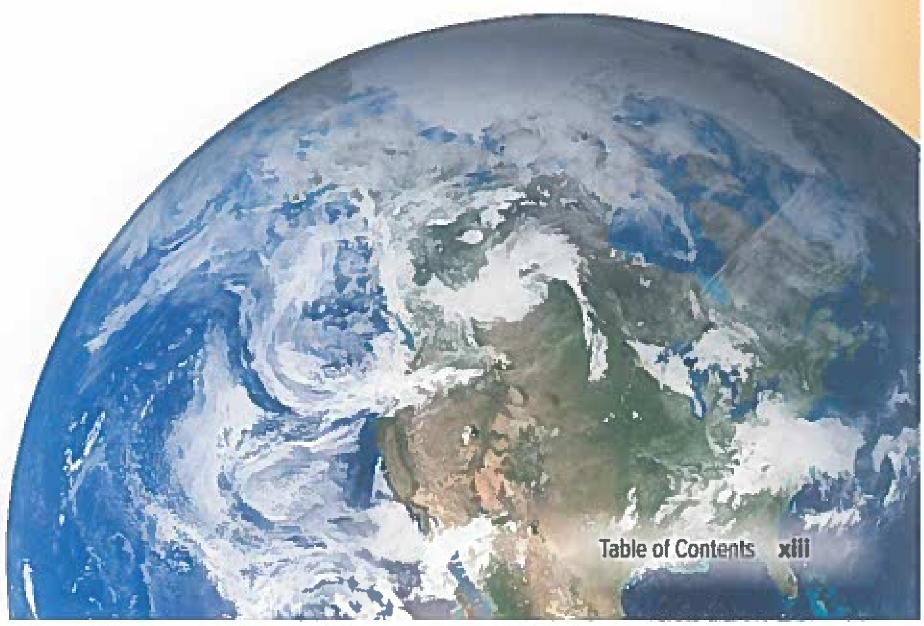
CHAPTER 5

CHAPTER 6

Motion in Two Dimensions

CHAPTER 7

Gravitation



CHAPTER 8

CHAPTER 9

CHAPTER 10

States of Matter

LaunchLAb Measuring buoyancy
MiniLABs Pressure
Jumpers
PhysicsLABs Evaporative Cooling
Under Pressure
The Buoyant Force of Water
The First Forensic Scientist

STUDENT RESOURCES

Reference Tables R-1

REAL-WORLD PHYSICS

Physics: Principles and Problems **makes physics real. Throughout the text, find personal physics connections, surprising examples of physics in careers, and how physicists are engaged in cutting-edge science research.**

SECTION 1

Momentum and forces

PHYSICS 4 YOU Lacrosse players wear helmets and padding to protect themselves from flying balls. Lacrosse balls are not very massive (about 145 g), but players can hurl them at speeds over 40 m/s. Why are lacrosse balls so dangerous?

MAINIDEA

An object's momentum is equal to its mass multiplied by its velocity.

Essential Questions

- What is impulse?
- What is momentum?
- What is angular momentum?

Review Vocabulary

angular velocity the angular displacement of an object divided by the time needed to make the displacement

New Vocabulary

impulse

Impulse-Momentum Theorem

It can be exciting to watch a baseball player hit a home run. The pitcher hurls the baseball toward the plate. The batter swings, and the ball recoils from the impact. Before the collision, the baseball moves toward the bat. During the collision, the ball is squashed against the bat. After the collision, the ball moves at a high velocity away from the bat, and the bat continues along its path but at a slower velocity.

According to Newton's second law of motion, the force from the bat changed the ball's velocity. This force changes over time, as shown in Figure 1. Just after contact, the ball is squeezed, and the force increases to a maximum more than 10,000 times the weight of the ball. The ball then recovers its shape and rebounds from the bat. The force on the ball rapidly returns to zero. This whole event takes place within about ... How can you calculate the change in velocity of the baseball?

Impulse Newton's second law of motion ($F = ma$) can be rewritten in terms of the change in velocity divided by the time for that change.

$$F = ma = m\left(\frac{\Delta v}{\Delta t}\right)$$

PHYSICS
4 YOU
at the beginning of each section tells you how the physics you are about to learn relates to your life.

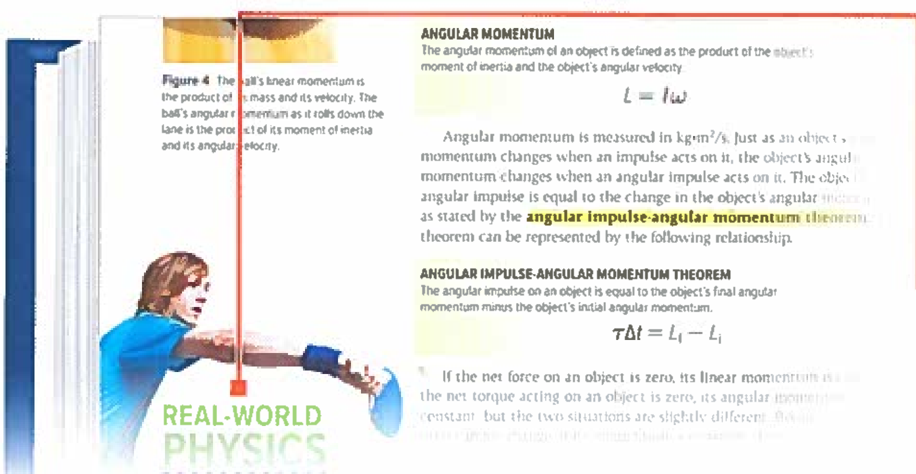


Figure 4 The ball's linear momentum is the product of its mass and its velocity. The ball's angular momentum as it rolls down the lane is the product of its moment of inertia and its angular velocity.

REAL-WORLD PHYSICS

ANGULAR MOMENTUM

The angular momentum of an object is defined as the product of the object's moment of inertia and the object's angular velocity.

$$L = I\omega$$

Angular momentum is measured in $kg{\cdot}m^2/s$. Just as an object's linear momentum changes when an impulse acts on it, the object's angular momentum changes when an angular impulse acts on it. The object's angular impulse is equal to the change in the object's angular momentum, as stated by the **angular impulse-angular momentum theorem**. The theorem can be represented by the following relationship.

ANGULAR IMPULSE-ANGULAR MOMENTUM THEOREM

The angular impulse on an object is equal to the object's final angular momentum minus the object's initial angular momentum.

$$\tau\Delta t = L_f - L_i$$

If the net force on an object is zero, its linear momentum is constant. If the net torque acting on an object is zero, its angular momentum is constant, but the two situations are slightly different.

Throughout the book,
REAL-WORLD
PHYSICS
demonstrates how the physics you are learning applies to the world around you.

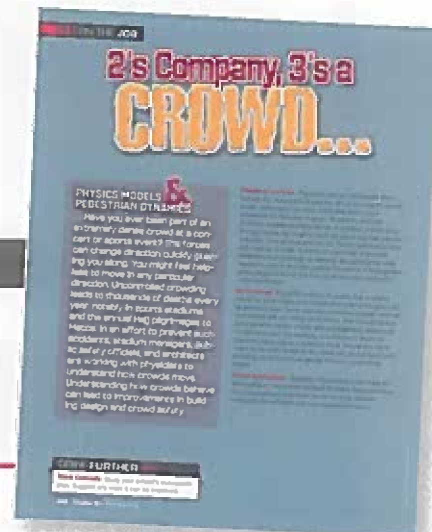
End-of-chapter features highlight physics in careers, how it connects to the real world, and what today's physicists are doing to learn more about our universe.

PHYSICS THAT'S ENTERTAINMENT!

How does physics apply to entertainment? You might be surprised! Explore the physics of special effects, 3-D movies, theater acoustics, and more!

A CLOSER LOOK

Take "A Closer Look" at a number of physics topics and discover the story behind some of the most interesting physics applications!



ON THE JOB

You might be surprised to discover the physics that can be found in many different careers. Explore jobs that unexpectedly rely on an understanding of physics.

FRONTIERS IN PHYSICS

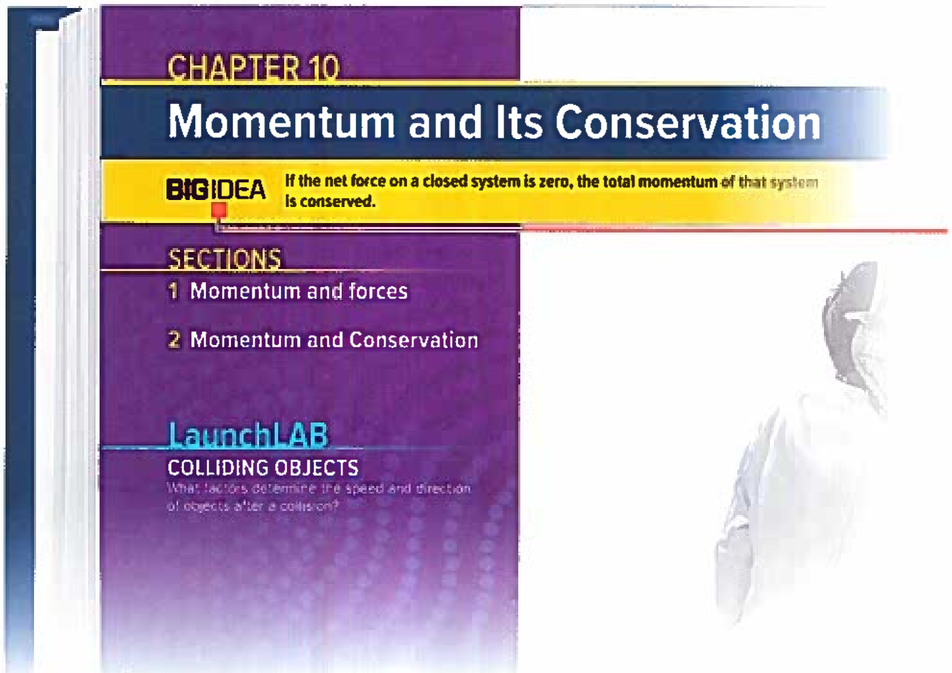
What is being discovered in today's physics research? Explore the work being done by today's physicists.

HOW IT WORKS

Explore the physics of everyday objects or natural phenomena by discovering how they "work."

UNDERSTANDING PHYSICS

At the start of each chapter, you will see the **BIGIDEA** that will help you understand how what you are about to investigate fits into the big picture of science.


CHAPTER 10

Momentum and Its Conservation

BIGIDEA If the net force on a closed system is zero, the total momentum of that system is conserved.

SECTIONS

1 Momentum and forces

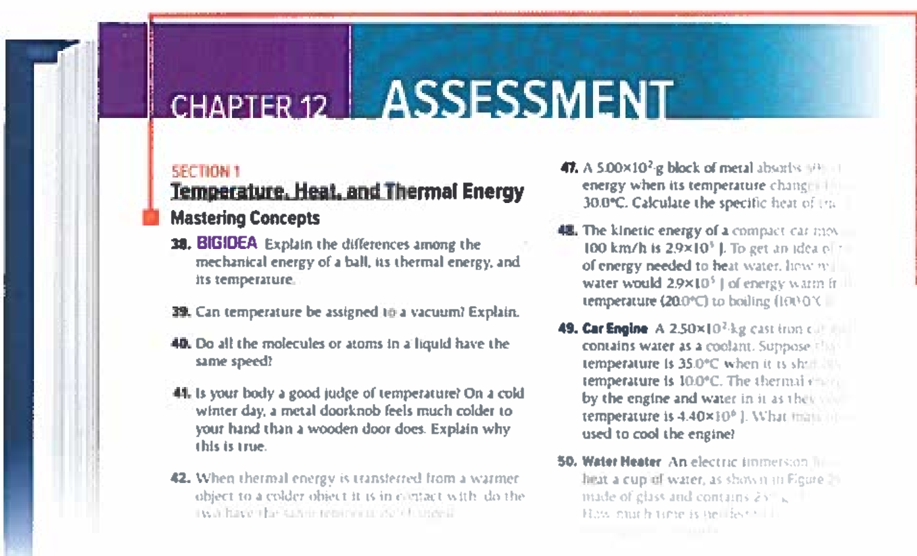
2 Momentum and Conservation

LaunchLAB

COLLIDING OBJECTS

What factors determine the speed and direction of objects after a collision?

The **BIGIDEA** is the focus of the chapter. By reading the text, doing labs and answering Practice Problems, Section Reviews, and Chapter Assessments, you will build an in-depth understanding of this idea.


CHAPTER 12 ASSESSMENT

SECTION 1

Temperature, Heat, and Thermal Energy

Mastering Concepts

38. BIGIDEA Explain the differences among the mechanical energy of a ball, its thermal energy, and its temperature.

39. Can temperature be assigned to a vacuum? Explain.

40. Do all the molecules or atoms in a liquid have the same speed?

41. Is your body a good judge of temperature? On a cold winter day, a metal doorknob feels much colder to your hand than a wooden door does. Explain why this is true.

42. When thermal energy is transferred from a warmer object to a colder object it is in contact with, do the two have the same temperature change?

47. A 5.00×10^2-g block of metal absorbs ... energy when its temperature changes ... 30.0°C. Calculate the specific heat of the ...

48. The kinetic energy of a compact car moving at 100 km/h is 2.9×10^5 J. To get an idea of the amount of energy needed to heat water, how much water would 2.9×10^5 J of energy warm from room temperature (20.0°C) to boiling (100.0°C)?

49. **Car Engine** A 2.50×10^2-kg cast-iron car engine contains water as a coolant. Suppose the engine's temperature is 35.0°C when it is shut off ... temperature is 10.0°C. The thermal energy ... by the engine and water in it as they ... temperature is 4.40×10^6 J. What mass ... used to cool the engine?

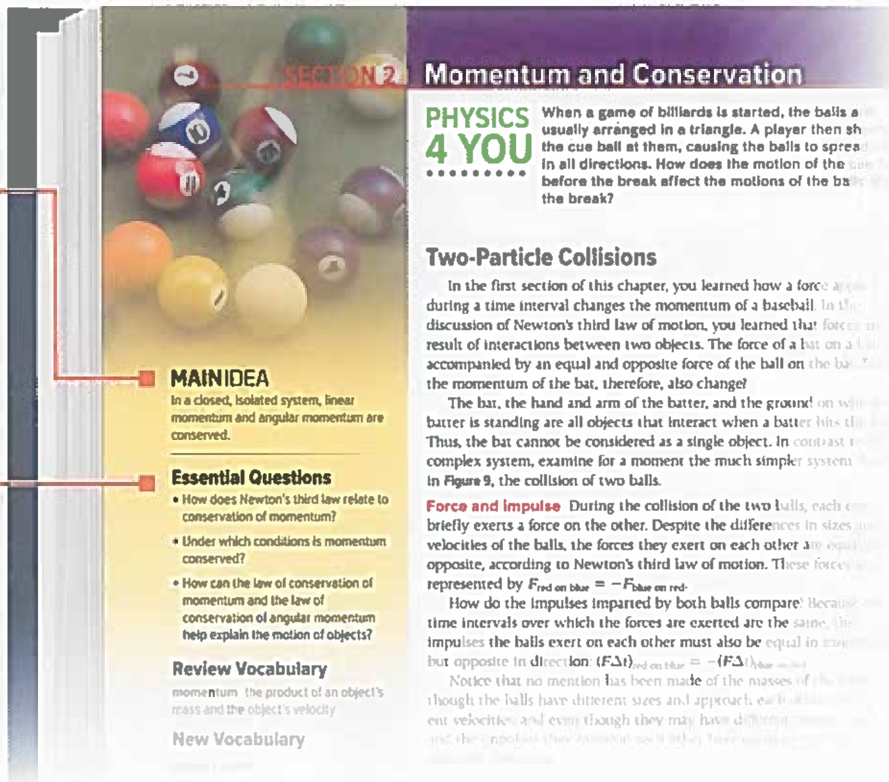
50. **Water Heater** An electric immersion heater ... heat a cup of water, as shown in Figure 2... made of glass and contains ... How much time is needed ...

In the Chapter Assessment, you will find a question or problem that will help you evaluate your understanding of the **BIGIDEA**.

At the start of each section, you will find a Reading Preview that summarizes what you will learn while exploring the section.

The **MAINIDEA** is the core concept covered in the section. Together, the Main Ideas from all the sections in the chapter support the chapter's Big Idea.

Essential Questions reflect the important objectives of the section. Together, an understanding of these questions will lead toward understanding the section's Main Idea.


SECTION 2 Momentum and Conservation

PHYSICS 4 YOU When a game of billiards is started, the balls a usually arranged in a triangle. A player then sh the cue ball at them, causing the balls to sprea in all directions. How does the motion of the before the break affect the motions of the ba the break?

MAINIDEA
In a closed, isolated system, linear momentum and angular momentum are conserved.

Essential Questions
- How does Newton's third law relate to conservation of momentum?
- Under which conditions is momentum conserved?
- How can the law of conservation of momentum and the law of conservation of angular momentum help explain the motion of objects?

Review Vocabulary
momentum the product of an object's mass and the object's velocity

New Vocabulary

Two-Particle Collisions

In the first section of this chapter, you learned how a force during a time interval changes the momentum of a baseball. In the discussion of Newton's third law of motion, you learned that result of interactions between two objects. The force of a bat on a accompanied by an equal and opposite force of the ball on the momentum of the bat, therefore, also change?

The bat, the hand and arm of the batter, and the ground batter is standing are all objects that interact when a batter Thus, the bat cannot be considered as a single object. In complex system, examine for a moment the much simpler in Figure 9, the collision of two balls.

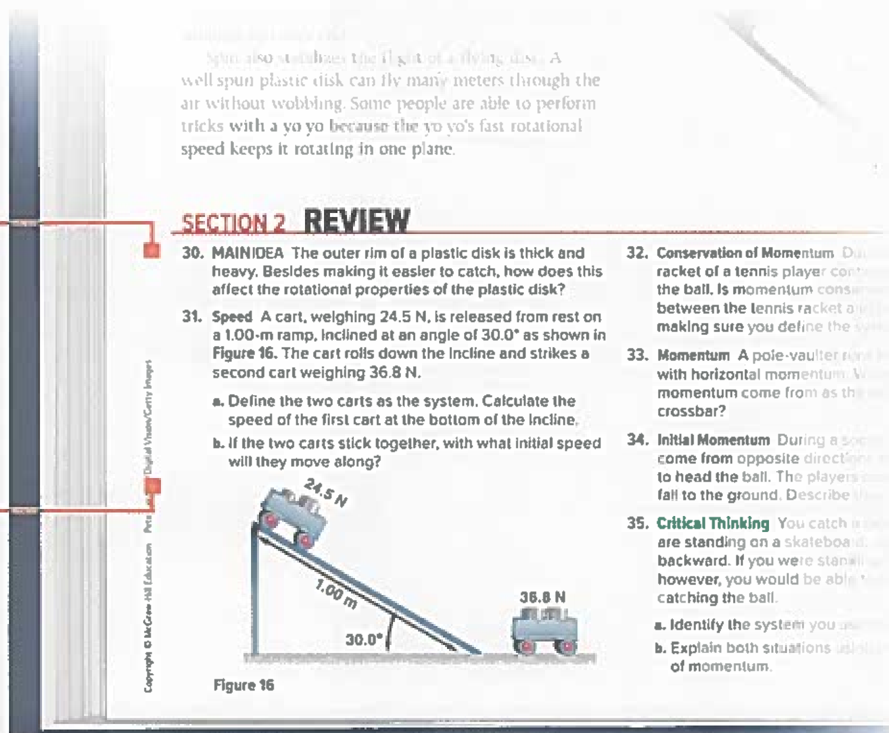
Force and Impulse During the collision of the two balls, each briefly exerts a force on the other. Despite the differences in sizes velocities of the balls, the forces they exert on each other are opposite, according to Newton's third law of motion. These forces represented by $F_{\text{red on blue}} = -F_{\text{blue on red}}$.

How do the impulses imparted by both balls compare? time intervals over which the forces are exerted are the same, impulses the balls exert on each other must also be equal in but opposite in direction: $(F\Delta t)_{\text{red on blue}} = -(F\Delta t)_{\text{blue on red}}$

Notice that no mention has been made of the masses of though the balls have different sizes and approach each ent velocities and even though they may have different

In the Section Review, you will find a question that will help you to assess your understanding of the section's **MAINIDEA**.

The remaining questions assess your understanding of the **Essential Questions**


Spin also stabilizes the flight of a flying disk. A well spun plastic disk can fly many meters through the air without wobbling. Some people are able to perform tricks with a yo-yo because the yo-yo's fast rotational speed keeps it rotating in one plane.

SECTION 2 REVIEW

30. MAINIDEA The outer rim of a plastic disk is thick and heavy. Besides making it easier to catch, how does this affect the rotational properties of the plastic disk?

31. Speed A cart, weighing 24.5 N, is released from rest on a 1.00-m ramp, inclined at an angle of 30.0° as shown in Figure 16. The cart rolls down the incline and strikes a second cart weighing 36.8 N.
a. Define the two carts as the system. Calculate the speed of the first cart at the bottom of the incline.
b. If the two carts stick together, with what initial speed will they move along?

24.5 N
1.00 m
30.0°
36.8 N

Figure 16

32. Conservation of Momentum racket of a tennis player the ball. Is momentum between the tennis racket making sure you define the

33. Momentum A pole-vaulter with horizontal momentum momentum come from as crossbar?

34. Initial Momentum During a come from opposite to head the ball. The players fall to the ground. Describe

35. Critical Thinking You catch are standing on a skateboard backward. If you were however, you would be able catching the ball.
a. Identify the system you
b. Explain both situations of momentum.

Copyright © McGraw-Hill Education Peter Digital Vision/Getty Images

CHAPTER 1

A Physics Toolkit

BIGIDEA **Physicists use scientific methods to investigate energy and matter.**

SECTIONS

1 Methods of Science

2 Mathematics and Physics

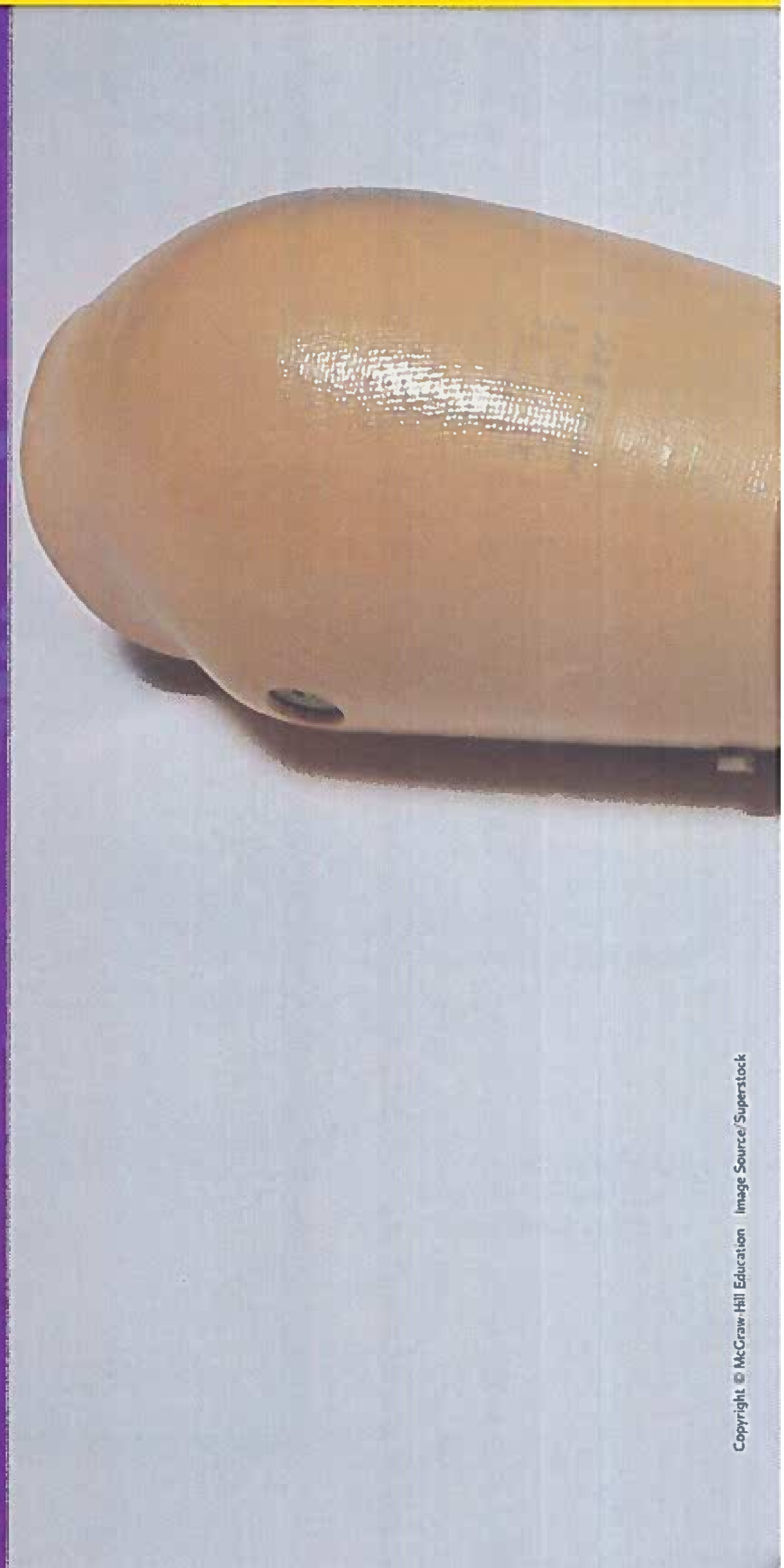
3 Measurement

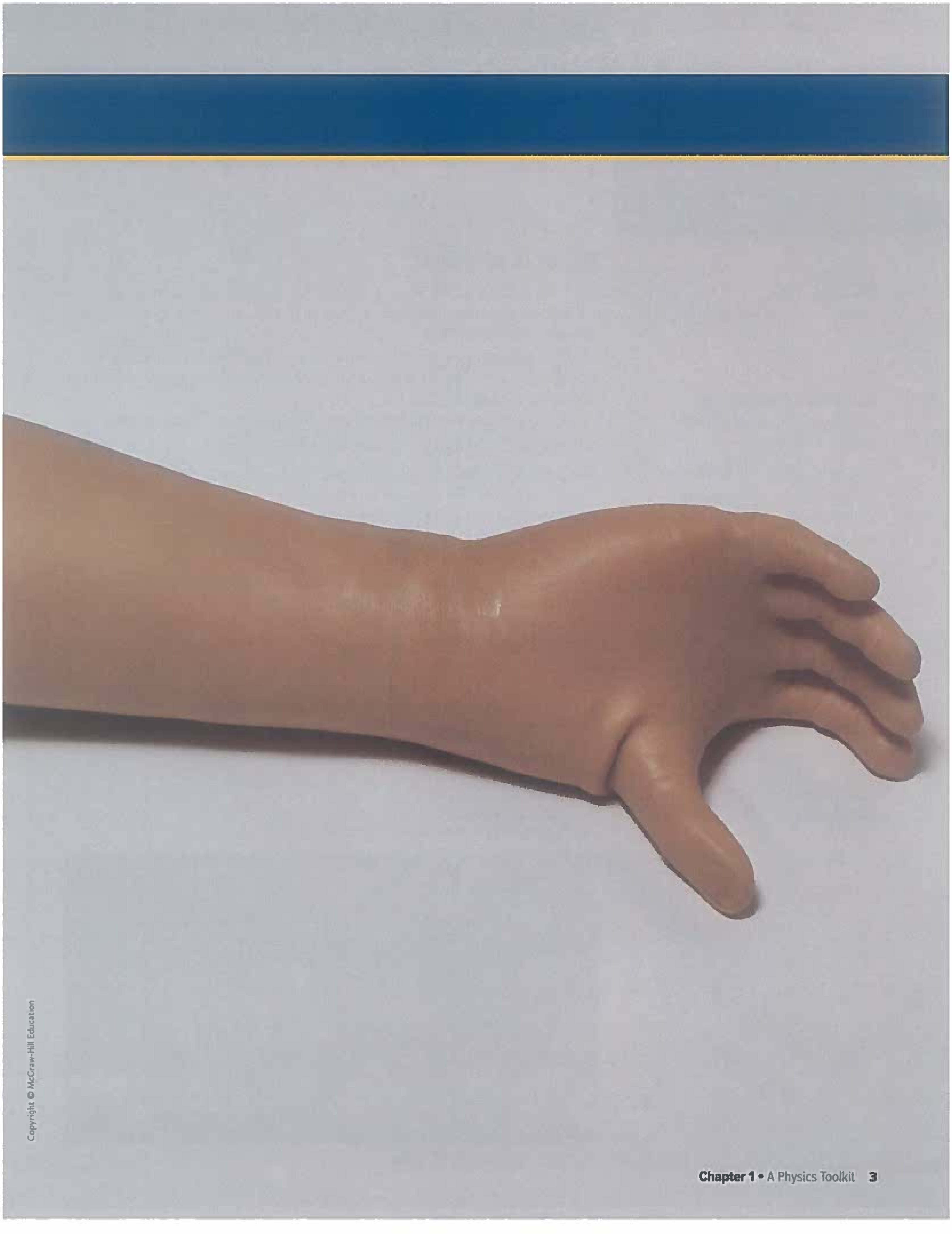
4 Graphing Data

LaunchLAB

MASS AND FALLING OBJECTS

Does mass affect the rate at which an object falls?





SECTION 1

Methods of Science

PHYSICS 4 YOU **Think about what the world would be like if we still thought Earth was flat or if we didn't have indoor plumbing or electricity. Science helps us learn about the natural world and improve our lives.**

MAINIDEA

Scientific investigations do not always proceed with identical steps but do contain similar methods.

Essential Questions

- What are the characteristics of scientific methods?
- Why do scientists use models?
- What is the difference between a scientific theory and a scientific law?
- What are some limitations of science?

Review Vocabulary

control the standard by which test results in an experiment can be compared

New Vocabulary

physics
scientific methods
hypothesis
model
scientific theory
scientific law

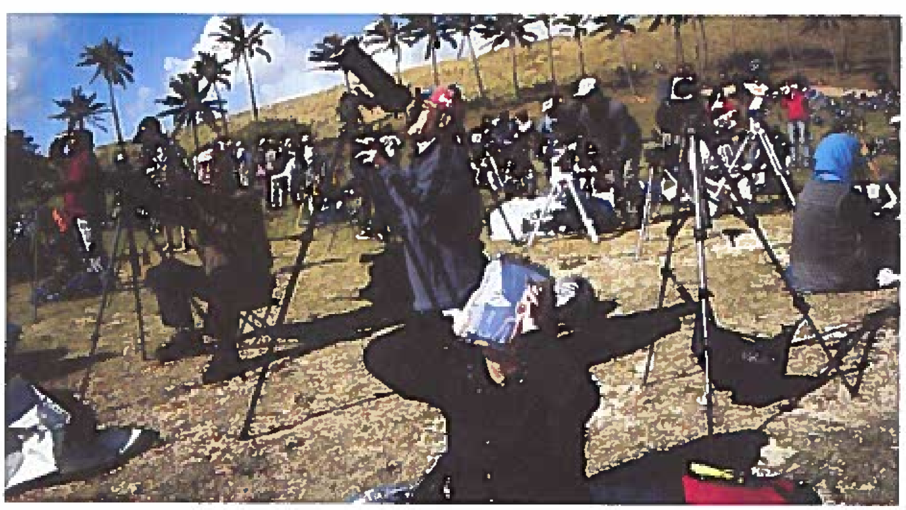
What is physics?

Science is not just a subject in school. It is a method for studying the natural world. After all, science comes from the Latin word *scientia*, which means "knowledge." Science is a process based on inquiry that helps develop explanations about events in nature. **Physics** is a branch of science that involves the study of the physical world: energy, matter, and how they are related.

When you see the word *physics* you might picture a chalkboard full of formulas and mathematics: $E = mc^2$, $I = \frac{V}{R}$, $x = \left(\frac{1}{2}\right)at^2 + v_0t + x_0$. Maybe you picture scientists in white lab coats or well-known figures such as Marie Curie and Albert Einstein. Alternatively, you might think of the many modern technologies created with physics, such as weather satellites, laptop computers, or lasers. Physicists investigate the motions of electrons and rockets, the energy in sound waves and electric circuits, the structure of the proton and of the universe. The goal of this course is to help you better understand the physical world.

People who study physics go on to many different careers. Some become scientists at universities and colleges, at industries, or in research institutes. Others go into related fields, such as engineering, computer science, teaching, medicine, or astronomy, as shown in **Figure 1.** Still others use the problem-solving skills of physics to work in finance, construction, or other very different disciplines. In the last 50 years, research in the field of physics has led to many new technologies, including satellite-based communications and high-speed microscanners used to detect disease.

Figure 1 Physicists may choose from a variety of careers.



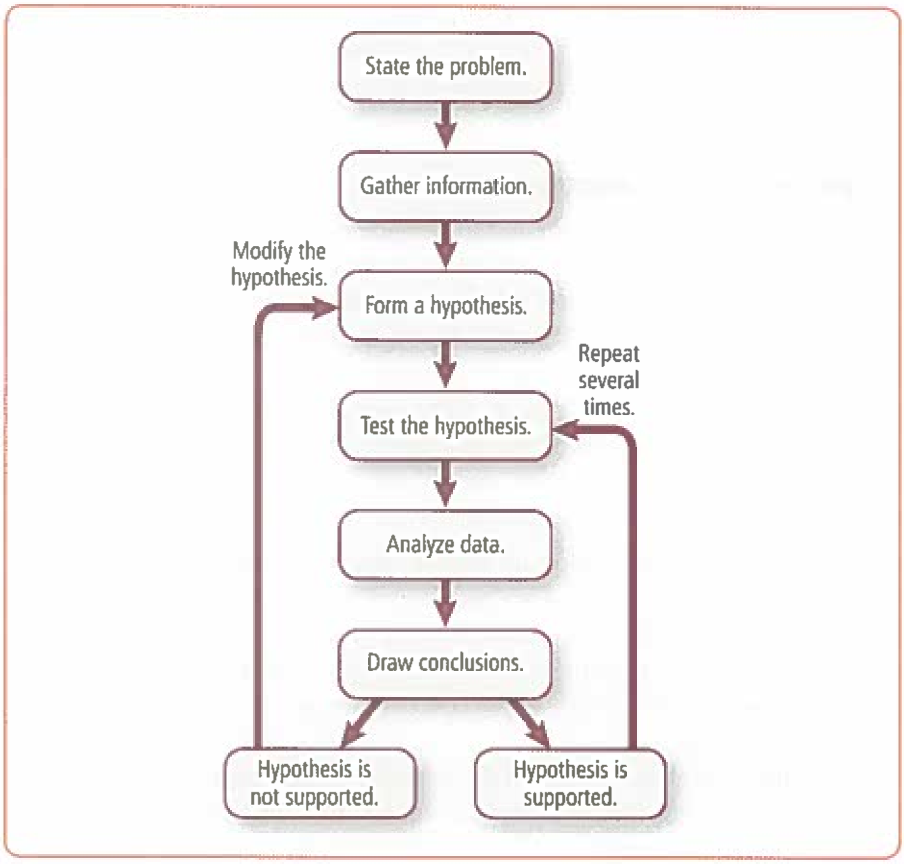


Figure 2 The series of procedures shown here is one way to use scientific methods to solve a problem.

Scientific Methods

Although physicists do not always follow a rigid set of steps, investigations often follow similar patterns. These patterns of investigation procedures are called **scientific methods.** Common steps found in scientific methods are shown in **Figure 2.** Depending on the particular investigation, a scientist might add new steps, repeat some steps, or skip steps altogether.

State the problem When you begin an investigation, you should state what you are going to investigate. Many investigations begin when someone observes an event in nature and wonders why or how it occurs. The question of "why" or "how" is the problem.

Scientists once posed questions about why objects fall to Earth, what causes day and night, and how to generate electricity for daily use. Many times a statement of a problem arises when an investigation is complete and its results lead to new questions. For example, once scientists understood why we experience day and night, they wanted to know why Earth rotates.

Sometimes a new question is posed during the course of an investigation. In the 1940s, researcher Percy Spencer was trying to answer the question of how to mass-produce the magnetron tubes used in radar systems. When he stood in front of an operating magnetron, which produces microwaves, a candy bar in his pocket melted. The new question of how the magnetron was cooking food was then asked.

Research and gather information Before beginning an investigation, it is useful to research what is already known about the problem. Making and examining observations and interpretations from reliable sources fine-tune the question and form it into a hypothesis.

Form and test a hypothesis A **hypothesis** is a possible explanation for a problem using what you know and have observed. A scientific hypothesis can be tested through experimentation and observation. Sometimes scientists must wait for new technologies before a hypothesis can be tested. For example, the first hypotheses about the existence of atoms were developed more than 2300 years ago, but the technologies to test these hypotheses were not available for many centuries.

Some hypotheses can be tested by making observations. Others can be tested by building a model and relating it to real-life situations. One common way to test a hypothesis is to perform an experiment. An experiment tests the effect of one thing on another, using a control. Sometimes it is not possible to perform experiments; in these cases, investigations become descriptive in nature. For example, physicists cannot conduct experiments in deep space. They can, however, collect and analyze valuable data to help us learn more about events occurring there.

MiniLAB

MEASURING CHANGE

How does increasing mass affect the length of a spring?

Analyze the data An important part of every investigation includes recording observations and organizing data into easy-to-read tables and graphs. Later in this chapter, you will study ways to display data. When you are making and recording observations, you should include all results, even unexpected ones. Many important discoveries have been made from unexpected results.

Scientific inferences are based on scientific observations. All possible scientific explanations must be considered. If the data are not organized in a logical manner, incorrect conclusions can be drawn. When a scientist communicates and shares data, other scientists will examine those data, how the data were analyzed, and compare the data to the work of others. Scientists, such as the physicist in **Figure 3**, share their data and analyses through reports and conferences.

Draw conclusions Based on the analysis of the data, the next step is to decide whether the hypothesis is supported. For the hypothesis to be considered valid and widely accepted, the results of the experiment must be the same every time it is repeated. If the experiment does not support the hypothesis, the hypothesis must be reconsidered. Perhaps the hypothesis needs to be revised, or maybe the experimenter's procedure needs to be refined.

Figure 3 An important part of scientific methods is to share data and results with other scientists. This physicist is giving a presentation at the World Science Festival.

Peer review Before it is made public, science-based information is reviewed by scientists' peers–scientists who are in the same field of study. Peer review is a process by which the procedures and results of an experiment are evaluated by peer scientists of those who conducted the research. Reviewing other scientists' work is a responsibility that many scientists have.

Being objective One also should be careful to reduce bias in scientific investigations. Bias can occur when the scientist's expectations affect how the results are analyzed or the conclusions are made. This might cause a scientist to select a result from one trial over those from other trials. Bias might also be found if the advantages of a product being tested are used in a promotion and the drawbacks are not presented. Scientists can lessen bias by running as many trials as possible and by keeping accurate notes of each observation made.

Models

Sometimes, scientists cannot see everything they are testing. They might be observing an object that is too large or too small, a process that takes too much time to see completely, or a material that is hazardous. In these cases, scientists use models. A **model** is a representation of an idea, event, structure, or object that helps people better understand it.

Models in history Models have been used throughout history. In the early 1900s, British physicist J.J. Thomson created a model of the atom that consisted of electrons embedded in a ball of positive charge. Several years later, physicist Ernest Rutherford created a model of the atom based on new research. Later in the twentieth century, scientists discovered the nucleus is not a solid ball but is made of protons and neutrons. The present-day model of the atom is a nucleus made of protons and neutrons surrounded by an electron cloud. All three of these models are shown in **Figure 4.** Scientists use models of atoms to represent their current understanding because of the small size of an atom.

Figure 4 Throughout history, scientists have made models of the atom.

Infer Why have models of the atom changed over the years?

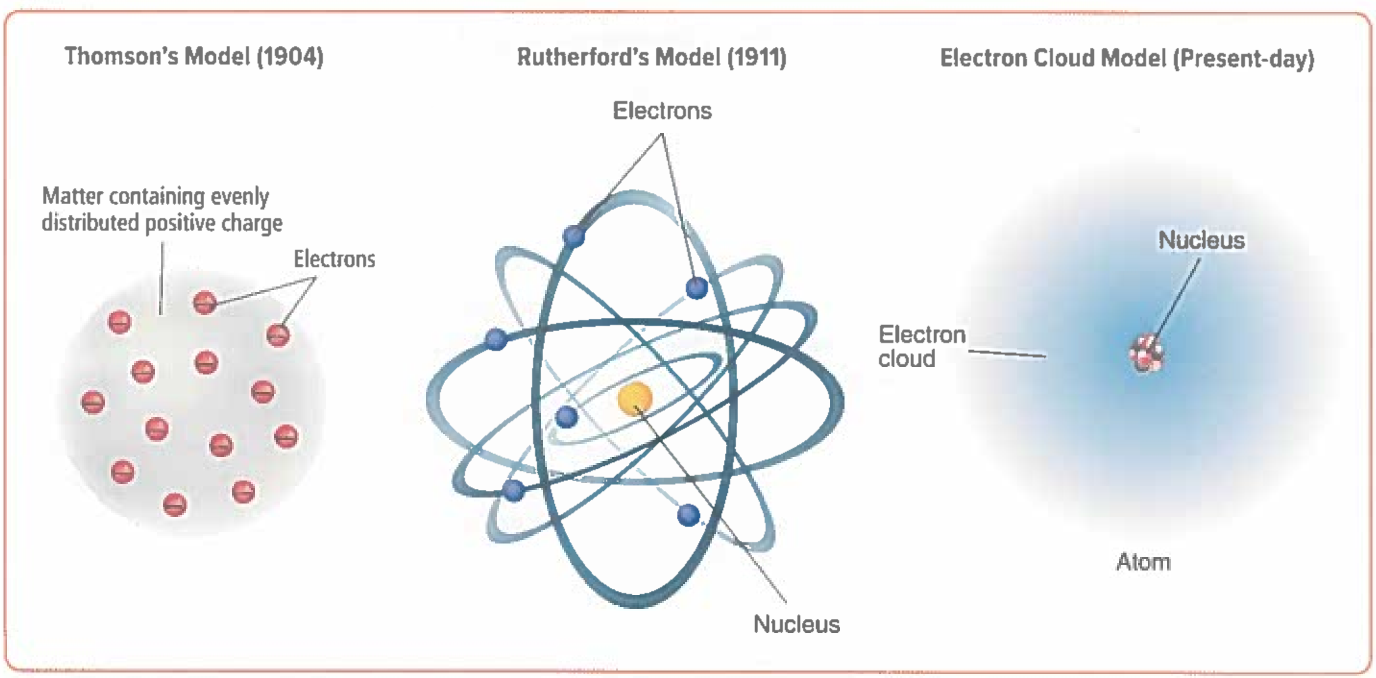


Figure 5 This is a computer simulation of an aircraft landing on a runway. The image on the screen in front of the pilot mimics what he would see if he were landing a real plane.

Identify other models around your classroom.

High-tech models Scientific models are not always something you can touch. Another type of model is a computer simulation. A computer simulation uses a computer to test a process or procedure and to collect data. Computer software is designed to mimic the processes under study. For instance, it is not possible for astronomers to observe how our solar system was formed, but when models of the process are proposed, they can be tested with computers.

Computer simulations also enable pilots, such as the ones shown in **Figure 5,** to practice all aspects of flight without ever leaving the ground. In addition, the computer simulation can simulate harsh weather conditions or other potentially dangerous in-flight challenges that pilots might face.

☑ **READING CHECK** **Identify** two advantages of using computer simulations.

Scientific Theories and Laws

A **scientific theory** is an explanation of things or events based on knowledge gained from many observations and investigations.

It is not a guess. If scientists repeat an investigation and the results always support the hypothesis, the hypothesis can be called a theory. Just because a scientific theory has data supporting it does not mean it will never change. As new information becomes available, theories can be refined or modified, as shown in **Figure 6** on the next page.

A **scientific law** is a statement about what happens in nature and seems to be true all the time. Laws tell you what will happen under certain conditions, but they don't explain why or how something happens. Gravity is an example of a scientific law. The law of gravity states that any one mass will attract another mass. To date, no experiments have been performed that disprove the law of gravity.

A theory can be used to explain a law, but theories do not become laws. For example, many theories have been proposed to explain how the law of gravity works. Even so, there are few accepted theories in science and even fewer laws.

Greek philosophers proposed that objects fall because they seek their natural places. The more massive the object, the faster it falls.

↓ **Revision**

Galileo showed that the speed at which an object falls depends on the amount of time for which that object has fallen and not on the object's mass.

↓ **Revision**

Newton provided an explanation for why objects fall. Newton proposed that objects fall because the object and Earth are attracted by a force. Newton also stated that there is a force of attraction between any two objects with mass.

↓ **Revision**

Einstein suggested that the force of attraction between two objects is due to mass causing the space around it to curve.

Figure 6 If experiments provide new insight and evidence about a theory, the theory is modified accordingly. The theory describing the behavior of falling objects has undergone many revisions based on new evidence.

The Limitations of Science

Science can help you explain many things about the world, but science cannot explain or solve everything. Although it is the scientist's job to make guesses, the scientist also has to make sure his or her guesses can be tested and verified.

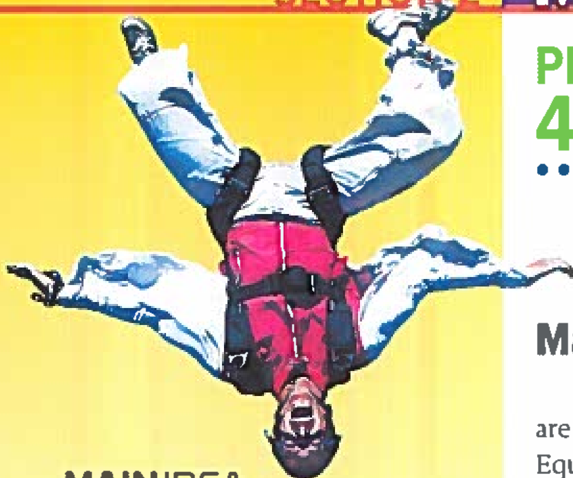
Questions about opinions, values, or emotions are not scientific because they cannot be tested. For example, some people may find a particular piece of art beautiful while others do not. Some people may think that certain foods, such as pizza, taste delicious while others do not. Or, some people might think that the best color is blue, while others think it is green. You might take a survey to gather opinions about such questions, but that would not prove the opinions are true for everyone.

SECTION 1 REVIEW

1. **MAINIDEA** Summarize the steps you might use to carry out an investigation using scientific methods.
2. **Define** the term hypothesis and identify three ways in which a hypothesis can be tested.
3. **Describe** why it is important for scientists to avoid bias.
4. **Explain** why scientists use models. Give an example of a scientific model not mentioned in this section.
5. **Explain** why a scientific theory cannot become a scientific law.
6. **Analyze** Your friend conducts a survey, asking students in your school about lunches provided by the cafeteria. She finds that 90 percent of students surveyed like pizza. She concludes that this scientifically proves that everyone likes pizza. How would you respond to her conclusion?
7. **Critical Thinking** An accepted value for free-fall acceleration is 9.8 m/s^2. In an experiment with pendulums, you calculate that the value is 9.4 m/s^2. Should the accepted value be tossed out to accommodate your new finding? Explain.

SECTION 2

Mathematics and Physics



MAIN IDEA

We use math to express concepts in physics.

Essential Questions

- Why do scientists use the metric system?
- How can dimensional analysis help evaluate answers?
- What are significant figures?

Review Vocabulary

SI Système International d'Unités–the improved, universally accepted version of the metric system that is based on multiples of ten; also called the International System of Units

New Vocabulary

dimensional analysis
significant figures

PHYSICS 4 YOU If you were to toss a tennis ball straight up into the air, how could you determine how far the ball would rise or how long it would stay in the air? How could you determine the velocity of the skydiver in the photo? Physicists use mathematics to help find the answers to these and other questions about motion, forces, energy, and matter.

Mathematics in Physics

Physicists often use the language of mathematics. In physics, equations are important tools for modeling observations and for making predictions. Equations are one way of representing relationships between measurements. Physicists rely on theories and experiments with numerical results to support their conclusions. For example, you can predict that if you drop a penny, it will fall, but can you predict how fast it will be going when it strikes the ground below? Different models of falling objects give different answers to how the speed of the object changes as it falls or on what the speed depends. By measuring how an object falls, you can compare the experimental data with the results predicted by different models. This tests the models, allowing you to pick the best one or to develop a new model.

SI Units

To communicate results, it is helpful to use units that everyone understands. The worldwide scientific community currently uses an adaptation of the metric system for measurements. **Table 1** shows that the Système International d'Unités, or SI, uses seven base quantities. Other units, called derived units, are created by combining the base units in various ways. Velocity is measured in meters per second (m/s). Often, derived units are given special names. For example, electric charge is measured in ampere-seconds (A•s), which are also called coulombs (C).

The base quantities were originally defined in terms of direct measurements. Scientific institutions have since been created to define and regulate measurements. SI is regulated by the International Bureau of Weights and Measures in Sèvres, France.

Table 1 SI Base Units

Base Quantity	Base Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Temperature	kelvin	K
Amount of a substance	mole	mol
Electric current	ampere	A
Luminous intensity	candela	cd

This bureau and the National Institute of Science and Technology (NIST) in Gaithersburg, Maryland, keep the standards of length, time, and mass against which our metersticks, clocks, and balances are calibrated. The standard for a kilogram is shown in **Figure 7.**

You probably learned in math class that it is much easier to convert meters to kilometers than feet to miles. The ease of switching between units is another feature of SI. To convert between units, multiply or divide by the appropriate power of 10. Prefixes are used to change SI base units by powers of 10, as shown in **Table 2.** You often will encounter these prefixes in daily life, as in, for example, milligrams, nanoseconds, and centimeters.

Figure 7 The International Prototype Kilogram, the standard for the mass of a kilogram, is a mixture of platinum and iridium. It is kept in a vacuum so it does not lose mass. Scientists are working to redefine the standard for a kilogram, using a perfect sphere made of silicon.

Describe Why is it important to have standards for measurements?

Table 2 Prefixes Used with SI Units

Prefix	Symbol	Multiplier	Scientific Notation	Example
femto–	f	0.000000000000001	10^{-15}	femtosecond (fs)
pico–	p	0.000000000001	10^{-12}	picometer (pm)
nano–	n	0.000000001	10^{-9}	nanometer (nm)
micro–	μ	0.000001	10^{-6}	microgram (μg)
milli–	m	0.001	10^{-3}	milliamps (mA)
centi–	c	0.01	10^{-2}	centimeter (cm)
deci–	d	0.1	10^{-1}	deciliter (dL)
kilo–	k	1000	10^{3}	kilometer (km)
mega–	M	1,000,000	10^{6}	megagram (Mg)
giga–	G	1,000,000,000	10^{9}	gigameter (Gm)
tera–	T	1,000,000,000,000	10^{12}	terahertz (THz)

READING CHECK **Identify** the prefix that would be used to express 2,000,000,000 bytes of computer memory.

Dimensional Analysis

You can use units to check your work. You often will need to manipulate a formula, or use a string of formulas, to solve a physics problem. One way to check whether you have set up a problem correctly is to write out the equation or set of equations you plan to use. Before performing calculations, check that the answer will be in the expected units. For example, if you are finding a car's speed and you see that your answer will be measured in s/m or m/s^2, you have made an error in setting up the problem. This method of treating the units as algebraic quantities that can be cancelled is called **dimensional analysis.** Knowing that your answer will be in the correct units is not a guarantee that your answer is right, but if you find that your answer will have the wrong units, you can be sure that you have made an error. Dimensional analysis also is used in choosing conversion factors. A conversion factor is a multiplier equal to 1.

For example, because 1 kg = 1000 g, you can construct the following conversion factors:

$$1 = \frac{1\ \text{kg}}{1000\ \text{g}} \qquad 1 = \frac{1000\ \text{g}}{1\ \text{kg}}$$

Choose a conversion factor that will make the initial units cancel, leaving the answer in the desired units. For example, to convert 1.34 kg of iron ore to grams, do as shown below.

$$1.34\ \cancel{\text{kg}}\left(\frac{1000\ \text{g}}{1\ \cancel{\text{kg}}}\right) = 1340\ \text{g}$$

You also might need to do a series of conversions. To convert 43 km/h to m/s, do the following:

$$\left(\frac{43\ \cancel{\text{km}}}{1\ \cancel{\text{h}}}\right)\left(\frac{1000\ \text{m}}{1\ \cancel{\text{km}}}\right)\left(\frac{1\ \cancel{\text{h}}}{60\ \cancel{\text{min}}}\right)\left(\frac{1\ \cancel{\text{min}}}{60\ \text{s}}\right) = 12\ \text{m/s}$$

Significant Figures

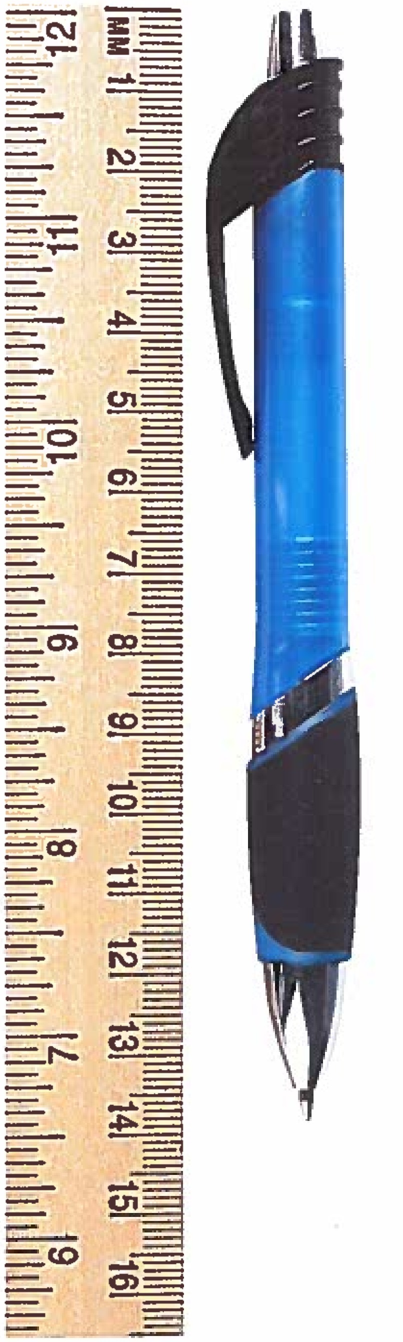


Figure 8 The student measuring this pen recorded the length as 138.1 mm.

Infer Why is the last digit in this measurement uncertain?

Suppose you use a metric ruler to measure a pen and you find that the end of the pen is just past 138 mm, as shown in **Figure 8.** You estimate that the pen is one-tenth of a millimeter past the last tic mark on the ruler and record the pen as being 138.1 mm long. This measurement has four valid digits: the first three digits are certain, and the last one is uncertain. The valid digits in a measurement are referred to as **significant figures.** The last digit given for any measurement is the uncertain digit. All nonzero digits in a measurement are significant.

Are all zeros significant? No. For example, in the measurement 0.0860 m, the first two zeros serve only to locate the decimal point and are not significant. The last zero, however, is the estimated digit and is significant. The measurement 172,000 m could have 3, 4, 5, or 6 significant figures. This ambiguity is one reason to use scientific notation. It is clear that the measurement 1.7200×10^5 m has five significant figures.

Arithmetic with significant figures When you perform any arithmetic operation, it is important to remember that the result never can be more precise than the least-precise measurement.

To add or subtract measurements, first perform the operation, then round off the result to correspond to the least-precise value involved. For example, 3.86 m + 2.4 m = 6.3 m because the least-precise measure is to one-tenth of a meter.

To multiply or divide measurements, perform the calculation and then round to the same number of significant figures as the least-precise measurement. For example, $\frac{409.2\ \text{km}}{11.4\ \text{L}} = 35.9$ km/L, because the least-precise measurement has three significant figures. Some calculators display several additional digits, while others round at different points. Be sure to record your answers with the correct number of digits.

Solving Problems

As you continue this course, you will complete practice problems. Most problems will be complex and require a strategy to solve. This textbook includes many example problems, each of which is solved using a three-step process. Read Example 1 and follow the steps to calculate a car's average speed using distance and time.

EXAMPLE 1

USING DISTANCE AND TIME TO FIND SPEED When a car travels 434 km in 4.5 h, what is the car's average speed?

1 ANALYZE AND SKETCH THE PROBLEM

The car's speed is unknown. The known values include the distance the car traveled and time. Use the relationship among speed, distance, and time to solve for the car's speed.

KNOWN	UNKNOWN
distance = 434 km	speed = ? km/h
time = 4.5 h	

2 SOLVE FOR THE UNKNOWN

distance = **speed** × time ◀ *State the relationship as an equation.*

$\textbf{speed} = \frac{\text{distance}}{\text{time}}$ ◀ *Solve the equation for speed.*

$\textbf{speed} = \frac{434\ \text{km}}{4.5\ \text{h}}$ ◀ *Substitute distance = 434 km and time = 4.5 h.*

speed = 96.4 km/h ◀ *Divide, and calculate units.*

3 EVALUATE THE ANSWER

Check your answer by using it to calculate the distance the car traveled.

distance = speed × time = 96.4 km/~~h~~ × 4.5 ~~h~~ = 434 km

The calculated distance matches the distance stated in the problem. This means the average speed is correct.

THE PROBLEM

1. Read the problem carefully.
2. Be sure you understand what is being asked.

ANALYZE AND SKETCH THE PROBLEM

1. Read the problem again.
2. Identify what you are given, and list the known data. If needed, gather information from graphs, tables, or figures.
3. Identify and list the unknowns.
4. Determine whether you need a sketch to help solve the problem.
5. Plan the steps you will follow to find the answer.

SOLVE FOR THE UNKNOWN

1. If the solution is mathematical, write the equation and isolate the unknown factor.
2. Substitute the known quantities into the equation.
3. Solve the equation.
4. Continue the solution process until you solve the problem.

EVALUATE THE ANSWER

1. Reread the problem. Is the answer reasonable?
2. Check your math. Are the units and the significant figures correct?

SECTION 2 REVIEW

8. **MAIN IDEA** Why are concepts in physics described with formulas?
9. **SI Units** What is one advantage to using SI Units in science?
10. **Dimensional Analysis** How many kilohertz are 750 megahertz?
11. **Dimensional Analysis** How many seconds are in a leap year?
12. **Significant Figures** Solve the following problems, using the correct number of significant figures each time.
    - **a.** 10.8 g − 8.264 g
    - **b.** 4.75 m − 0.4168 m
    - **c.** 139 cm × 2.3 cm
    - **d.** 13.78 g / 11.3 mL
    - **e.** 6.201 cm + 7.4 cm + 0.68 m + 12.0 cm
    - **f.** 1.6 km + 1.62 m + 1200 cm
13. **Solving Problems** Rewrite $F = Bqv$ to find v in terms of F, q, and B.
14. **Critical Thinking** Using values given in a example and the equation of distance = speed × time, you calculate a car's speed to be 290 km/h. Is this a reasonable answer? Why or why not? Under what circumstances might this be a reasonable answer?

SECTION 3

Measurement

MAIN IDEA

Making careful measurements allows scientists to repeat experiments and compare results.

Essential Questions

- Why are the results of measurements often reported with an uncertainty?
- What is the difference between precision and accuracy?
- What is a common source of error when making a measurement?

Review Vocabulary

parallax the apparent shift in the position of an object when it is viewed from different angles

New Vocabulary

measurement
precision
accuracy

PHYSICS 4 YOU There are many devices that you often use to make measurements. Clocks measure time, rulers measure distance, and speedometers measure speed. What other measuring devices have you used?

What is measurement?

When you visit the doctor for a checkup, many measurements are taken: your height, weight, blood pressure, and heart rate. Even your vision is measured and assigned numbers. Blood might be drawn so measurements can be made of blood cells or cholesterol levels. Measurements quantify our observations: a person's blood pressure isn't just "pretty good," it's $\frac{110}{60}$, the low end of the good range.

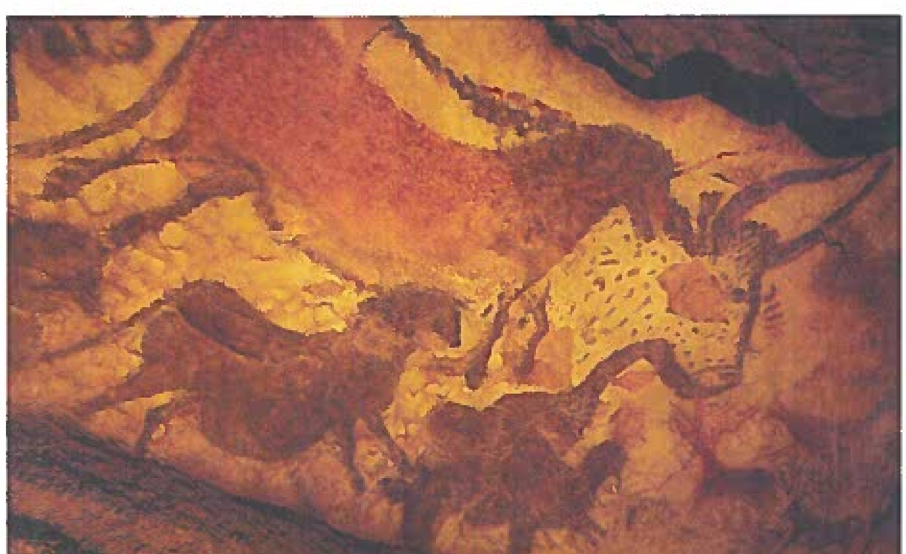
A **measurement** is a comparison between an unknown quantity and a standard. For example, if you measure the mass of a rolling cart used in an experiment, the unknown quantity is the mass of the cart and the standard is the gram, as defined by the balance or the spring scale you use. In the MiniLab in Section 1, the length of the spring was the unknown and the centimeter was the standard.

Comparing Results

As you learned in Section 1, scientists share their results. Before new data are fully accepted, other scientists examine the experiment, look for possible sources of error, and try to reproduce the results. Results often are reported with an uncertainty. A new measurement that is within the margin of uncertainty is in agreement with the old measurement.

For example, archaeologists use radiocarbon dating to find the age of cave paintings, such as those from the Lascaux cave, in **Figure 9**, and the Chauvet cave. Each radiocarbon date is reported with an uncertainty. Three radiocarbon ages from a panel in the Chauvet cave are 30,940 ± 610 years, 30,790 ± 600 years, and 30,230 ± 530 years. While none of the measurements exactly matches, the uncertainties in all three overlap, and the measurements agree with each other.

Figure 9 These drawings are from the Lascaux cave in France. Scientists estimate that the drawings were made 17,000 years ago.



Suppose three students performed the MiniLab from Section 1 several times, starting with springs of the same length. With two washers on the spring, student 1 made repeated measurements, which ranged from 14.4 cm to 14.8 cm. The average of student 1's measurements was 14.6 cm, as shown in **Figure 10.** This result was reported as (14.6 ± 0.2) cm. Student 2 reported finding the spring's length to be (14.8 ± 0.3) cm. Student 3 reported a length of (14.0 ± 0.1) cm.

Could you conclude that the three measurements are in agreement? Is student 1's result reproducible? The ranges of the results of students 1 and 2 overlap between 14.5 cm and 14.8 cm. However, there is no overlap and, therefore, no agreement, between their results and the result of student 3.

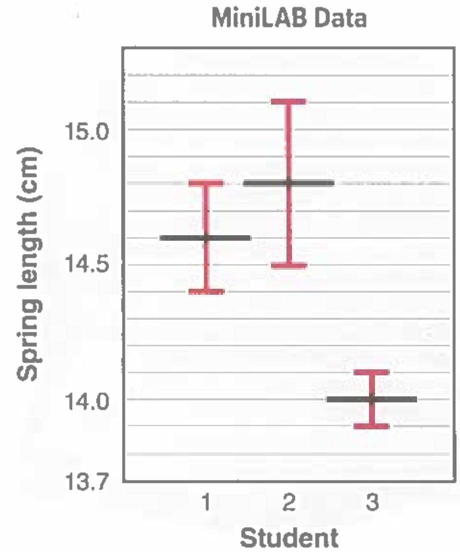


Figure 10 Three students took multiple measurements. The red bars show the uncertainty of each measurement.

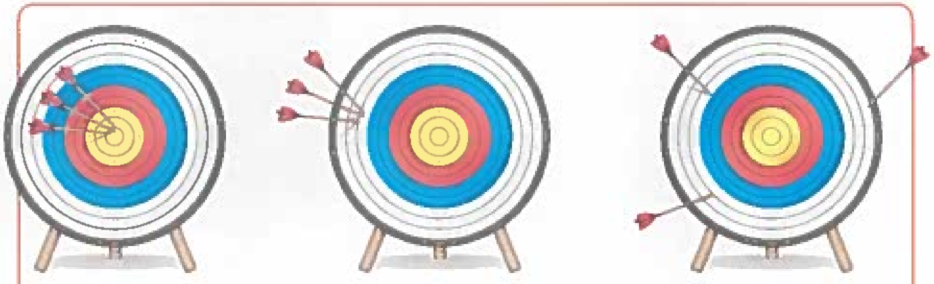
Explain Are the measurements in agreement? Is student 3's result reproducible? Why or why not?

Precision Versus Accuracy

Both precision and accuracy are characteristics of measured values as shown in **Figure 11.** How precise and accurate are the measurements of the three students above? The degree of exactness of a measurement is called its **precision.** In the example above, student 3's measurements are the most precise, within ± 0.1 cm. Both the measurements of student 1 and student 2 are less precise because they have a larger uncertainty (student 1 = ± 0.2 cm, student 2 = ± 0.3 cm).

Precision depends on the instrument and technique used to make the measurement. Generally, the device that has the finest division on its scale produces the most precise measurement. The precision of a measurement is one-half the smallest division of the instrument. For example, suppose a graduated cylinder has divisions of 1 mL. You could measure an object to within 0.5 mL with this device. However, if the smallest division on a beaker is 50 mL, how precise would your measurements be compared to those taken with the graduated cylinder?

The significant figures in an answer show its precision. A measure of 67.100 g is precise to the nearest thousandth of a gram. Recall from Section 2 the rules for performing operations with measurements given to different levels of precision. If you add 1.2 mL of acid to a beaker containing 2.4×10^2 mL of water, you cannot say you now have 2.412×10^2 mL of fluid because the volume of water was not measured to the nearest tenth of a milliliter, but to the nearest 10 mL.



The arrows clustered in the center represent measurements that are both accurate and precise.

The arrows clustered together far from the center represent three measurements that are precise but not accurate.

These arrows are both apart and far from the center. They represent three measurements that are inaccurate and imprecise.

Figure 11 The yellow area in the center of each target represents an accepted value for a particular measurement. The arrows represent measurements taken by a scientist during an experiment.

Figure 12 Accuracy is checked by zeroing an instrument before measuring.

Infer Is this instrument accurate? Why or why not?

Accuracy describes how well the results of a measurement agree with the "real" value; that is, the accepted value as measured by competent experimenters, as shown in **Figure 11.** If the length of the spring that the three students measured had been 14.8 cm, then student 2 would have been most accurate and student 3 least accurate. What might have led someone to make inaccurate measurements? How could you check the accuracy of measurements?

A common method for checking the accuracy of an instrument is called the two-point calibration. First, does the instrument read zero when it should, as shown in **Figure 12?** Second, does it give the correct reading when it is measuring an accepted standard? Regular checks for accuracy are performed on critical measuring instruments, such as the radiation output of the machines used to treat cancer.

☑ **READING CHECK** **Compare and contrast** precision and accuracy.

Techniques of Good Measurement

To assure accuracy and precision, instruments also have to be used correctly. Measurements have to be made carefully if they are to be as precise as the instrument allows. One common source of error comes from the angle at which an instrument is read. Scales should be read with one's eye directly in front of the measure, as shown in **Figure 13.** If the scale is read from an angle, also shown in **Figure 13,** a different, less accurate, value will be obtained. The difference in the readings is caused by parallax, which is the apparent shift in the position of an object when it is viewed from different angles. To experiment with parallax, place your pen on a ruler and read the scale with your eye directly over the tip, then read the scale with your head shifted far to one side.

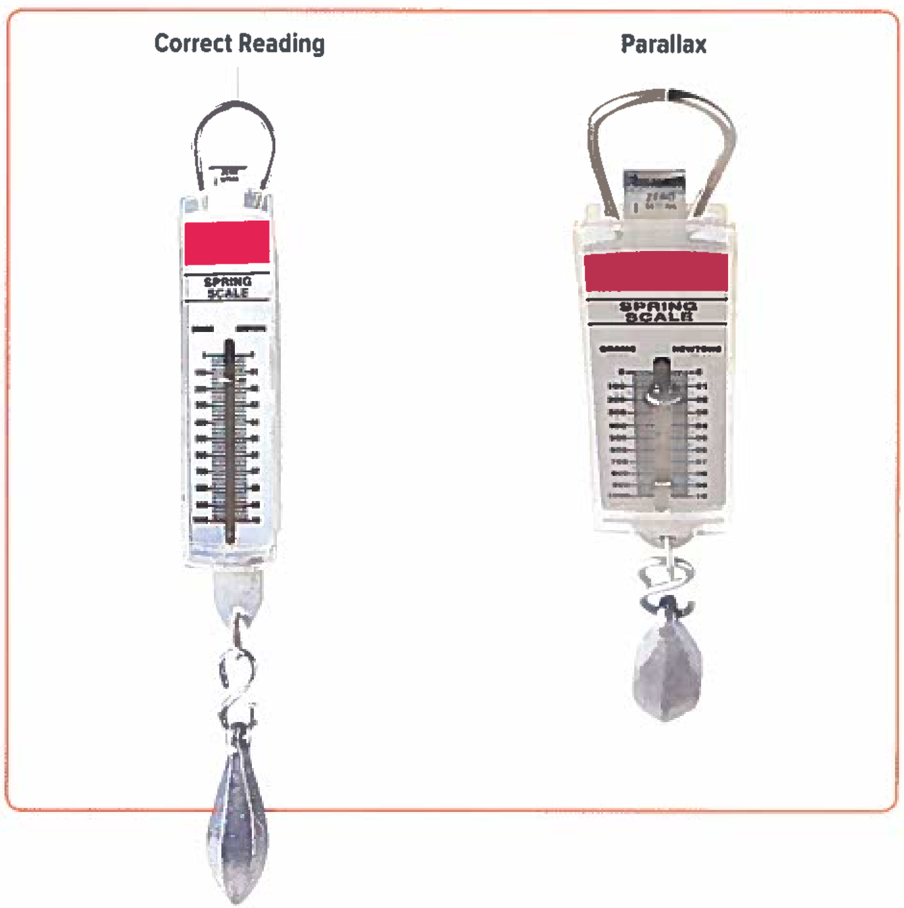


Figure 13 By positioning the scale head on (left), your results will be more accurate than if you read your measurements at an angle (right).

Identify How far did parallax shift the measurement on the right?

GPS The Global Positioning System, or GPS, offers an illustration of accuracy and precision in measurement. The GPS consists of 24 satellites with transmitters in orbit and numerous receivers on Earth. The satellites send signals with the time, measured by highly accurate atomic clocks. The receiver uses the information from at least four satellites to determine latitude, longitude, and elevation. (The clocks in the receivers are not as accurate as those on the satellites.)

Receivers have different levels of precision. A device in an automobile might give your position to within a few meters. Devices used by geophysicists, as in **Figure 14,** can measure movements of millimeters in Earth's crust.

The GPS was developed by the United States Department of Defense. It uses atomic clocks, which were developed to test Einstein's theories of relativity and gravity. The GPS eventually was made available for civilian use. GPS signals now are provided worldwide free of charge and are used in navigation on land, at sea, and in the air, for mapping and surveying, by telecommunications and satellite networks, and for scientific research into earthquakes and plate tectonics.

Figure 14 This scientist is setting up a highly accurate GPS receiver in order to record and analyze the movements of continental plates.

PhysicsLAB

MASS AND VOLUME

How does mass depend on volume?

SECTION 3 REVIEW

15. **MAIN IDEA** You find a micrometer (a tool used to measure objects to the nearest 0.001 mm) that has been badly bent. How would it compare to a new, high-quality meterstick in terms of its precision? Its accuracy?

16. **Accuracy** Some wooden rulers do not start with 0 at the edge, but have it set in a few millimeters. How could this improve the accuracy of the ruler?

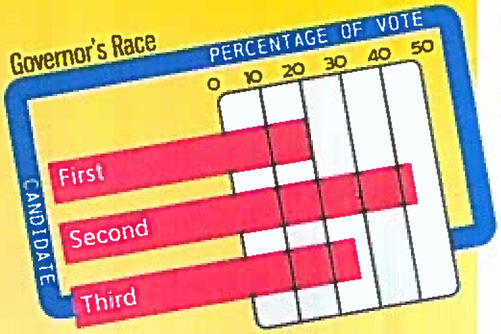
17. **Parallax** Does parallax affect the precision of a measurement that you make? Explain.

18. **Uncertainty** Your friend tells you that his height is 182 cm. In your own words, explain the range of heights implied by this statement.

19. **Precision** A box has a length of 18.1 cm and a width of 19.2 cm, and it is 20.3 cm tall.
    a. What is its volume?
    b. How precise is the measurement of length? Of volume?
    c. How tall is a stack of 12 of these boxes?
    d. How precise is the measurement of the height of one box? Of 12 boxes?

20. **Critical Thinking** Your friend states in a report that the average time required for a car to circle a 1.5-mi track was 65.414 s. This was measured by timing 7 laps using a clock with a precision of 0.1 s. How much confidence do you have in the results of the report? Explain.

SECTION 4 **Graphing Data**



MAIN IDEA

Graphs make it easier to interpret data, identify trends, and show relationships among a set of variables.

Essential Questions

- What can be learned from graphs?
- What are some common relationships in graphs?
- How do scientists make predictions?

Review Vocabulary

slope on a graph, the ratio of vertical change to horizontal change

New Vocabulary

independent variable
dependent variable
line of best fit
linear relationship
quadratic relationship
inverse relationship

PHYSICS 4 YOU

Graphs are often used in news stories after elections. Bar and circle graphs are used to show the number or percentage of votes various candidates received. Other graphs are used to show increases and decreases in population or resources over years.

Identifying Variables

When you perform an experiment, it is important to change only one factor at a time. For example, **Table 3** gives the length of a spring with different masses attached. Only the mass varies; if different masses were hung from different types of springs, you wouldn't know how much of the difference between two data pairs was due to the different masses and how much was due to the different springs.

Independent and dependent variables A variable is any factor that might affect the behavior of an experimental setup. The factor that is manipulated during an investigation is the **independent variable.** In this investigation, the mass was the independent variable. The factor that depends on the independent variable is the **dependent variable.** In this investigation, the amount the spring stretched depended on the mass, so the amount of stretch was the dependent variable. A scientist might also look at how radiation varies with time or how the strength of a magnetic field depends on the distance from a magnet.

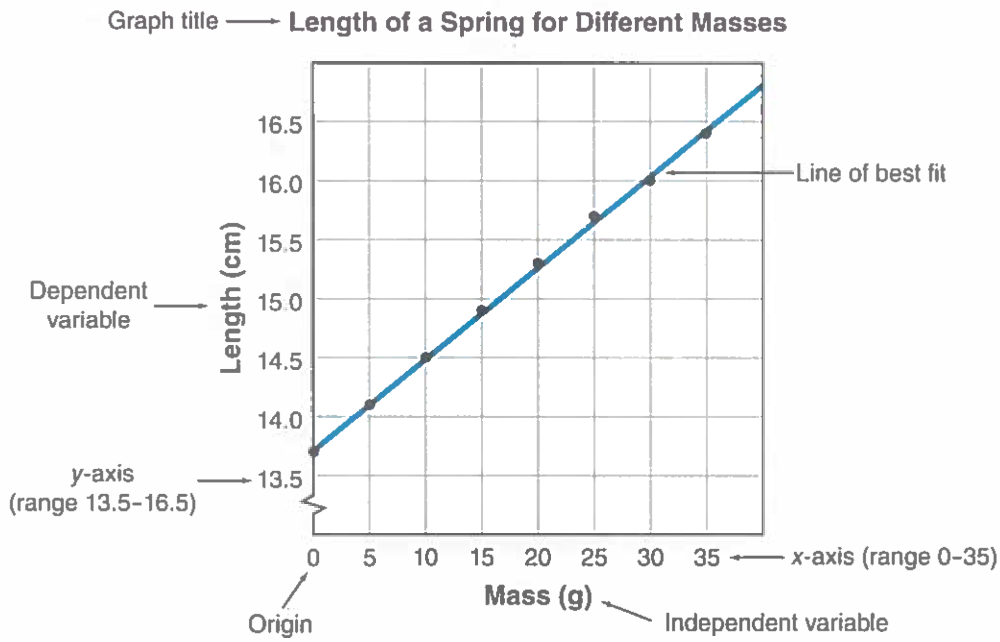
Line of best fit A line graph shows how the dependent variable changes with the independent variable. The data from **Table 3** are graphed in **Figure 15.** The line in blue, drawn as close to all the data points as possible, is called a **line of best fit.** The line of best fit is a better model for predictions than any one point along the line. **Figure 15** gives detailed instructions on how to construct a graph, plot data, and sketch a line of best fit.

A well-designed graph allows patterns that are not immediately evident in a list of numbers to be seen quickly and simply. The graph in **Figure 15** shows that the length of the spring increases as the mass suspended from the spring increases.

Table 3 Length of a Spring for Different Masses

Mass Attached to Spring (g)	Length of Spring (cm)
0	13.7
5	14.1
10	14.5
15	14.9
20	15.3
25	15.7
30	16.0
35	16.4

■ Plotting Line Graphs

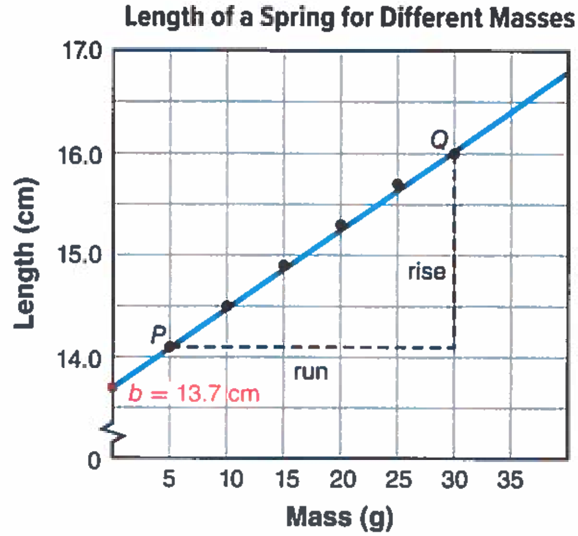


1. Identify the independent variable and dependent variable in your data. In this example, the independent variable is mass (g) and the dependent variable is length (cm). The independent variable is plotted on the horizontal axis, the *x*-axis. The dependent variable is plotted on the vertical axis, the *y*-axis.
2. Determine the range of the independent variable to be plotted. In this case the range is 0-35.
3. Decide whether the origin (0,0) is a valid data point.
4. Spread the data out as much as possible. Let each division on the graph paper stand for a convenient unit. This usually means units that are multiples of 2, 5, or 10.
5. Number and label the horizontal axis. The label should include the units, such as Mass (g).
6. Repeat steps 2-5 for the dependent variable.
7. Plot the data points on the graph.
8. Draw the best-fit straight line or smooth curve that passes through as many data points as possible. This is sometimes called *eyeballing*. Do not use a series of straight-line segments that connect the dots. The line that looks like the best fit to you may not be exactly the same as someone else's. There is a formal procedure, which many graphing calculators use, called the least-squares technique, that produces a unique best-fit line, but that is beyond the scope of this textbook.
9. Give the graph a title that clearly tells what the graph represents.

Figure 15 Use the steps above to plot line graphs from data tables.

Figure 16 In a linear relationship, the dependent variable—in this case, length—varies linearly with the independent variable. The independent variable in this experiment is mass.

Describe What happens to the length of the spring as mass decreases?



MiniLAB

HOW FAR AROUND?

What is the relationship between circumference and diameter?

Linear Relationships

Scatter plots of data take many different shapes, suggesting different relationships. Three of the most common relationships include linear relationships, quadratic relationships, and inverse relationships. You probably are familiar with them from math class.

When the line of best fit is a straight line, as in **Figure 15**, there is a linear relationship between the variables. In a **linear relationship,** the dependent variable varies linearly with the independent variable. The relationship can be written as the following equation.

LINEAR RELATIONSHIP BETWEEN TWO VARIABLES $y = mx + b$

Find the y-intercept (b) and the slope (m) as illustrated in **Figure 16.** Use points on the line–they may or may not be data points. The slope is the ratio of the vertical change to the horizontal change. To find the slope, select two points, P and Q, far apart on the line. The vertical change, or rise (Δy), is the difference between the vertical values of P and Q. The horizontal change, or run (Δx), is the difference between the horizontal values of P and Q.

SLOPE

The slope of a line is equal to the rise divided by the run, which also can be expressed as the vertical change divided by the horizontal change.

$$m = \frac{\Delta y}{\Delta x}$$

In **Figure 16:** $m = \frac{(16.0\text{ cm} - 14.1\text{ cm})}{(30\text{ g} - 5\text{ g})} = 0.08\text{ cm/g}$

If y gets smaller as x gets larger, then $\frac{\Delta y}{\Delta x}$ is negative, and the line slopes downward from left to right. The y-intercept (b) is the point at which the line crosses the vertical axis, or the y-value when the value of x is zero. In this example, $b = 13.7$ cm. This means that when no mass is suspended by the spring, it has a length of 13.7 cm. When $b = 0$, or $y = mx$, the quantity y is said to vary directly with x. In physics, the slope of the line and the y-intercept always contain information about the physical system that is described by the graph.

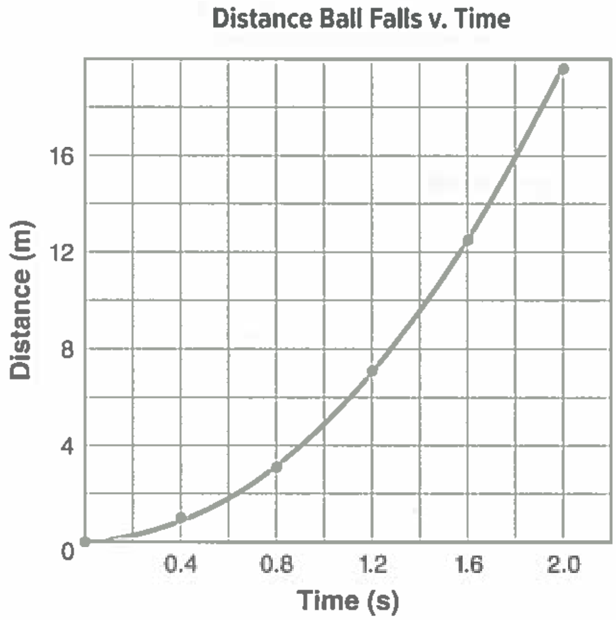


Figure 17 The quadratic, or parabolic, relationship shown here is an example of a nonlinear relationship.

Nonlinear Relationships

Figure 17 shows the distance a brass ball falls versus time. Note that the graph is not a straight line, meaning the relationship is not linear. There are many types of nonlinear relationships in science. Two of the most common are the quadratic and inverse relationships.

Quadratic relationship The graph in **Figure 17** is a quadratic relationship, represented by the equation below. A **quadratic relationship** exists when one variable depends on the square of another.

QUADRATIC RELATIONSHIP BETWEEN TWO VARIABLES

$$y = ax^2 + bx + c$$

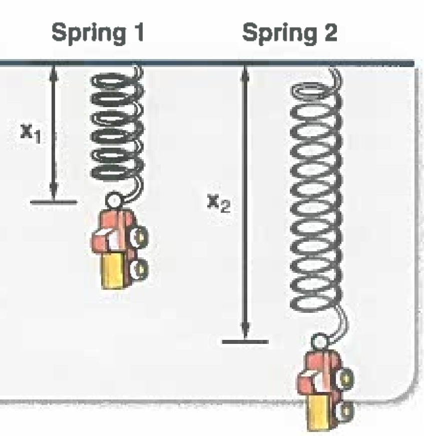
A computer program or graphing calculator easily can find the values of the constants a, b, and c in this equation. In **Figure 17**, the equation is $d = 5t^2$. See the Math Handbook in the back of this book or online for more on making and using line graphs.

READING CHECK Explain how two variables related to each other in a quadratic relationship.

PHYSICS CHALLENGE

An object is suspended from spring 1, and the spring's elongation (the distance it stretches) is x_1. Then the same object is removed from the first spring and suspended from a second spring. The elongation of spring 2 is x_2. x_2 is greater than x_1.

1. On the same axes, sketch the graphs of the mass versus elongation for both springs.
2. Should the origin be included in the graph? Why or why not?
3. Which slope is steeper?
4. At a given mass, $x_2 = 1.6x_1$. If $x_2 = 5.3$ cm, what is x_1?



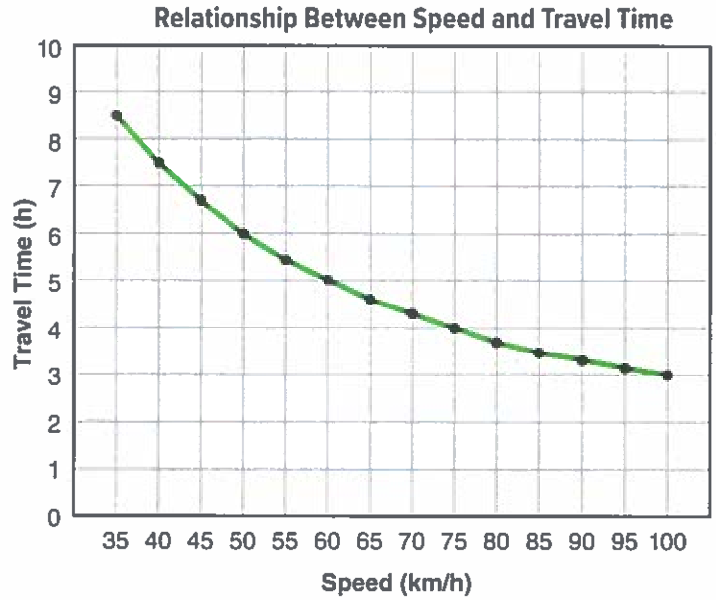


Figure 18 This graph shows the inverse relationship between speed and travel time.

Describe How does travel time change as speed increases?

Inverse relationship The graph in **Figure 18** shows how the time it takes to travel 300 km varies as a car's speed increases. This is an example of an inverse relationship, represented by the equation below. An **inverse relationship** is a hyperbolic relationship in which one variable depends on the inverse of the other variable.

INVERSE RELATIONSHIP BETWEEN TWO VARIABLES $y = \frac{a}{x}$

The three relationships you have learned about are a sample of the relations you will most likely investigate in this course. Many other mathematical models are used. Important examples include sinusoids, used to model cyclical phenomena, and exponential growth and decay, used to study radioactivity. Combinations of different mathematical models represent even more complex phenomena.

READING CHECK **Explain** how two variables are related to each other in an inverse relationship.

PhysicsLAB

IT'S IN THE BLOOD

FORENSICS LAB How can blood spatter provide clues?

APPLICATION

21. The mass values of specified volumes of pure gold nuggets are given in **Table 4.**

a. Plot mass versus volume from the values given in the table and draw the curve that best fits all points.

b. Describe the resulting curve.

c. According to the graph, what type of relationship exists between the mass of the pure gold nuggets and their volume?

d. What is the value of the slope of this graph? Include the proper units.

e. Write the equation showing mass as a function of volume for gold.

f. Write a word interpretation for the slope of the line.

Table 4 Mass of Pure Gold Nuggets

Volume (cm^3)	Mass (g)
1.0	19.4
2.0	38.6
3.0	58.1
4.0	77.4
5.0	96.5

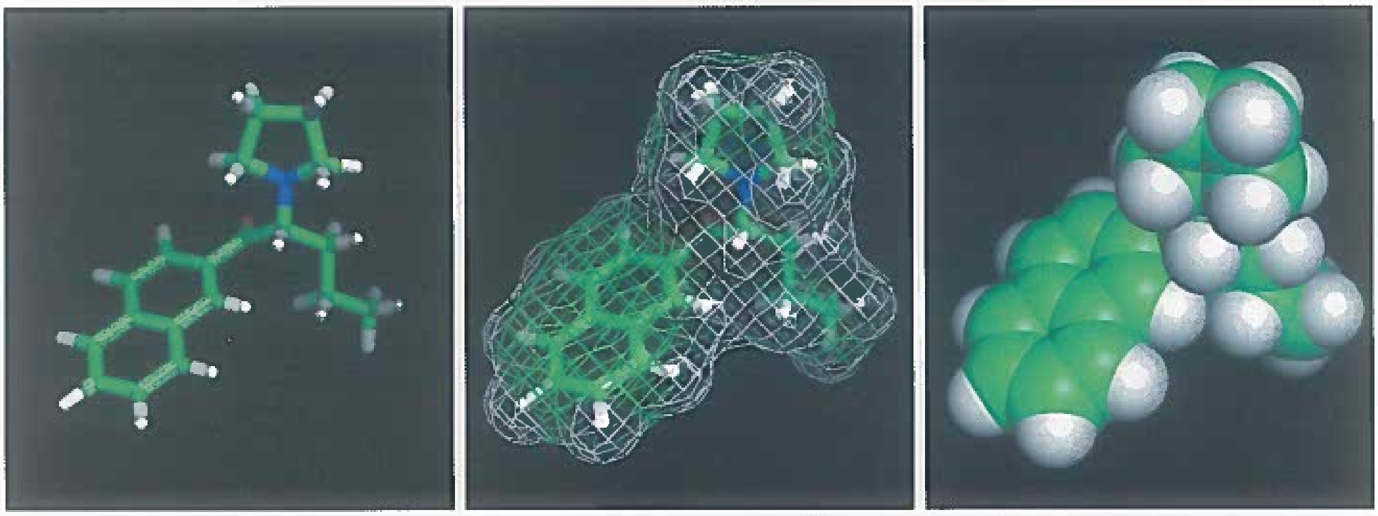


Figure 19 In order to create a realistic animation, computer animators use mathematical models of the real world to create a convincing fictional world. This computer model of a naphyrone molecule is in development on an animator's computer.

Predicting Values

When scientists discover relationships like the ones shown in the graphs in this section, they use them to make predictions. For example, the equation for the linear graph in **Figure 16** is as follows:

$$y = (0.08\ \text{cm/g})x + 13.7\ \text{cm}$$

Relationships, either learned as formulas or developed from graphs, can be used to predict values you haven't measured directly. How far would the spring in **Table 3** stretch with 49 g of mass?

$$y = (0.08\ \text{cm/g})(49\ \text{g}) + 13.7\ \text{cm}$$
$$= 18\ \text{cm}$$

It is important to decide how far you can extrapolate from the data you have. For example, 90 g is a value far outside the ones measured, and the spring might break rather than stretch that far.

Physicists use models to accurately predict how systems will behave: what circumstances might lead to a solar flare (an immense outburst of material from the Sun's surface into space), how changes to a grandfather clock's pendulum will change its ability to keep accurate time, or how magnetic fields will affect a medical instrument. People in all walks of life use models in many ways. One example is shown in **Figure 19.** With the tools you have learned in this chapter, you can answer questions and produce models for the physics questions you will encounter in the rest of this textbook.

PhysicsLAB

EXPLORING OBJECTS IN MOTION

How can you determine the speed of a vehicle?

SECTION 4 REVIEW

22. **MAINIDEA** Graph the following data. Time is the independent variable.

Time (s)	0	5	10	15	20	25	30	35
Speed (m/s)	12	10	8	6	4	2	2	2

23. **Interpret a Graph** What would be the meaning of a nonzero y-intercept in a graph of total mass versus volume?

24. **Predict** Use the relationship illustrated in **Figure 16** to determine the mass required to stretch the spring 15 cm.

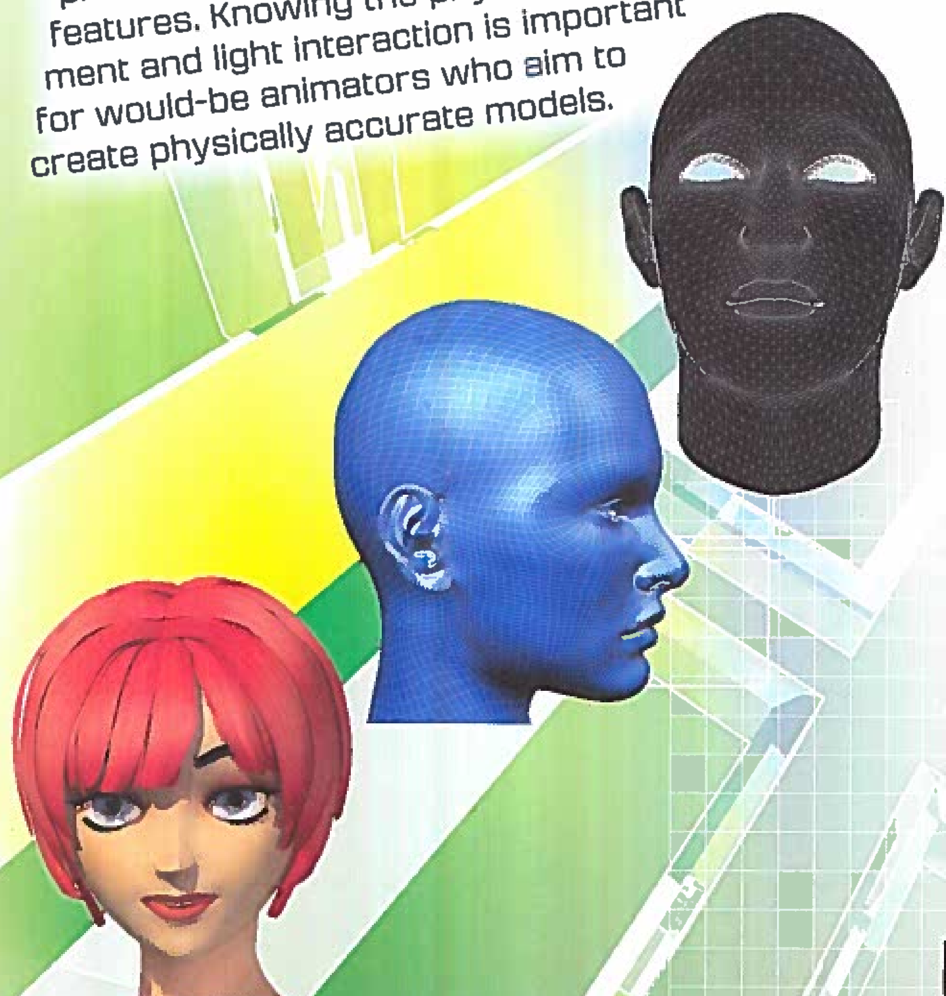
25. **Predict** Use the relationship shown in **Figure 18** to predict the travel time when speed is 110 km/h.

26. **Critical Thinking** Look again at the graph in **Figure 16.** In your own words, explain how the spring would be different if the line in the graph were shallower or had a smaller slope.

Coming to Life

The Physics Behind Animation

If you were asked to name careers that use physics, animator would probably not be the first that comes to your mind. Three-dimensional (3-D) computer animation has replaced traditional two-dimensional, hand-drawn animation as the preferred medium for big-screen animated features. Knowing the physics involved in movement and light interaction is important for would-be animators who aim to create physically accurate models.



Modeling movement Initially, 3-D models are either sculpted by hand or modeled directly in the computer. Internal control points are connected to a larger grid with fewer external control points called a cage, shown in **Figure 1.** Linear geometric equations linking the cage to animation variables allow animators to produce complex, physically accurate movement without needing to move each individual control point.

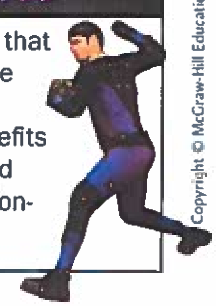
Computer power The computer power required to render all of these equations is substantial. For example, the rendering equation needed for global illumination—the simulation of light bouncing around an environment—typically involves 10 million points, each with its own equation. Each frame of the animation, representing 0.04 s of screen time, generally takes about six hours to render.

Realistic characters In the past, proponents of math-based animation avoided using complicated characters, such as human beings, who appeared jarringly unrealistic compared to their nonhuman counterparts. In these cases, many animation studios preferred the technique of motion capture. Improvements in the last decade have led to increasingly complex virtual environments, however, such as oceans, and more compelling "purely animated" human characters.

FIGURE 1 Each point on the numerous triangles that make up the character grid are linked by geometric equations.

GOINGFURTHER >>>

Research There is a debate that motion capture is a technique that takes the art out of animation. Compare the benefits and drawbacks of math-based animation with those of motion-capture animation.



STUDY GUIDE

BIG IDEA Physicists use scientific methods to investigate energy and matter.

SECTION 1 Methods of Science

VOCABULARY

- physics
- scientific methods
- hypothesis
- model
- scientific theory
- scientific law

MAIN IDEA Scientific investigations do not always proceed with identical steps but do contain similar methods.

- Scientific methods include making observations and asking questions about the natural world.
- Scientists use models to represent things that may be too small or too large, processes that take too much time to see completely, or a material that is hazardous.
- A scientific theory is an explanation of things or events based on knowledge gained from observations and investigations. A scientific law is a statement about what happens in nature, which seems to be true all the time.
- Science can't explain or solve everything. Questions about opinions or values can't be tested.

SECTION 2 Mathematics and Physics

VOCABULARY

- dimensional analysis
- significant figures

MAIN IDEA We use math to express concepts in physics.

- Using the metric system helps scientists around the world communicate more easily.
- Dimensional analysis is used to check that an answer will be in the correct units.
- Significant figures are the valid digits in a measurement.

SECTION 3 Measurement

VOCABULARY

- measurement
- precision
- accuracy

MAIN IDEA Making careful measurements allows scientists to repeat experiments and compare results.

- Measurements are reported with uncertainty because a new measurement that is within the margin of uncertainty confirms the old measurement.
- Precision is the degree of exactness with which a quantity is measured. Accuracy is the extent to which a measurement matches the true value.
- A common source of error that occurs when making a measurement is the angle at which an instrument is read. If the scale of an instrument is read at an angle, as opposed to at eye level, the measurement will be less accurate.

SECTION 4 Graphing Data

VOCABULARY

- independent variable
- dependent variable
- line of best fit
- linear relationship
- quadratic relationship
- inverse relationship

MAIN IDEA Graphs make it easier to interpret data, identify trends, and show relationships among a set of variables.

- Graphs contain information about the relationships among variables. Patterns that are not immediately evident in a list of numbers are seen more easily when the data are graphed.
- Common relationships shown in graphs include linear relationships, quadratic relationships, and inverse relationships. In a linear relationship the dependent variable varies linearly with the independent variable. A quadratic relationship occurs when one variable depends on the square of another. In an inverse relationship, one variable depends on the inverse of the other variable.
- Scientists use models and relationships between variables to make predictions.

SECTION 1 Methods of Science

Mastering Concepts

27. Describe a scientific method.

28. Explain why scientists might use each of the models listed below.
   a. physical model of the solar system
   b. computer model of airplane aerodynamics
   c. mathematical model of the force of attraction between two objects

SECTION 2 Mathematics and Physics

Mastering Concepts

29. Why is mathematics important to science?

30. What is the SI system?

31. How are base units and derived units related?

32. Suppose your lab partner recorded a measurement as 100 g.
   a. Why is it difficult to tell the number of significant figures in this measurement?
   b. How can the number of significant figures in such a number be made clear?

33. Give the name for each of the following multiples of the meter.
   a. $\frac{1}{100}$ m
   b. $\frac{1}{1000}$ m
   c. 1000 m

34. To convert 1.8 h to minutes, by what conversion factor should you multiply?

35. Solve each problem. Give the correct number of significant figures in the answers.
   a. 4.667×10^4 g + 3.02×10^5 g
   b. $(1.70\times10^2$ J$) \div (5.922\times10^{-4}$ cm$^3)$

Mastering Problems

36. Convert each of the following measurements to meters.
   a. 42.3 cm
   b. 6.2 pm
   c. 21 km
   d. 0.023 mm
   e. 214 μm
   f. 57 nm

37. Add or subtract as indicated.
   a. 5.80×10^9 s + 3.20×10^8 s
   b. 4.87×10^{-6} m − 1.93×10^{-6} m
   c. 3.14×10^{-5} kg + 9.36×10^{-5} kg
   d. 8.12×10^7 g − 6.20×10^6 g

38. **Ranking Task** Rank the following numbers according to the number of significant figures they have, from most to least: 1.234, 0.13, 0.250, 7.603, 0.08. Specifically indicate any ties.

39. State the number of significant figures in each of the following measurements.
   a. 0.00003 m
   b. 64.01 fm
   c. 80.001 m
   d. 6×10^8 kg
   e. 4.07×10^{16} m

40. Add or subtract as indicated.
   a. 16.2 m + 5.008 m + 13.48 m
   b. 5.006 m + 12.0077 m + 8.0084 m
   c. 78.05 cm^2 − 32.046 cm^2
   d. 15.07 kg − 12.0 kg

41. Multiply or divide as indicated.
   a. $(6.2\times10^{18}$ m$)(4.7\times10^{-10}$ m$)$
   b. $\frac{(5.6\times10^{-7}\text{ m})}{(2.8\times10^{-12}\text{ s})}$
   c. $(8.1\times10^{-4}$ km$)(1.6\times10^{-3}$ km$)$
   d. $\frac{(6.5\times10^5\text{ kg})}{(3.4\times10^3\text{ m}^3)}$

42. **Gravity** The force due to gravity is $F = mg$ where $g = 9.8$ N/kg.
   a. Find the force due to gravity on a 41.63-kg object.
   b. The force due to gravity on an object is 632 N. What is its mass?

43. **Dimensional Analysis** Pressure is measured in pascals, where 1 Pa = 1 kg/(m•s^2). Will the following expression give a pressure in the correct units?
$$\frac{(0.55\text{ kg})(2.1\text{ m/s})}{9.8\text{ m/s}^2}$$

SECTION 3 Measurement

Mastering Concepts

44. What determines the precision of a measurement?

45. How does the last digit differ from the other digits in a measurement?

Mastering Problems

46. A water tank has a mass of 3.64 kg when it is empty and a mass of 51.8 kg when it is filled to a certain level. What is the mass of the water in the tank?

47. The length of a room is 16.40 m, its width is 4.5 m, and its height is 3.26 m. What volume does the room enclose?

48. The sides of a quadrangular plot of land are 132.68 m, 48.3 m, 132.736 m, and 48.37 m. What is the perimeter of the plot?

49. How precise a measurement could you make with the scale shown in **Figure 20?**

Figure 20

50. Give the measurement shown on the meter in **Figure 21** as precisely as you can. Include the uncertainty in your answer.

Figure 21

51. Estimate the height of the nearest door frame in centimeters. Then measure it. How accurate was your estimate? How precise was your estimate? How precise was your measurement? Why are the two precisions different?

52. Temperature The temperature drops linearly from 24°C to 10°C in 12 hours.

a. Find the average temperature change per hour.

b. Predict the temperature in 2 more hours if the trend continues.

c. Could you accurately predict the temperature in 24 hours? Explain why or why not.

SECTION 4 Graphing Data

Mastering Concepts

53. How do you find the slope of a linear graph?

54. When driving, the distance traveled between seeing a stoplight and stepping on the brakes is called the reaction distance. Reaction distance for a given driver and vehicle depends linearly on speed.

a. Would the graph of reaction distance versus speed have a positive or a negative slope?

b. A driver who is distracted takes a longer time to step on the brake than a driver who is not. Would the graph of reaction distance versus speed for a distracted driver have a larger or smaller slope than for a normal driver? Explain.

55. During a laboratory experiment, the temperature of the gas in a balloon is varied and the volume of the balloon is measured. Identify the independent variable and the dependent variable.

56. What type of relationship is shown in **Figure 22?** Give the general equation for this type of relation.

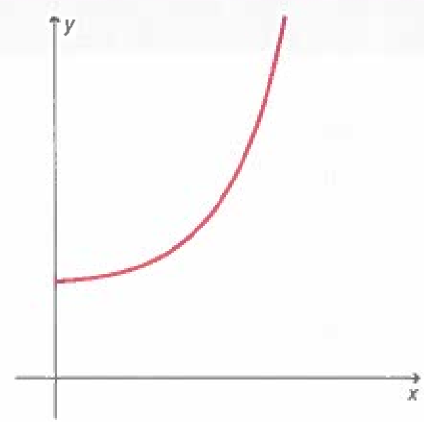


Figure 22

57. Given the equation $F = \frac{mv^2}{R}$, what kind of relationship exists between each of the following?

a. F and R

b. F and m

c. F and v

Mastering Problems

58. Figure 23 shows the masses of three substances for volumes between 0 and 60 cm^3.

a. What is the mass of 30 cm^3 of each substance?

b. If you had 100 g of each substance, what would be each of their volumes?

c. In one or two sentences, describe the meaning of the slopes of the lines in this graph.

d. Explain the meaning of each line's y-intercept.

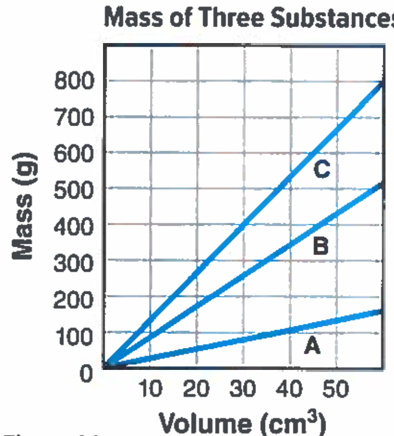


Figure 23

59. Suppose a mass is placed on a horizontal table that is nearly frictionless. Various horizontal forces are applied to the mass. The distance the mass traveled in 5 seconds for each force applied is measured. The results of the experiment are shown in **Table 5.**

Table 5 Distance Traveled with Different Forces

Force (N)	Distance (cm)
5.0	24
10.0	49
15.0	75
20.0	99
25.0	120
30.0	145

a. Plot the values given in the table and draw the curve that best fits all points.

b. Describe the resulting curve.

c. Use the graph to write an equation relating the distance to the force.

d. What is the constant in the equation? Find its units.

e. Predict the distance traveled when a 22.0-N force is exerted on the object for 5 s.

60. Suppose the procedure from the previous problem changed. The mass was varied while the force was kept constant. Time and distance were measured, and the acceleration of each mass was calculated. The results of the experiment are shown in **Table 6.**

Table 6 Acceleration of Different Masses

Mass (kg)	Acceleration (m/s^2)
1.0	12.0
2.0	5.9
3.0	4.1
4.0	3.0
5.0	2.5
6.0	2.0

a. Plot the values given in the table and draw the curve that best fits all points.

b. Describe the resulting curve.

c. Write the equation relating acceleration to mass given by the data in the graph.

d. Find the units of the constant in the equation.

e. Predict the acceleration of an 8.0kg mass.

61. During an experiment, a student measured the mass of 10.0 cm^3 of alcohol. The student then measured the mass of 20.0 cm^3 of alcohol. In this way, the data in **Table 7** were collected.

Table 7
The Mass Values of Specific Volumes of Alcohol

Volume (cm^3)	Mass (g)
10.0	7.9
20.0	15.8
30.0	23.7
40.0	31.6
50.0	39.6

a. Plot the values given in the table and draw the curve that best fits all the points.

b. Describe the resulting curve.

c. Use the graph to write an equation relating the volume to the mass of the alcohol.

d. Find the units of the slope of the graph. What is the name given to this quantity?

e. What is the mass of 32.5 cm^3 of alcohol?

Applying Concepts

62. Is a scientific method one set of clearly defined steps? Support your answer.

63. Explain the difference between a scientific theory and a scientific law.

64. **Figure 24** gives the height above the ground of a ball that is thrown upward from the roof of a building, for the first 1.5 s of its trajectory. What is the ball's height at $t = 0$? Predict the ball's height at $t = 2$ s and at $t = 5$ s.

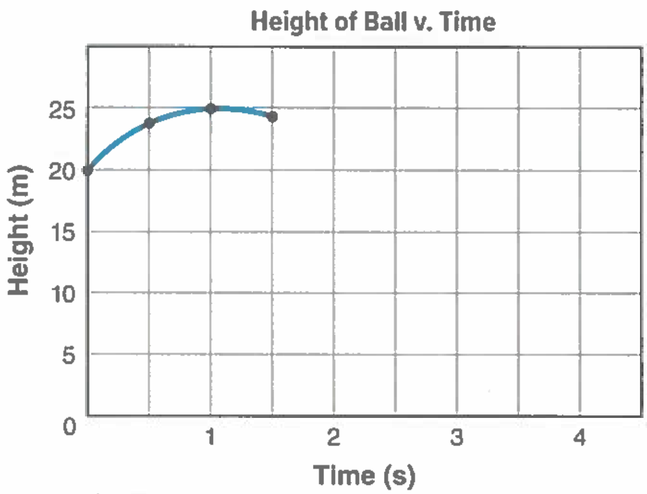


Figure 24

65. **Density** The density of a substance is its mass divided by its volume.

a. Give the metric unit for density.

b. Is the unit for density a base unit or a derived unit?

66. What metric unit would you use to measure each of the following?

a. the width of your hand

b. the thickness of a book cover

c. the height of your classroom

d. the distance from your home to your classroom

67. **Size** Make a chart of sizes of objects. Lengths should range from less than 1 mm to several kilometers. Samples might include the size of a cell, the distance light travels in 1 s, and the height of a room.

68. **Time** Make a chart of time intervals. Sample intervals might include the time between heartbeats, the time between presidential elections, the average lifetime of a human, and the age of the United States. In your chart, include several examples of very short and very long time intervals.

69. **Speed of Light** Two scientists measure the speed of light. One obtains $(3.001 \pm 0.001)\times 10^8$ m/s; the other obtains $(2.999 \pm 0.006)\times 10^8$ m/s.

a. Which is more precise?

b. Which is more accurate? (You can find the speed of light in the back of this textbook.)

70. You measure the dimensions of a desk as 132 cm, 83 cm, and 76 cm. The sum of these measures is 291 cm, while the product is 8.3×10^5 cm^3. Explain how the significant figures were determined in each case.

71. **Money** Suppose you receive AED 60.0 at the beginning of a week and spend AED 10.0 each day for lunch. You prepare a graph of the amount you have left at the end of each day for one week. Would the slope of this graph be positive, zero, or negative? Why?

72. Data are plotted on a graph, and the value on the y-axis is the same for each value of the independent variable. What is the slope? Why? How does y depend on x?

73. **Driving** The graph of braking distance versus car speed is part of a parabola. Thus, the equation is written $d = av^2 + bv + c$. The distance (d) has units in meters, and velocity (v) has units in meters/second. How could you find the units of a, b, and c? What would they be?

74. How long is the leaf in **Figure 25**? Include the uncertainty in your measurement.

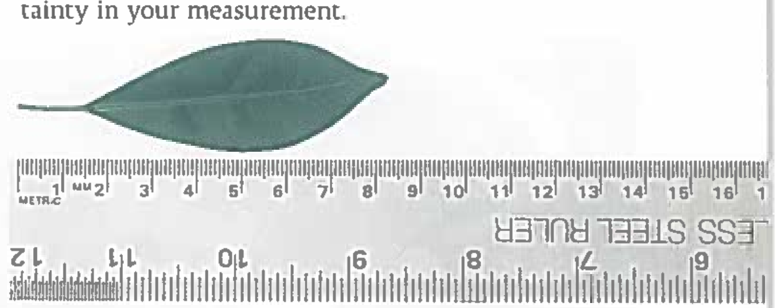


Figure 25

75. Explain the difference between a hypothesis and a scientific theory.

76. Give an example of a scientific law.

77. What reason might the ancient Greeks have had not to question the (incorrect) hypothesis that heavier objects fall faster than lighter objects? *Hint: Did you ever question which falls faster?*

78. A graduated cylinder is marked every mL. How precise a measurement can you make with this instrument?

79. **Reverse Problem** Write a problem with real-life objects for which the graph in **Figure 26** could be part of the solution.

Figure 26

Mixed Review

80. Arrange the following numbers from most precise to least precise: 0.0034 m, 45.6 m, 1234 m.

81. **Figure 27** shows an engine of a jet plane. Explain why a width of 80 m would be an unreasonable value for the diameter of the engine. What would be a reasonable value?

Figure 27

82. You are cracking a code and have discovered the following conversion factors: 1.23 longs = 23.0 mediums, and 74.5 mediums = 645 shorts. How many shorts are equal to one long?

83. You are given the following measurements of a rectangular bar: length = 2.347 m, height = 3.452 cm, thickness = 2.31 mm, mass = 1659 g. Determine the volume, in cubic meters, and density, in g/cm^3, of the beam.

84. A drop of water contains 1.7×10^{21} molecules. If the water evaporated at the rate of one million molecules per second, how many years would it take for the drop to completely evaporate?

85. A 17.6-g sample of metal is placed in a graduated cylinder containing 10.0 cm^3 of water. If the water level rises to 12.20 cm^3, what is the density of the metal?

Thinking Critically

86. **Apply Concepts** It has been said that fools can ask more questions than the wise can answer. In science, it is frequently the case that one wise person is needed to ask the right question rather than to answer it. Explain.

87. **Apply Concepts** Find the approximate mass of water in kilograms needed to fill a container that is 1.40 m long and 0.600 m wide to a depth of 34.0 cm. Report your result to one significant figure. (Use a reference source to find the density of water.)

88. **Analyze and Conclude** A container of gas with a pressure of 101 kPa has a volume of 324 cm^3 and a mass of 4.00 g. If the pressure is increased to 404 kPa, what is the density of the gas? Pressure and volume are inversely proportional.

89. BIGIDEA **Design an Experiment** How high can you throw a ball? What variables might affect the answer to this question?

90. **Problem Posing** Complete this problem so that the final answer will have 3 significant figures: "A home remedy used to prevent swimmer's ear calls for equal parts vinegar and rubbing alcohol. You measure 45.62 mL of vinegar . . . ."

Writing in Physics

91. Research and describe a topic in the history of physics. Explain how ideas about the topic changed over time. Be sure to include the contributions of scientists and to evaluate the impact of their contributions on scientific thought and the world outside the laboratory.

92. Explain how improved precision in measuring time would have led to more accurate predictions about how an object falls.

CHAPTER 1 STANDARDIZED TEST PRACTICE

MULTIPLE CHOICE

1. Two laboratories use radiocarbon dating to measure the age of two wooden spear handles found in the same grave. Lab A finds an age of 2250 ± 40 years for the first object; lab B finds an age of 2215 ± 50 years for the second object. Which is true?

A. Lab A's reading is more accurate than lab B's.
B. Lab A's reading is less accurate than lab B's.
C. Lab A's reading is more precise than lab B's.
D. Lab A's reading is less precise than lab B's.

2. Which of the following is equal to 86.2 cm?

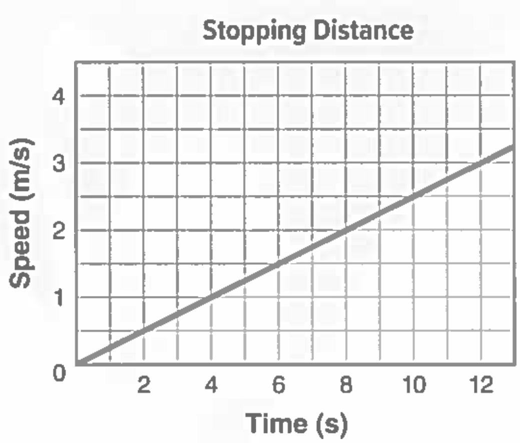
A. 8.62 m **C.** 8.62×10^{-4} km
B. 0.862 mm **D.** 862 dm

3. Ahmed has a problem to do involving time, distance, and velocity, but he has forgotten the formula. The question asks him for a measurement in seconds, and the numbers that are given have units of m/s and km. What could Ahmed do to get the answer in seconds?

A. Multiply the km by the m/s, then multiply by 1000.
B. Divide the km by the m/s, then multiply by 1000.
C. Divide the km by the m/s, then divide by 1000.
D. Multiply the km by the m/s, then divide by 1000.

4. What is the slope of the graph?

A. 0.25 m/s^2 **C.** 2.5 m/s^2
B. 0.4 m/s^2 **D.** 4.0 m/s^2



5. Which formula is equivalent to $D = \frac{m}{V}$?

A. $V = \frac{m}{D}$ **C.** $V = \frac{mD}{V}$
B. $V = Dm$ **D.** $V = \frac{D}{m}$

6. A computer simulation is an example of what?

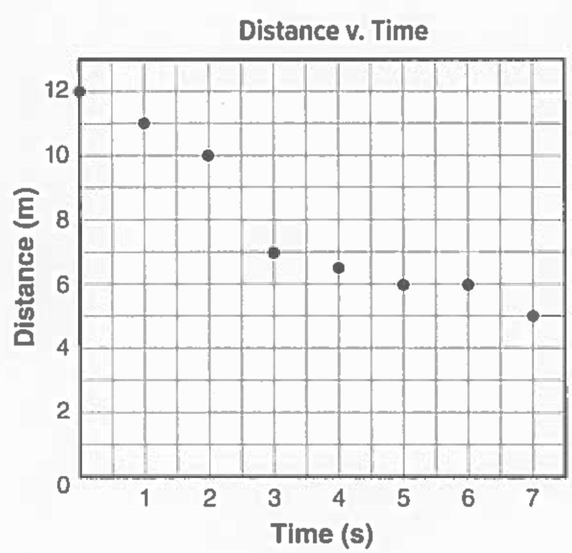
A. a hypothesis **C.** a scientific law
B. a model **D.** a scientific theory

FREE RESPONSE

7. You want to calculate an acceleration, in units of m/s^2, given a force, in N, and the mass, in g, on which the force acts. ($1\ N = 1\ kg{\cdot}m/s^2$)

a. Rewrite the equation $F = ma$ so a is in terms of m and F.
b. What conversion factor will you need to multiply by to convert grams to kilograms?
c. A force of 2.7 N acts on a 350g mass. Write the equation you will use, including the conversion factor, to find the acceleration.

8. Find an equation for a line of best fit for the data shown below.



CHAPTER 2

Representing Motion

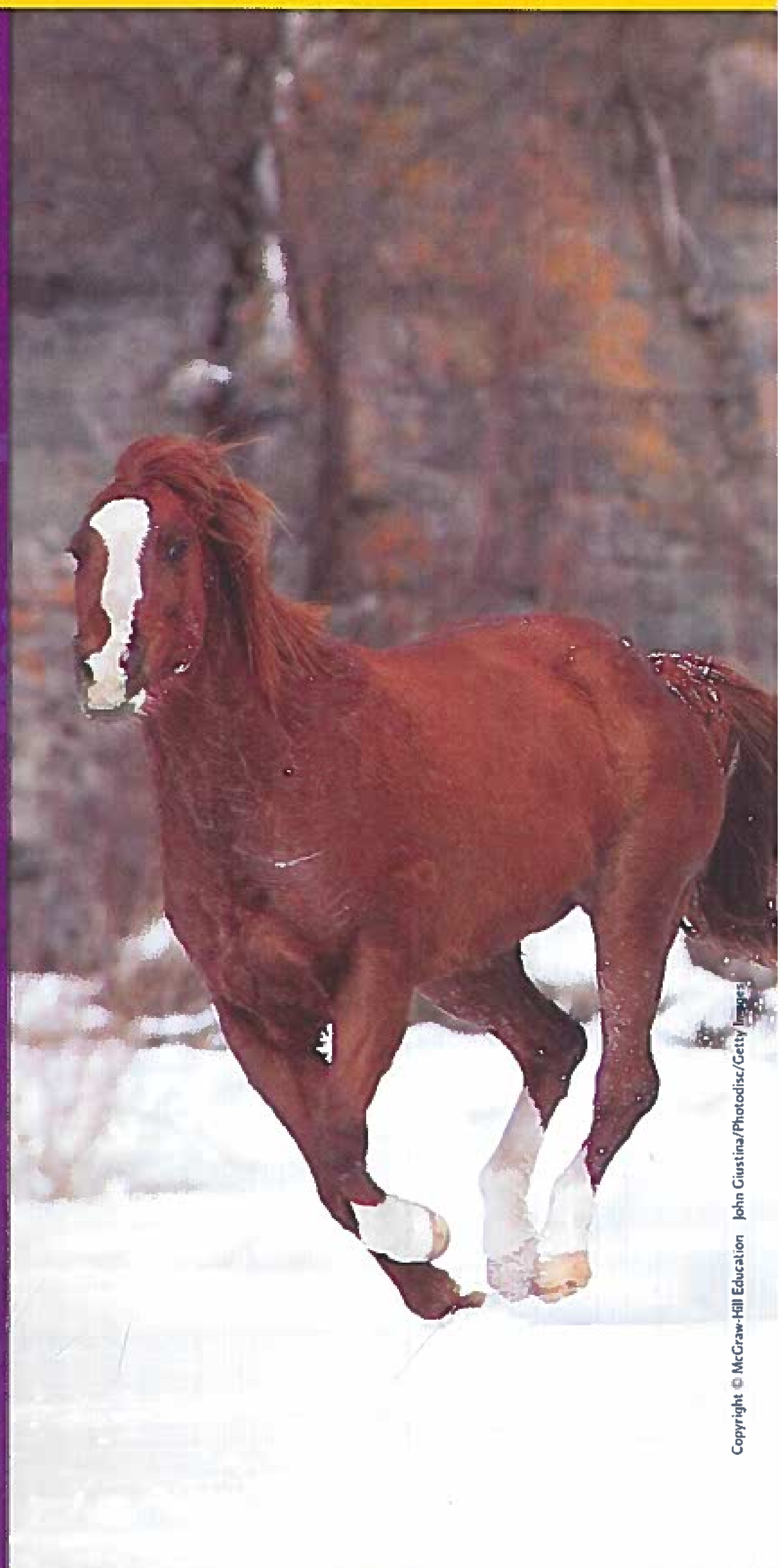
BIGIDEA **You can use displacement and velocity to describe an object's motion.**

SECTIONS

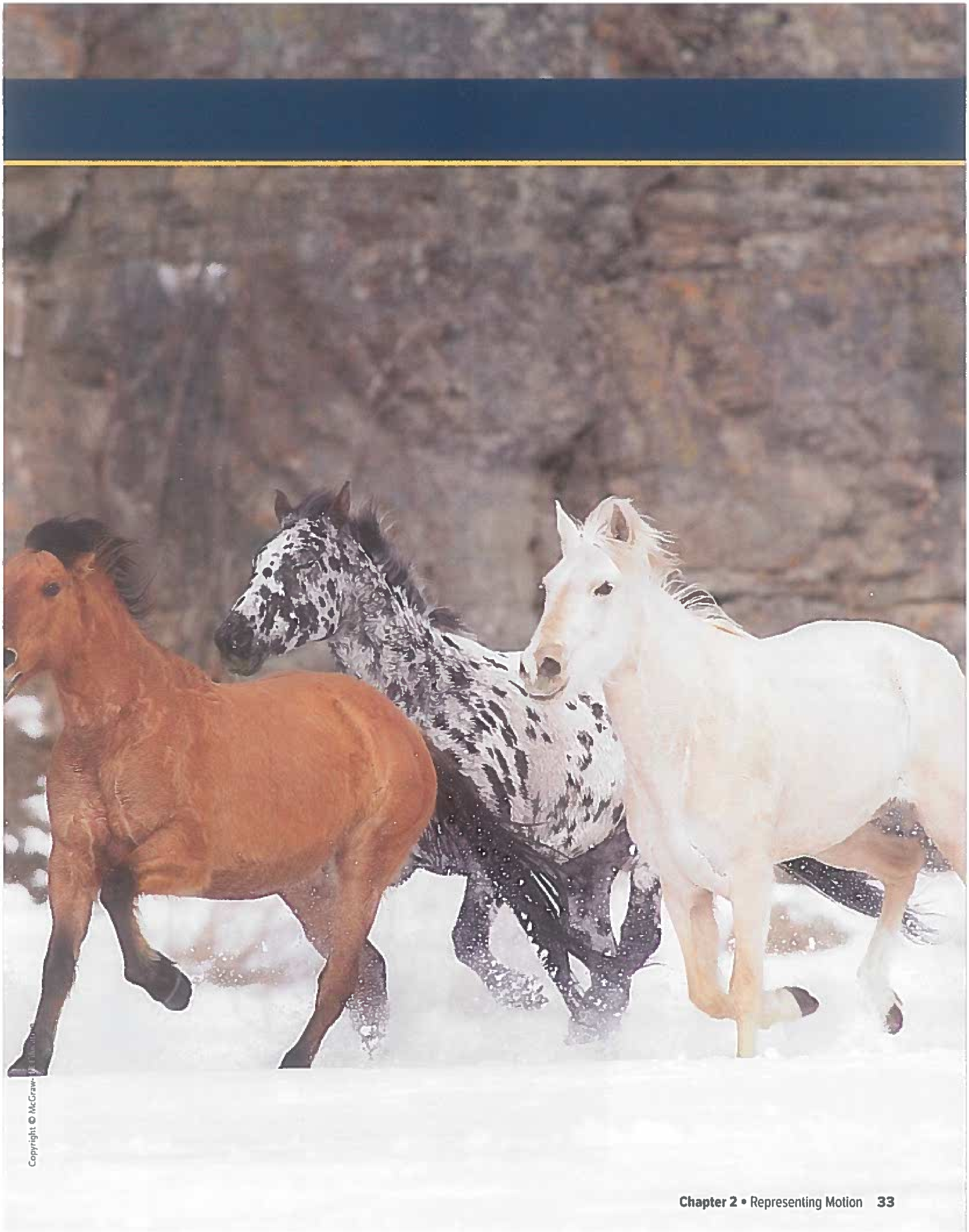
LaunchLAB

TOY CAR RACE

What factors determine an object's speed?

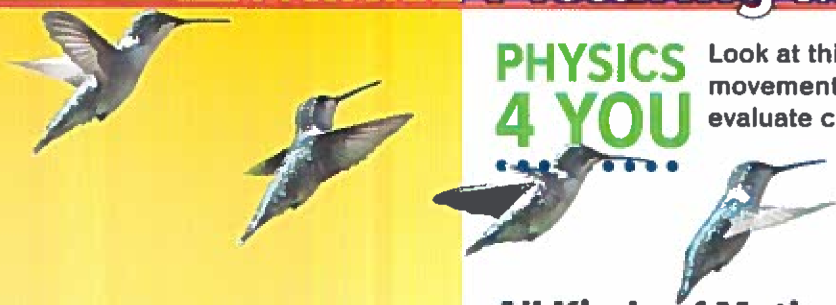


Glencoe Physics: Principles & Problems, Student Edition © 2017



SECTION 1

Picturing Motion



PHYSICS 4 YOU **Look at this multiple-exposure photograph of a bird's movement. Physicists can use these photographs to evaluate changes in position and velocity.**

MAIN IDEA

You can use motion diagrams to show how an object's position changes over time.

Essential Questions

- How do motion diagrams represent motion?
- How can you use a particle model to represent a moving object?

Review Vocabulary

model a representation of an idea, event, structure, or object to help people better understand it

New Vocabulary

motion diagram
particle model

All Kinds of Motion

You have learned about scientific processes that will be useful in your study of physics. You will now begin to use these tools to analyze motion. In subsequent chapters, you will apply these processes to many kinds of motion. You will use words, sketches, diagrams, graphs, and equations. These concepts will help you determine how fast and how far an object moves, in which direction that object is moving, whether that object is speeding up or slowing down, and whether that object is standing still or moving at a constant speed.

Changes in position What comes to your mind when you hear the word *motion*? A spinning ride at an amusement park? A baseball soaring over a fence for a home run? Motion is all around you—from fast trains and speedy skiers to slow breezes and lazy clouds. Objects move in many different ways, such as the straight-line path of a bowling ball in a bowling lane's gutter, the curved path of a car rounding a turn, the spiral of a falling kite, and swirls of water circling a drain. When an object is in motion, such as the subway train in **Figure 1**, its position changes.

Some types of motion are more complicated than others. When beginning a new area of study, it is generally a good idea to begin with the least complicated situation, learn as much as possible about it, and then gradually add more complexity to that simple model. In the case of motion, you will begin your study with movement along a straight line.

Figure 1 The subway train appears blurry in the photograph because its position changed during the time the camera shutter was open.

Describe how the picture would be different if the train were sitting still.

Movement along a straight line In general, an object can move along many different kinds of paths, but straight-line motion follows a path directly between two points without turning left or right. For example, you might describe an object's motion as forward and backward, up and down, or north and south. In each of these cases, the object moves along a straight line.

Suppose you are reading this textbook at home. As you start to read, you glance over at your pet rabbit and see that it is sitting in a corner of the cage. Sometime later you look over again, and you see that it now is sitting next to the food dish in the opposite corner of the cage. You can infer that your rabbit has moved from one place to another in the time between your observations. What factors helped you make this inference about the rabbit's movement?

The description of motion is a description of place and time. You must answer the questions of where an object is located and when it is at that position in order to clearly describe its motion. Next, you will look at some tools that help determine when an object is at a particular place.

☑ **READING CHECK** **Identify** two factors you must know in order to describe the motion of an object along a straight line.

Motion Diagrams

Consider the following example of straight-line motion: a runner jogs along a straight path. One way of representing the runner's motion is to create a series of images showing the runner's position at equal time intervals. You can do this by photographing the runner in motion to obtain a sequence of pictures. Each photograph will show the runner at a point that is farther along the straight path.

Consecutive images Suppose you point a camera in a direction and a runner crosses the camera's field of view. Then you take a series of photographs of the runner at equal time intervals, without moving the camera. **Figure 2** shows what a series of consecutive images for a runner might look like. Notice that the runner is in a different position in each image, but everything in the background remains in the same position. This indicates that, relative to the camera and the ground, only the runner is in motion.

☑ **READING CHECK** **Decide** whether the spaces between a moving object's position must be equal if photographs are taken of the object at equal time intervals. Explain.

Figure 2 You can tell that the jogger is in motion because his position changes relative to the tree and the ground.

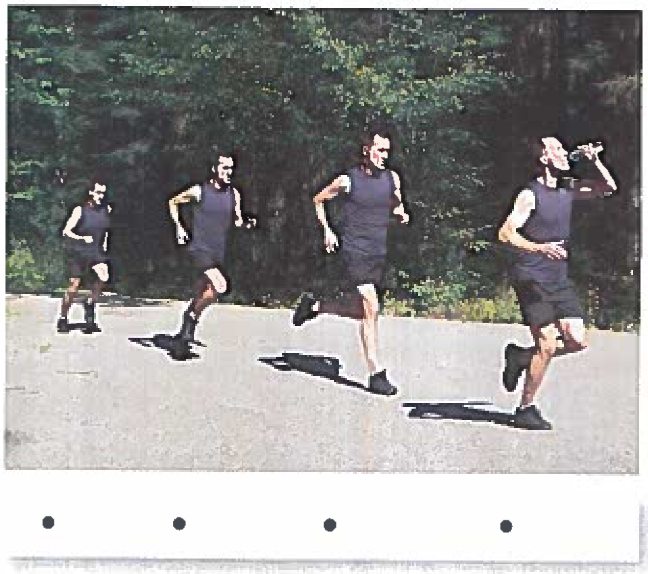


Figure 3 Combining the images from **Figure 2** produces this motion diagram of the jogger's movement. The series of dots at the bottom of the figure is a particle model that corresponds to the motion diagram.

Explain how the particle model shows that the jogger's speed is not changing.

View an **animation of motion diagrams v. particle motion.**

Combining images Suppose that you layered the four images of the runner from **Figure 2** one on top of the other. **Figure 3** shows what such a layered image might look like. You see more than one image of the moving runner, but you see only a single image of the tree and other motionless objects in the background. A series of images showing the positions of a moving object at equal time intervals is called a **motion diagram.**

Particle Models

Keeping track of the runner's motion is easier if you disregard the movement of his arms and his legs and instead concentrate on a single point at the center of his body. In effect, you can disregard the fact that the runner has size and imagine that he is a very small object located precisely at that central point. In a **particle model,** you replace the object or objects of interest with single points. Use of the particle model is common throughout the study of physics.

To use the particle model, the object's size must be much less than the distance it moves. The object's internal motions, such as the waving of the runner's arms or the movement of his legs, are ignored in the particle model. In the photographic motion diagram, you could identify one central point on the runner, such as a point centered at his waistline, and draw a dot at its position at different times. The bottom of **Figure 3** shows the particle model for the runner's motion. In the next section, you will learn how to create and use a motion diagram that shows how far an object moved and how much time it took to move that far.

PhysicsLAB

MOTION DIAGRAMS

How do the motion diagrams of a fast toy car and a slow toy car differ?

SECTION 1 REVIEW

1. **MAINIDEA** How does a motion diagram represent an object's motion?

2. **Motion Diagram of a Bike Rider** Draw a particle model motion diagram for a bike rider moving at a constant pace along a straight path.

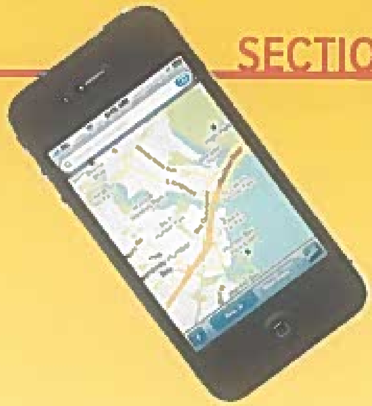
3. **Motion Diagram of a Car** Draw a particle model motion diagram corresponding to the motion diagram in **Figure 4** for a car coming to a stop at a stop sign. What point on the car did you use to represent the car?

Figure 4

4. **Motion Diagram of a Bird** Draw a particle model motion diagram corresponding to the motion diagram in **Figure 5** for a flying bird. What point on the bird did you choose to represent the bird?

Figure 5

5. **Critical Thinking** Draw particle model motion diagrams for two runners during a race in which the first runner crosses the finish line as the other runner is three-fourths of the way to the finish line.



SECTION 2

Where and When?

PHYSICS 4 YOU Have you ever used an electronic map for directions? These useful devices display the distances and directions you need to go. Many even show the time for different parts of the trip. To find your way to a place, you need clear directions for getting there.

MAIN IDEA

A coordinate system is helpful when you are describing motion.

Essential Questions

- What is a coordinate system?
- How does the chosen coordinate system affect the sign of objects' positions?
- How are time intervals measured?
- What is displacement?
- How are motion diagrams helpful in answering questions about an object's position or displacement?

Review Vocabulary

dimension extension in a given direction; one dimension is along a straight line; three dimensions are height, width, and length

New Vocabulary

coordinate system
origin
position
distance
magnitude
vector
scalar
time interval
displacement
resultant

Coordinate Systems

Is it possible to measure distance and time on a motion diagram? Before photographing a runner, you could place a long measuring tape on the ground to show where the runner is in each image. A stopwatch within the camera's view could show the time. But where should you place the end of the measuring tape? When should you start the stopwatch?

Position and distance It is useful to identify a system in which you have chosen where to place the zero point of the measuring tape and when to start the stopwatch. A **coordinate system** gives the location of the zero point of the variable you are studying and the direction in which the values of the variable increase. The **origin** is the point at which all variables in a coordinate system have the value zero. In the example of the runner, the origin, which is the zero point of the measuring tape, could be 6 m to the left of the tree. Because the motion is in a straight line, your measuring tape should lie along this line. The straight line is an axis of the coordinate system.

You can indicate how far the runner in **Figure 6** is from the origin at a certain time on the motion diagram by drawing an arrow from the origin to the point that represents the runner, shown at the bottom of the figure. This arrow represents the runner's **position**, the distance and direction from the origin to the object. In general, **distance** is the entire length of an object's path, even if the object moves in many directions. Because the motion in **Figure 6** is in one direction, the arrow lengths represent distance.

Motion Diagram

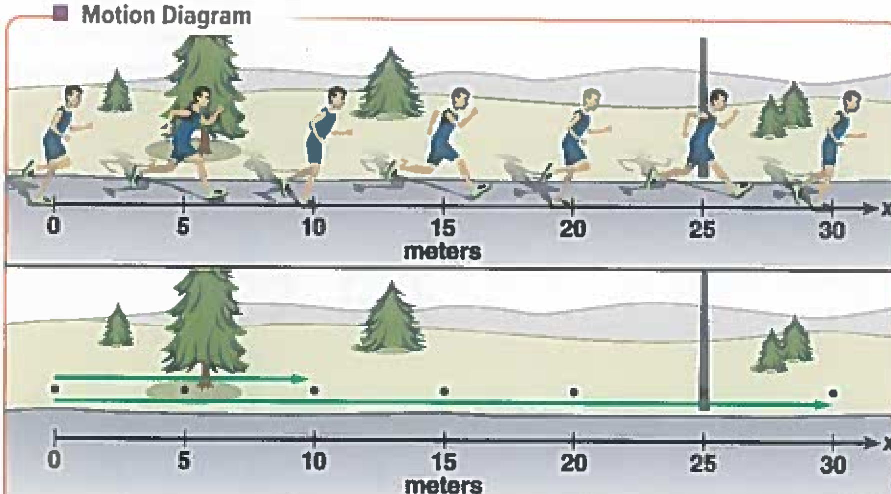


Figure 6 A simplified motion diagram uses dots to represent a moving object and arrows to indicate positions.

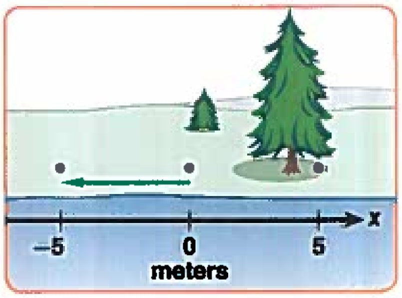


Figure 7 The green arrow indicates a negative position of −5 m if the direction right of the origin is chosen as positive.

Infer What position would the arrow indicate if you chose the direction left of the origin as positive?

Negative position Is there such a thing as a negative position? Suppose you chose the coordinate system just described but this time placed the origin 4 m left of the tree with the *x*-axis extending in a positive direction to the right. A position 9 m left of the tree, or 5 m left of the origin, would be a negative position, as shown in **Figure 7.**

Vectors and Scalars

Many quantities in physics have both size, also called **magnitude,** and direction. A quantity that has both magnitude and direction is called a **vector.** You can represent a vector with an arrow. The length of the arrow represents the magnitude of the vector, and the direction of the arrow represents the direction of the vector. A quantity that is just a number without any direction, such as distance, time, or temperature, is called a **scalar.** In this textbook, we will use boldface letters to represent vector quantities and regular letters to represent scalars.

Time intervals are scalars. When analyzing the runner's motion, you might want to know how long it took his to travel from the tree to the lamppost. You can obtain this value by finding the difference between the stopwatch reading at the tree and the stopwatch reading at the lamppost. **Figure 8** shows these stopwatch readings. The difference between two times is called a **time interval.**

A common symbol for a time interval is Δt, where the Greek letter delta (Δ) is used to represent a change in a quantity. Let t_i represent the initial (starting) time, when the runner was at the tree. Let t_f represent the final (ending) time of the interval, when the runner was at the lamppost. We define a time interval mathematically as follows.

TIME INTERVAL

The time interval is equal to the change in time from the initial time to the final time.

$$\Delta t = t_f - t_i$$

The subscripts i and f represent the initial and final times, but they can be the initial and final times of any time interval you choose. In the example of the runner, the time it takes for his to go from the tree to the lamppost is $t_f - t_i = 5.0\text{ s} - 1.0\text{ s} = 4.0\text{ s}$. You could instead describe the time interval for the runner to go from the origin to the lamppost. In this case the time interval would be $t_f - t_i = 5.0\text{ s} - 0.0\text{ s} = 5.0\text{ s}$. The time interval is a scalar because it has no direction. What about the runner's position? Is it also a scalar?

VOCABULARY
Science Usage v. Common Usage

Magnitude
- **Science usage**
  a measure of size
  When drawing vectors, the magnitude of a vector is proportional to that vector's length.
- **Common usage**
  great size or extent
  The magnitude of the Grand Canyon is difficult to capture in photographs.

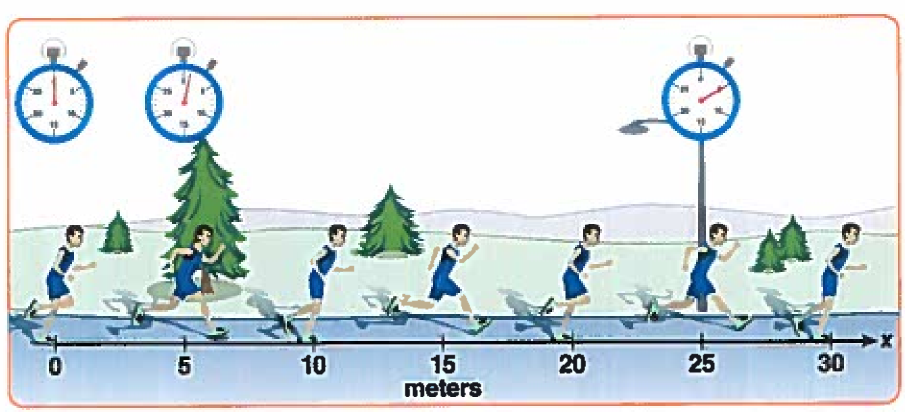


Figure 8 You can use the clocks in the figure to calculate the time interval (Δt) for the runner's movement from one position to another.

Positions and displacements are vectors. You have already seen how a position can be described as negative or positive in order to indicate whether that position is to the left or the right of a coordinate system's origin. This suggests that position is a vector because position has direction–either right or left in this case.

Figure 9 shows the position of the runner at both the tree and the lamppost. Notice that you can draw an arrow from the origin to the location of the runner in each case. These arrows have magnitude and direction. In common speech, a position refers to a certain place, but in physics, the definition of a position is more precise. A position is a vector with the arrow's tail at the origin of a coordinate system and the arrow's tip at the place.

You can use the symbol $\mathbf{x}$ to represent position vectors mathematically. In **Figure 9**, the symbol $\mathbf{x}_i$ represents the position at the tree, and the symbol $\mathbf{x}_f$ represents the position at the lamppost. The symbol $\Delta\mathbf{x}$ represents the change in position from the tree to the lamppost. Because a change in position is described and analyzed so often in physics, it has a special name. In physics, a change in position is called a **displacement**. Because displacement has direction, it is a vector.

READING CHECK Contrast the distance an object moves and the object's displacement for straight-line motion.

What was the runner's displacement when he ran from the tree to the lamppost? By looking at **Figure 9**, you can see that this displacement is 20 m to the right. Notice also, that the displacement from the tree to the lamppost ($\Delta\mathbf{x}$) equals the position at the lamppost ($\mathbf{x}_f$) minus the position at the tree ($\mathbf{x}_i$). This is true in general; displacement equals final position minus initial position.

DISPLACEMENT

Displacement is the change in position from initial position to final position.

$$\Delta \mathbf{x} = \mathbf{x}_f - \mathbf{x}_i$$

Remember that the initial and final positions are the start and the end of any interval you choose. Although position is a vector, sometimes the magnitude of a position is described without the boldface. In this case, a plus or minus sign might be used to indicate direction.

READING CHECK Describe what the direction and length of a displacement arrow indicate.

MiniLAB

VECTOR MODELS

How can you model vector addition using construction toys?

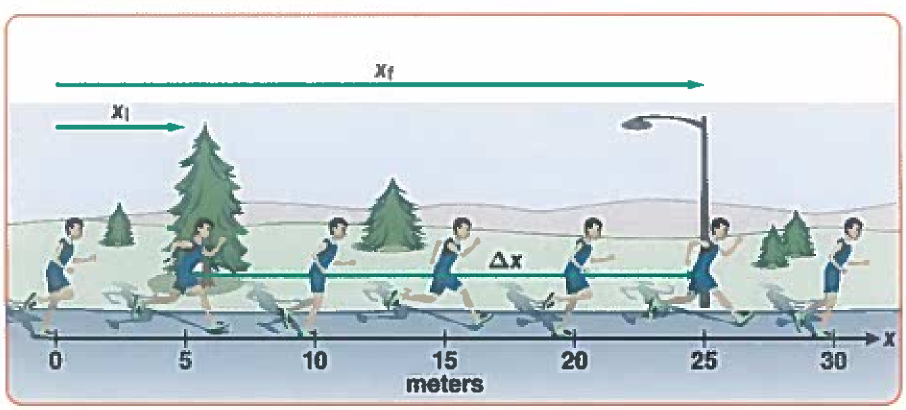


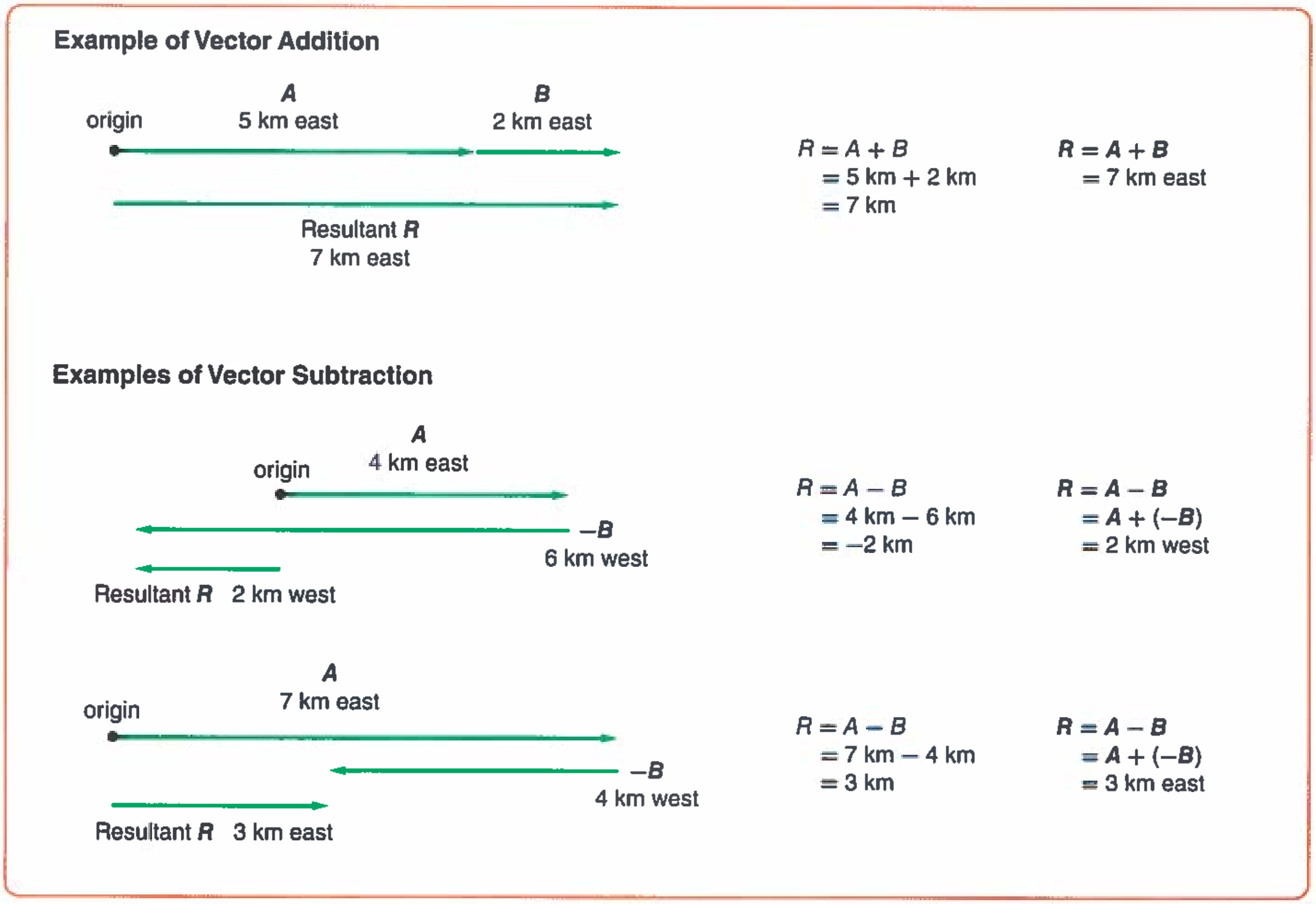
Figure 9 The vectors $\mathbf{x}_i$ and $\mathbf{x}_f$ represent positions. The vector $\Delta\mathbf{x}$ represents displacement from $\mathbf{x}_i$ to $\mathbf{x}_f$.

Describe the displacement from the lamppost to the tree.

Vector addition and subtraction You will learn about many different types of vectors in physics, including velocity, acceleration, and momentum. Often, you will need to find the sum of two vectors or the difference between two vectors. A vector that represents the sum of two other vectors is called a **resultant.** **Figure 10** shows how to add and subtract vectors in one dimension. In a later chapter, you will learn how to add and subtract vectors in two dimensions.

Figure 10 You can use a diagram or an equation to combine vectors.

Analyze What is the sum of a vector 12 m north and a vector 8 m north?



SECTION 2 REVIEW

6. **MAINIDEA** Identify a coordinate system you could use to describe the motion of a girl swimming across a rectangular pool.

7. **Displacement** The motion diagram for a car traveling on an interstate highway is shown below. The starting and ending points are indicated.

   Start • • • • • • End

   Make a copy of the diagram. Draw a vector to represent the car's displacement from the starting time to the end of the third time interval.

8. **Position** Two students added a vector for a moving object's position at $t = 2$ s to a motion diagram. When they compared their diagrams, they found that their vectors did not point in the same direction. Explain.

9. **Displacement** The motion diagram for a boy walking to school is shown below.

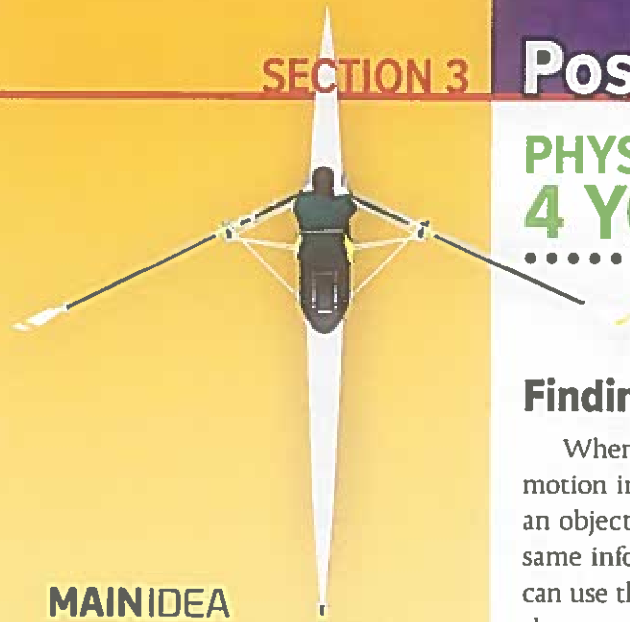
   Home • • • • • • • • • • School

   Make a copy of this motion diagram, and draw vectors to represent the displacement between each pair of dots.

10. **Critical Thinking** A car travels straight along a street from a grocery store to a post office. To represent its motion, you use a coordinate system with its origin at the grocery store and the direction the car is moving as the positive direction. Your friend uses a coordinate system with its origin at the post office and the opposite direction as the positive direction. Would the two of you agree on the car's position? Displacement? Distance? The time interval the trip took? Explain.

SECTION 3

Position-Time Graphs



PHYSICS 4 YOU

Many graphs show trends over time. For example, a graph might show the price of gasoline through the course of several months or years. Similarly, a position-time graph can show how a rower's position changes through time. Rowers can use graphs to analyze their performances.

MAIN IDEA

You can use position-time graphs to determine an object's position at a certain time.

Essential Questions

- What information do position-time graphs provide?
- How can you use a position-time graph to interpret an object's position or displacement?
- What are the purposes of equivalent representations of an object's motion?

Review Vocabulary

intersection a point where lines meet and cross

New Vocabulary

position-time graph
instantaneous position

Finding Positions

When analyzing complex motion, it often is useful to represent the motion in a variety of ways. A motion diagram contains information about an object's position at various times. Tables and graphs can also show this same information. Review the motion diagrams in **Figure 8** and **Figure 9.** You can use these diagrams to organize the times and corresponding positions of the runner, as in **Table 1.**

Plotting data The data listed in **Table 1** can be presented on a **position-time graph,** in which the time data is plotted on a horizontal axis and the position data is plotted on a vertical axis. The graph of the runner's motion is shown in **Figure 11.** To draw this graph, first plot the runner's positions. Then, draw a line that best fits the points.

Estimating time and position Notice that the graph is not a picture of the runner's path–the graphed line is sloped, but the runner's path was horizontal. Instead, the line represents the most likely positions of the runner at the times between the recorded data points. Even though there is no data point exactly when the runner was 12.0 m beyond his starting point or where he was at $t = 4.5$ s, you can use the graph to estimate the time or his position. The example problem on the next page shows how.

Table 1 Position v. Time

Time (s)	Position (m)
0.0	0.0
1.0	5.0
2.0	10.0
3.0	15.0
4.0	20.0
5.0	25.0

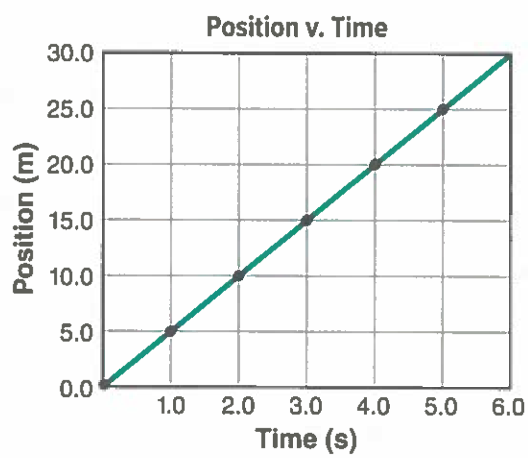


Figure 11 You can create a position-time graph by plotting the positions and times from the table. By drawing a best-fit line, you can estimate other times and positions.

Explain Why is the line on the graph sloped even though it describes motion along a flat path?

EXAMPLE 1

ANALYZE A POSITION-TIME GRAPH When did the runner whose motion is described in **Figure 11** reach 12.0 m beyond the starting point? Where was he after 4.5 s?

1 ANALYZE THE PROBLEM

Restate the questions.

Question 1: At what time was the magnitude of the runner's position (x) equal to 12.0 m?

Question 2: What was the runner's position at time $t = 4.5$ s?

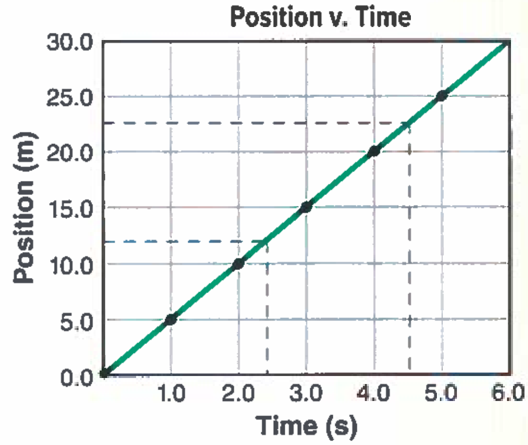
2 SOLVE FOR THE UNKNOWN

Question 1

Examine the graph to find the intersection of the best-fit line with a horizontal line at the 12.0 m mark. Next, find where a vertical line from that point crosses the time axis. The value of t there is 2.4 s.

Question 2

Find the intersection of the graph with a vertical line at 4.5 s (halfway between 4.0 s and 5.0 s on this graph). Next, find where a horizontal line from that point crosses the position axis. The value of x is approximately 22.5 m.



APPLICATION

*For problems 11–13, refer to **Figure 12**.*

11. The graph in **Figure 12** represents the motion of a car moving along a straight highway. Describe in words the car's motion.

12. Draw a particle model motion diagram that corresponds to the graph.

13. Answer the following questions about the car's motion. Assume that the positive x-direction is east of the origin and the negative x-direction is west of the origin.

a. At what time was the car's position 25.0 m east of the origin?

b. Where was the car at time $t = 1.0$ s?

c. What was the displacement of the car between times $t = 1.0$ s and $t = 3.0$ s?

14. The graph in **Figure 13** represents the motion of two pedestrians who are walking along a straight sidewalk in a city. Describe in words the motion of the pedestrians. Assume that the positive direction is east of the origin.

15. CHALLENGE Salem walked down the hall at school from the cafeteria to the band room, a distance of 100.0 m. A class of physics students recorded and graphed his position every 2.0 s, noting that he moved 2.6 m every 2.0 s. When was Salem at the following positions?

a. 25.0 m from the cafeteria

b. 25.0 m from the band room

c. Create a graph showing Salem's motion.

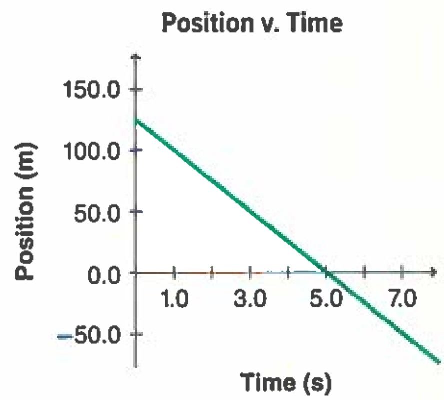


Figure 12

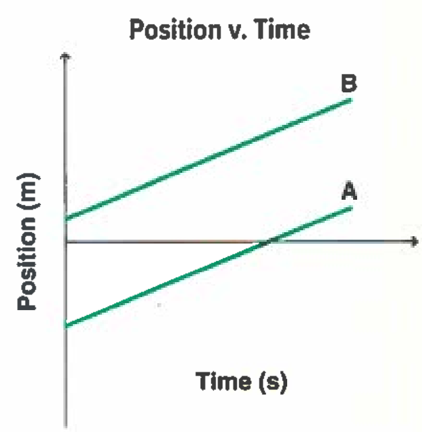
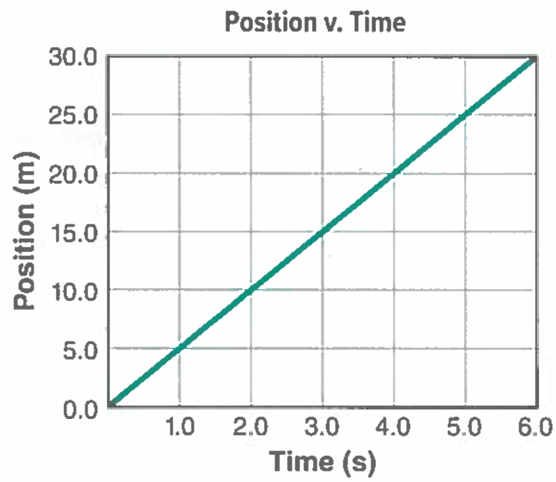


Figure 13

Table 1 Position v. Time	
Time (s)	Position (m)
0.0	0.0
1.0	5.0
2.0	10.0
3.0	15.0
4.0	20.0
5.0	25.0



Motion Diagram

Begin • • • • • • • End

Figure 14 You can describe the runner's motion using the data table, the motion diagram, and the graph.

Identify one benefit the table has over the graph.

Instantaneous position How long did the runner spend at any location? Each position has been linked to a time, but how long did that time last? You could say "an instant," but how long is that? If an instant lasts for any finite amount of time, then the runner would have stayed at the same position during that time, and he would not have been moving. An instant is not a finite period of time, however. It lasts zero seconds. The symbol **x** represents the runner's **instantaneous position**—the position at a particular instant. Instantaneous position is usually simply called position.

☑ **READING CHECK Explain** what is meant by the instantaneous position of a runner.

Equivalent representations As shown in **Figure 14**, you now have several different ways to describe motion. You might describe motion using words, pictures (or pictorial representations), motion diagrams, data tables, or position-time graphs. All of these representations contain the same information about the runner's motion. However, depending on what you want to learn about an object's motion, some types of representations will be more useful than others. In the pages that follow, you will practice constructing these equivalent representations and learn which ones are most useful for solving different kinds of problems.

PHYSICS CHALLENGE

POSITION-TIME GRAPHS Khaled , Kareem, and Ashraf all enjoy exercising and often go to a path along the river for this purpose. Kareem bicycles at a very consistent 40.25 km/h, Ashraf runs south at a constant speed of 16.0 km/h, and Khaled walks south at a brisk 6.5 km/h. Kareem starts biking north at noon from the waterfalls. Khaled and Ashraf both start at 11:30 A.M. at the canoe dock, 20.0 km north of the falls.

1. Draw position-time graphs for each person.
2. At what time will the three exercise enthusiasts be located within the smallest distance interval from each other?
3. What is the length of that distance interval?

Multiple Objects on a Position-Time Graph

A position-time graph for two different runners is shown in Example Problem 2 below. Notice that runner A is ahead of runner B at time $t = 0$, but the motion of each runner is different. When and where does one runner pass the other? First, you should restate this question in physics terms: At what time are the two runners at the same position? What is their position at this time? You can evaluate these questions by identifying the point on the position-time graph at which the lines representing the two runners' motions intersect.

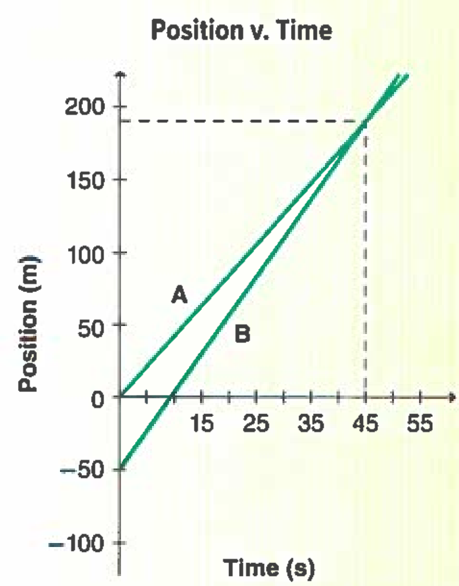
The intersection of two lines on a position-time graph tells you when objects have the same position, but does this mean that they will collide? Not necessarily. For example, if the two objects are runners and if they are in different lanes, they will not collide, even though they might be the same distance from the starting point.

READING CHECK **Explain** what the intersection of two lines on a position-time graph means.

What else can you learn from a position-time graph? Notice in Example 2 that the lines on the graph have different slopes. What does the slope of the line on a position-time graph tell you? In the next section, you will use the slope of a line on a position-time graph to determine the velocity of an object. When you study accelerated motion, you will draw other motion graphs and learn to interpret the areas under the plotted lines. In later studies, you will continue to refine your skills with creating and interpreting different types of motion graphs.

EXAMPLE 2

INTERPRETING A GRAPH The graph to the right describes the motion of two runners moving along a straight path. The lines representing their motion are labeled A and B. When and where does runner B pass runner A?



1 ANALYZE THE PROBLEM

Restate the questions.

Question 1: At what time are runner A and runner B at the same position?

Question 2: What is the position of runner A and runner B at this time?

2 SOLVE FOR THE UNKNOWN

Question 1

Examine the graph to find the intersection of the line representing the motion of runner A with the line representing the motion of runner B. These lines intersect at time 45 s.

Question 2

Examine the graph to determine the position when the lines representing the motion of the runners intersect. The position of both runners is about 190 m from the origin.

Runner B passes runner A about 190 m beyond the origin, 45 s after A has passed the origin.

APPLICATION

For problems 16–19, refer to the figure in Example 2 on the previous page.

16. Where was runner A located at $t = 0$ s?

17. Which runner was ahead at $t = 48.0$ s?

18. When runner A was at 0.0 m, where was runner B?

19. How far apart were runners A and B at $t = 20.0$ s?

20. CHALLENGE Ahmed goes for a walk. Later her friend Omar starts to walk after him. Their motions are represented by the position-time graph in **Figure 15.**

a. How long had Ahmed been walking when Omar started his walk?

b. Will Omar catch up to Mona? How can you tell?

c. What was Ahmed's position at $t = 0.2$ h?

d. At what time was Omar 5.0 km from the start?

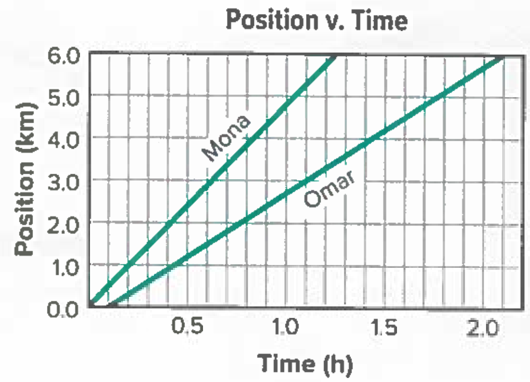


Figure 15

SECTION 3 REVIEW

21. MAINIDEA Using the particle model motion diagram in **Figure 16** of a baby crawling across a kitchen floor, plot a position-time graph to represent the baby's motion. The time interval between successive dots on the diagram is 1 s.

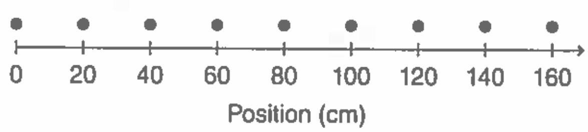


Figure 16

*For problems 22–25, refer to **Figure 17.***

22. Particle Model Create a particle model motion diagram from the position-time graph in **Figure 17** of a hockey puck gliding across a frozen pond.

23. Time Use the hockey puck's position-time graph to determine the time when the puck was 10.0 m beyond the origin.

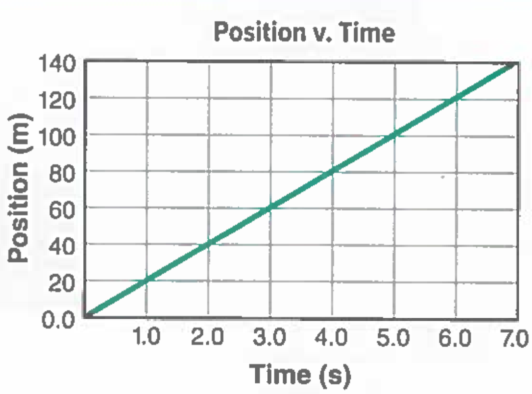


Figure 17

24. Distance Use the position-time graph in **Figure 17** to determine how far the hockey puck moved between times 0.0 s and 5.0 s.

25. Time Interval Use the position-time graph for the hockey puck to determine how much time it took for the puck to go from 40 m beyond the origin to 80 m beyond the origin.

26. Critical Thinking Look at the particle model diagram and the position-time graph shown in **Figure 18.** Do they describe the same motion? How do you know? Do not confuse the position coordinate system in the particle model with the horizontal axis in the position-time graph. The time intervals in the particle model diagram are 2 s.

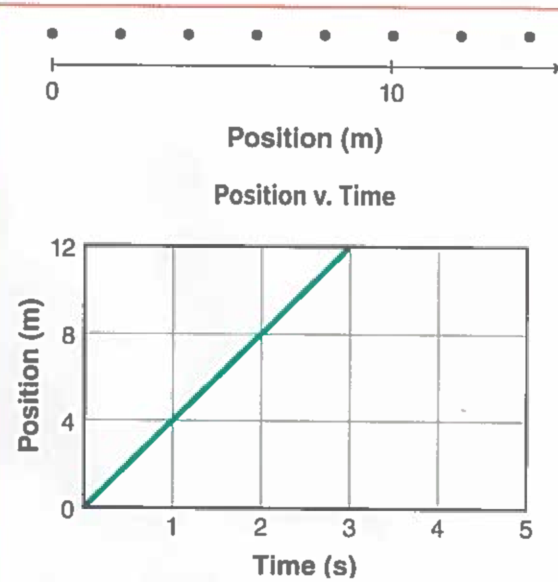
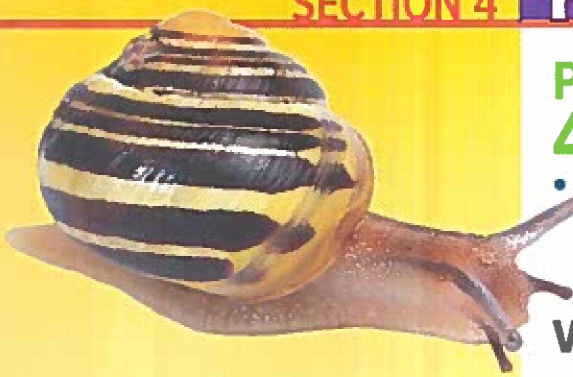


Figure 18

SECTION 4

How Fast?



PHYSICS 4 YOU Snails move much slower than cheetahs. You can see this by observing how far the animals travel during a given time period. For example, a cheetah can travel 30 m in a second, but a snail might move only 1 cm in that time interval.

MAINIDEA

An object's velocity is the rate of change in its position.

Essential Questions

- What is velocity?
- What is the difference between speed and velocity?
- How can you determine an object's average velocity from a position-time graph?
- How can you represent motion with pictorial, physical, and mathematical models?

Review Vocabulary

absolute value magnitude of a number, regardless of sign

New Vocabulary

average velocity
average speed
instantaneous velocity

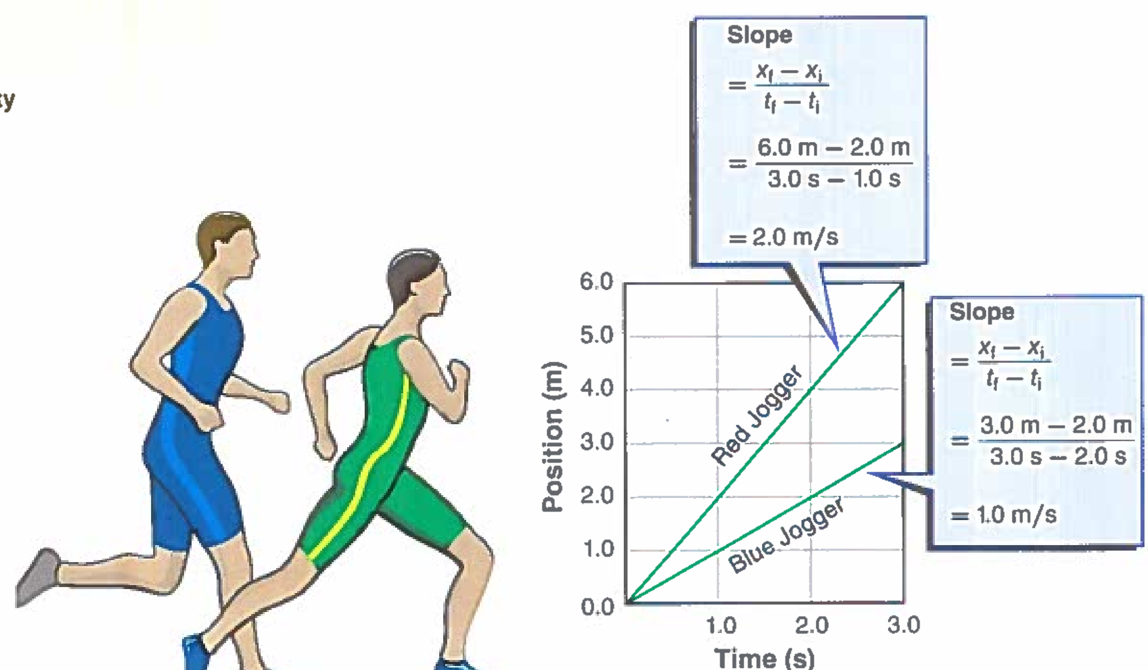
Velocity and Speed

Suppose you recorded the motion of two joggers on one diagram, as shown by the graph in **Figure 19**. The position of the jogger wearing red changes more than that of the jogger wearing blue. For a fixed time interval, the magnitude of the displacement ($\Delta \mathbf{x}$) is greater for the jogger in red because he is moving faster. Now, suppose that each jogger travels 100 m. The time interval (Δt) for the 100 m would be smaller for the jogger in red than for the one in blue.

Slope on a position-time graph Compare the lines representing the joggers in the graph in **Figure 19.** The slope of the red jogger's line is steeper, indicating a greater change in position during each time interval. Recall that you find the slope of a line by first choosing two points on the line. Next, you subtract the vertical coordinate (x in this case) of the first point from the vertical coordinate of the second point to obtain the rise of the line. After that, you subtract the horizontal coordinate (t in this case) of the first point from the horizontal coordinate of the second point to obtain the run. The rise divided by the run is the slope.

Figure 19 A greater slope shows that the red jogger traveled faster.

Analyze How much farther did the red jogger travel than the blue jogger in the 3 s interval described by the graph?



Average velocity Notice that the slope of the faster runner's line in **Figure 19** is a greater number. A greater slope indicates a faster speed. Also notice that the slope's units are meters per second. Looking at how the slope is calculated, you can see that slope is the change in the magnitude of the position divided by the time interval during which that change took place: $\frac{x_f - x_i}{t_f - t_i}$, or $\frac{\Delta x}{\Delta t}$. When Δx gets larger, the slope gets larger; when Δt gets larger, the slope gets smaller. This agrees with the interpretation given on the previous page of the speeds of the red and blue joggers. **Average velocity** is the ratio of an object's change in position to the time interval during which the change occurred. If the object is in uniform motion, so that its speed does not change, then its average velocity is the slope of its position-time graph.

AVERAGE VELOCITY

Average velocity is defined as the change in position divided by the time during which the change occurred.

$$\bar{v} \equiv \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}$$

The symbol ≡ means that the left-hand side of the equation is defined by the right-hand side.

Interpreting slope The position-time graph's slope in **Figure 20** is −5.0 m/s. Notice that the slope of the graph indicates both magnitude and direction. By calculating the slope from the rise divided by the run between two points, you find that the object whose motion is represented by the graph has an average velocity of −5.0 m/s. The object started out at a positive position and moves toward the origin. After 4 s, it passes the origin and continues moving in the negative direction at a rate of 5.0 m/s.

READING CHECK **Explain** the meaning of a position-time graph slope that is upward or downward, and above or below the *x*-axis.

Average speed The slope's absolute value is the object's **average speed,** 5.0 m/s, which is the distance traveled divided by the time taken to travel that distance. For uniform motion, average speed is the absolute value of the slope of the object's position-time graph. The combination of an object's average speed ($\bar{v}$) and the direction in which it is moving is the average velocity ($\bar{v}$). Remember that if an object moves in the negative direction, its change in position is negative. This means that an object's displacement and velocity are both always in the same direction.

PhysicsLABs

CONSTANT SPEED

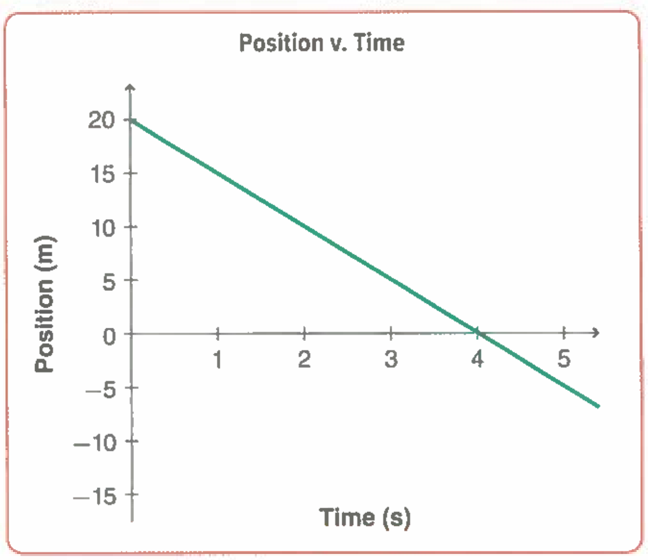
How can you determine average speed by measuring distance and time?

MEASURE VELOCITY

PROBEWARE LAB How can you measure velocity with a motion detector?

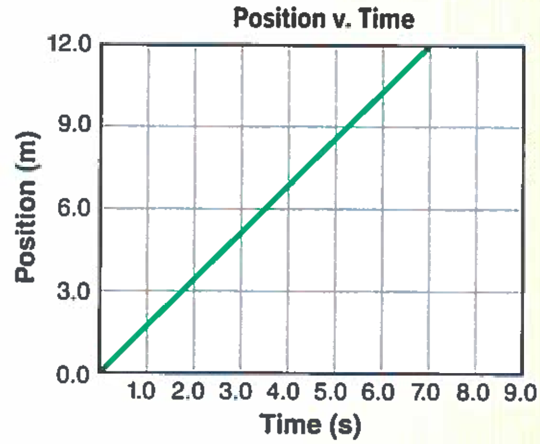
Figure 20 The downward slope of this position-time graph shows that the motion is in the negative direction.

Analyze What would the graph look like if the motion were at the same speed, but in the positive direction?



EXAMPLE 3

AVERAGE VELOCITY The graph at the right describes the straight-line motion of a student riding her skateboard along a smooth, pedestrian-free sidewalk. What is her average velocity? What is her average speed?



1 ANALYZE AND SKETCH THE PROBLEM

Identify the graph's coordinate system.

UNKNOWN

$\bar{v} = ?$ $\quad \bar{v} = ?$

2 SOLVE FOR THE UNKNOWN

Find the average velocity using two points on the line.

$$\bar{v} = \frac{\Delta x}{\Delta t}$$

$$= \frac{x_f - x_i}{t_f - t_i}$$

$$= \frac{12.0\ \text{m} - 0.0\ \text{m}}{7.0\ \text{s} - 0.0\ \text{s}}$$

◀ Substitute $x_2 = 12.0$ m, $x_1 = 0.0$ m, $t_2 = 7.0$ s, $t_1 = 0.0$ s.

$\bar{v} = 1.7$ m/s in the positive direction

The average speed ($\bar{v}$) is the absolute value of the average velocity, or 1.7 m/s.

3 EVALUATE THE ANSWER

- **Are the units correct?** The units for both velocity and speed are meters per second.
- **Do the signs make sense?** The positive sign for the velocity agrees with the coordinate system. No direction is associated with speed.

APPLICATION

27. The graph in **Figure 21** describes the motion of a cruise ship drifting slowly through calm waters. The positive *x*-direction (along the vertical axis) is defined to be south.

a. What is the ship's average speed?

b. What is its average velocity?

28. Describe, in words, the cruise ship's motion in the previous problem.

29. What is the average velocity of an object that moves from 6.5 cm to 3.7 cm relative to the origin in 2.3 s?

30. The graph in **Figure 22** represents the motion of a bicycle.

a. What is the bicycle's average speed?

b. What is its average velocity?

31. Describe, in words, the bicycle's motion in the previous problem.

32. CHALLENGE A bicycle started at a constant speed equal 0.55 m/s. Draw a motion diagram and a position-time graph to represent motion of the bicycle for 19.8m distance .

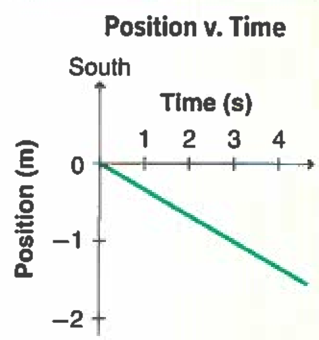


Figure 21

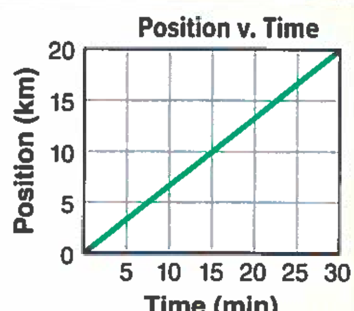


Figure 22

Instantaneous velocity Why do we call the quantity $\frac{\Delta x}{\Delta t}$ average velocity? Why don't we just call it velocity? A motion diagram shows the position of a moving object at the beginning and end of a time interval. It does not, however, indicate what happened within that time interval. During the time interval, the object's speed could have remained the same, increased, or decreased. The object may have stopped or even changed direction. You can find the average velocity for each time interval in the motion diagram, but you cannot find the speed and the direction of the object at any specific instant. The speed and the direction of an object at a particular instant is called the **instantaneous velocity.** In this textbook, the term velocity will refer to instantaneous velocity, represented by the symbol $\boldsymbol{v}$.

☑ **READING CHECK** **Explain** how average velocity is different from velocity.

Average velocity on motion diagrams When an object moves between two points, its average velocity is in the same direction as its displacement. The two quantities are also proportional–when displacement is greater during a given time interval, so is average velocity. A motion diagram indicates the average velocity's direction and magnitude.

Imagine two cars driving down the road at different speeds. A video camera records the motion of the cars at the rate of one frame every second. Imagine that each car has a paintbrush attached to it that automatically descends and paints a red line on the ground for half a second every second. The faster car would paint a longer line on the ground. The vectors you draw on a motion diagram to represent the velocity are like the lines that the paintbrushes make on the ground below the cars. In this book, we use red to indicate velocity vectors on motion diagrams. **Figure 23** shows motion diagrams with velocity vectors for two cars. One is moving to the right, and the other is moving to the left.

☑ **READING CHECK** **Identify** what the lengths of velocity vectors mean.

Equation of Motion

Often it is more efficient to use an equation, rather than a graph, to solve problems. Any time you graph a straight line, you can find an equation to describe it. Take another look at the graph in **Figure 20** for the object moving with a constant velocity of −5.0 m/s. Recall that you can represent any straight line with the equation $y = mx + b$, where y is the quantity plotted on the vertical axis, m is the line's slope, x is the quantity plotted on the horizontal axis, and b is the line's y-intercept.

For the graph in **Figure 20,** the quantity plotted on the vertical axis is position, represented by the variable $\mathbf{x}$. The line's slope is −5.0 m/s, which is the object's average velocity ($\overline{v}$). The quantity plotted on the horizontal axis is time (t). The y-intercept is 20.0 m. What does this 20.0 m represent? This shows that the object was at a position of 20.0 m when t = 0.0 s. This is called the initial position of the object and it is designated $\mathbf{x}_i$.

REAL-WORLD PHYSICS

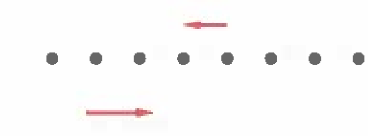
SPEED RECORDS The world record for the men's 100-m dash is 9.58 s, established in 2009 by Usain Bolt. The world record for the women's 100-m dash is 10.49 s, established in 1988 by Florence Griffith-Joyner.

MiniLAB

VELOCITY VECTORS

How can velocity vectors represent the motion of a mass on a string?

Figure 23 The length of each velocity vector is proportional to the magnitude of the velocity that it represents.



CONNECTING MATH TO PHYSICS

Lines and Graphs Symbols used in the point-slope equation of a line relate to symbols used for motion variables on a position-time graph.

General Variable	Specific Motion Variable	Value in Figure 20
y	x	
m	$\bar{v}$	−5.0 m/s
x	t	
b	x_i	20.0 m

A summary is given to the left of how the general variables in the straight-line formula are changed to the specific variables you have been using to describe motion. The table also shows the numerical values for the average velocity and initial position. Consider the graph shown in **Figure 20.** The mathematical equation for the line graphed is as follows:

$$y = (-5.0 \text{ m/s})x + 20.0 \text{ m}$$

You can rewrite this equation, using x for position and t for time.

$$x = (-5.0 \text{ m/s})t + 20.0 \text{ m}$$

It might be confusing to use y and x in math but use x and t in physics. You do this because there are many types of graphs in physics, including position v. time graphs, velocity v. time graphs, and force v. position graphs. For a position v. time graph, the math equation $y = mx + b$ can be rewritten as follows:

POSITION

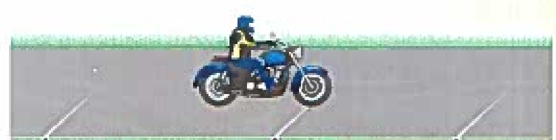
An object's position is equal to the average velocity multiplied by time plus the initial position.

$$x = \bar{v}t + x_i$$

This equation gives you another way to represent motion. Note that a graph of x v. t would be a straight line.

EXAMPLE 4

POSITION The figure shows a motorcyclist traveling east along a straight road. After passing point B, the cyclist continues to travel at an average velocity of 12 m/s east and arrives at point C 3.0 s later. What is the position of point C?



1 ANALYZE THE PROBLEM

Choose a coordinate system with the origin at A.

KNOWN	UNKNOWN
$\bar{v}$ = 12 m/s east	x = ?
x_i = 46 m east	
t = 3.0 s	

2 SOLVE FOR THE UNKNOWN

$x = \bar{v}t + x_i$ ◀ Use magnitudes for the calculations.

$= (12 \text{ m/s})(3.0 \text{ s}) + 46 \text{ m}$ ◀ Substitute $\bar{v}$ = 12 m/s, t = 3.0 s, and x_i = 46 m.

$= 82 \text{ m}$

x = 82 m east

3 EVALUATE THE ANSWER

- **Are the units correct?** Position is measured in meters.
- **Does the direction make sense?** The motorcyclist is traveling east the entire time.

APPLICATION

For problems 33–36, refer to ***Figure 24.***

33. The diagram at the right shows the path of a ship that sails at a constant velocity of 42 km/h east. What is the ship's position when it reaches point *C*, relative to the starting point, *A*, if it sails from point *B* to point *C* in exactly 1.5 h?

34. Another ship starts at the same time from point *B*, but its average velocity is 58 km/h east. What is its position, relative to *A*, after 1.5 h?

35. What would a ship's position be if that ship started at point *B* and traveled at an average velocity of 35 km/h west to point *D* in a time period of 1.2 h?

36. CHALLENGE Suppose two ships start from point *B* and travel west. One ship travels at an average velocity of 35 km/h for 2.2 h. Another ship travels at an average velocity of 26 km/h for 2.5 h. What is the final position of each ship?

Figure 24

SECTION 4 REVIEW

37. MAINIDEA How is an object's velocity related to its position?

For problems 38–40, refer to ***Figure 25.***

38. Ranking Task Rank the position-time graphs according to the average speed, from greatest average speed to least average speed. Specifically indicate any ties.

39. Contrast Average Velocities Describe differences in the average velocities shown on the graph for objects A and B. Describe differences in the average velocities shown on the graph for objects C and D.

40. Ranking Task Rank the graphs in **Figure 25** according to each object's initial position, from most positive position to most negative position. Specifically indicate any ties. Would your ranking be different if you ranked according to initial distance from the origin?

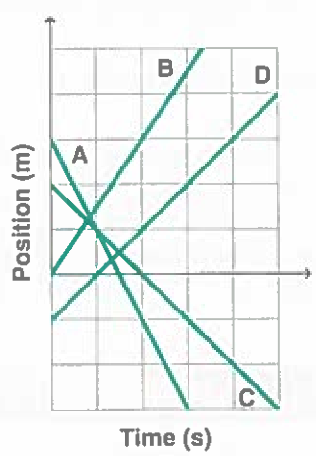


Figure 25

41. Average Speed and Average Velocity Explain how average speed and average velocity are related to each other for an object in uniform motion.

42. Position Two cars are traveling along a straight road, as shown in **Figure 26.** They pass each other at point B and then continue in opposite directions. The red car travels for 0.25 h from point B to point C at a constant velocity of 32 km/h east. The blue car travels for 0.25 h from point B to point D at a constant velocity of 48 km/h west. How far has each car traveled from point B? What is the position of each car relative to the origin, point A?

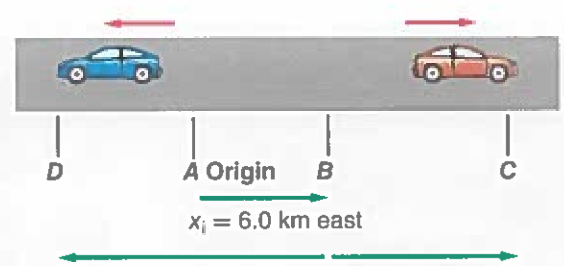


Figure 26

43. Position A car travels north along a straight highway at an average speed of 85 km/h. After driving 2.0 km, the car passes a gas station and continues along the highway. What is the car's position relative to the start of its trip 0.25 h after it passes the gas station?

44. Critical Thinking In solving a physics problem, why is it important to create pictorial and physical models before trying to solve an equation?

A CLOSER LOOK

Got the time?

What is time? If one hour of time passes for you, does one hour of time also pass for your friend? You might think that the answer is yes, but it is actually no. Time passes at different rates depending on your point of view.

Speed and time Think about how wrong that last sentence seems. For example, suppose that you tell your friend to meet you at the mall in one hour. You both assume that when one hour passes for you, one hour also passes for your friend.

This is because you and your friend move very slowly relative to each other. At slow speeds, one hour for you is almost exactly the same as one hour for your friend. As you move faster relative to your friend, however, the difference between your time and your friend's time increases.

How fast? You would need to travel very fast relative to your friend in order for any difference to be noticeable. If you travel at 100,000 km/s, then only 57 minutes passes for you when one hour passes for your friend. At 200,000 km/s, only 45 minutes passes for you during your friend's hour. **Figure 1** shows how your time compares to one hour of your friend's time as you travel faster and faster relative to your friend.

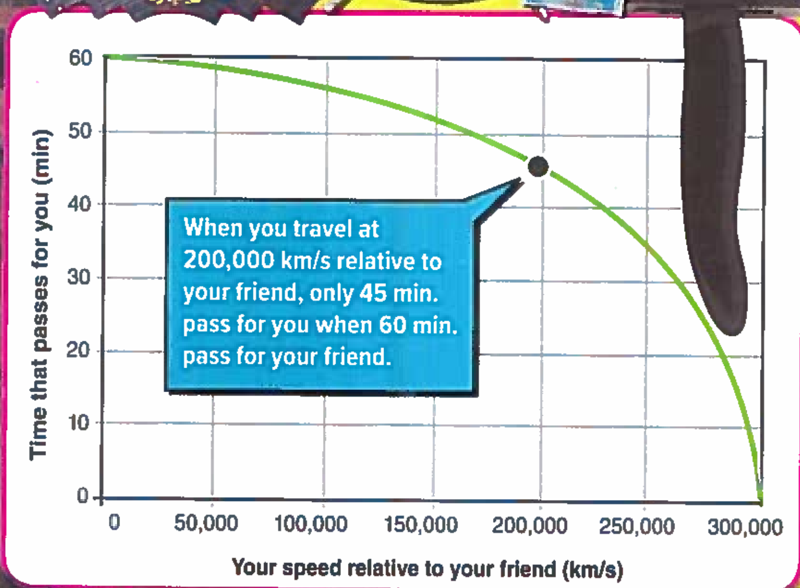


FIGURE 1 In this graph, 60 minutes always passes for your friend, but other amounts of time pass for you.

Real-World Application All of this might seem rather pointless. After all, even the fastest spacecraft travel at less than 100 km/s. Have you ever used a GPS receiver, such as the one shown in **Figure 2**? At 4 km/s, a GPS satellite travels fast enough for time differences to affect the accuracy of the GPS receiver. The effect is small—approximately 10 μs in one day. It is enough, however, that the GPS would become completely useless within one month if engineers did not account for it.

FIGURE 2 This GPS receiver would be completely inaccurate if the designers of the Global Positioning System did not understand the relativity of time.

GOING FURTHER >>>

Research Gravity also affects time. Research how gravity affects time on Earth and on a GPS satellite.

CHAPTER 2

STUDY GUIDE

BIG IDEA You can use displacement and velocity to describe an object's motion.

VOCABULARY
- motion diagram
- particle model

SECTION 1 Picturing Motion

MAIN IDEA You can use motion diagrams to show how an object's position changes over time.

- A motion diagram shows the position of an object at successive equal time intervals.
- In a particle model motion diagram, an object's position at successive times is represented by a series of dots. The spacing between dots indicates whether the object is moving faster or slower.

VOCABULARY
- coordinate system
- origin
- position
- distance
- magnitude
- vector
- scalar
- time interval
- displacement
- resultant

SECTION 2 Where and When?

MAIN IDEA A coordinate system is helpful when you are describing motion.

- A coordinate system gives the location of the zero point of the variable you are studying and the direction in which the values of the variable increase.
- A vector drawn from the origin of a coordinate system to an object indicates the object's position in that coordinate system. The directions chosen as positive and negative on the coordinate system determine whether the objects' positions are positive or negative in the coordinate system.
- A time interval is the difference between two times.

$$\Delta t = t_f - t_i$$

- Change in position is displacement, which has both magnitude and direction.

$$\Delta x = x_f - x_i$$

- On a motion diagram, the displacement vector's length represents how far the object was displaced. The vector points in the direction of the displacement, from x_i to x_f.

VOCABULARY
- position-time graph
- instantaneous position

SECTION 3 Position-Time Graphs

MAIN IDEA You can use a position-time graph to determine an object's position at a certain time.

- Position-time graphs provide information about the motion of objects. They also might indicate where and when two objects meet.
- The line on a position-time graph describes an object's position at each time.
- Motion can be described using words, motion diagrams, data tables, or graphs.

VOCABULARY
- average velocity
- average speed
- instantaneous velocity

SECTION 4 How Fast?

MAIN IDEA An object's velocity is the rate of change in its position.

- An object's velocity tells how fast it is moving and in what direction it is moving.
- Speed is the magnitude of velocity.
- Slope on a position-time graph describes the average velocity of the object.

$$\bar{v} \equiv \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}$$

- You can represent motion with pictures and physical models. A simple equation relates an object's initial position (x_i), its constant average velocity ($\bar{v}$), its position (x), and the time (t) since the object was at its initial position.

$$x = \bar{v}t + x_i$$

SECTION 1 Picturing Motion

Mastering Concepts

45. What is the purpose of drawing a motion diagram?

46. Under what circumstances is it legitimate to treat an object as a particle when solving motion problems?

SECTION 2 Where and When?

Mastering Concepts

47. The following quantities describe location or its change: position, distance, and displacement. Briefly describe the differences among them.

48. How can you use a clock to find a time interval?

SECTION 3 Position-Time Graphs

Mastering Concepts

49. In-line Skating How can you use the position-time graphs for two in-line skaters to determine if and when one in-line skater will pass the other one?

SECTION 4 How Fast?

Mastering Concepts

50. BIGIDEA Which equation describes how the average velocity of a moving object relates to its displacement?

51. Walking Versus Running A walker and a runner leave your front door at the same time. They move in the same direction at different constant velocities. Describe the position-time graphs of each.

52. What does the slope of a position-time graph measure?

53. If you know the time it took an object to travel between two points and the positions of the object at the points, can you determine the object's instantaneous velocity? Its average velocity? Explain.

Mastering Problems

54. You ride a bike at a constant speed of 4.0 m/s for 5.0 s. How far do you travel?

55. Astronomy Light from the Sun reaches Earth in about 8.3 min. The speed of light is 3.00×10^8 m/s. What is the distance from the Sun to Earth?

56. Problem Posing Complete this problem so that someone must solve it using the concept of average speed: "A butterfly travels 15 m from one flower to another ...."

57. Nora jogs several times a week and always keeps track of how much time she runs each time she goes out. One day she forgets to take her stopwatch with her and wonders if there is a way she can still have some idea of her time. As she passes a particular bank building, she remembers that it is 4.3 km from her house. She knows from her previous training that she has a consistent pace of 4.0 m/s. How long has Nora been jogging when she reaches the bank?

58. Driving You and a friend each drive 50.0 km. You travel at 90.0 km/h; your friend travels at 95.0 km/h. How much sooner will your friend finish the trip?

Applying Concepts

59. Ranking Task The position-time graph in **Figure 27** shows the motion of four cows walking from the pasture back to the barn. Rank the cows according to their average velocity, from slowest to fastest.

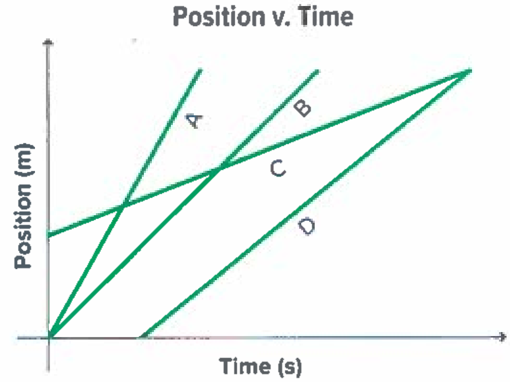


Figure 27

60. Figure 28 is a position-time graph for a rabbit running away from a dog. How would the graph differ if the rabbit ran twice as fast? How would it differ if the rabbit ran in the opposite direction?

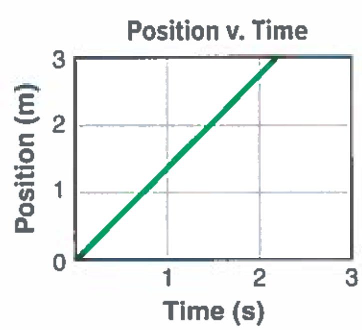


Figure 28

61. Test the following combinations and explain why each does not have the properties needed to describe the concept of velocity: $\Delta \mathbf{x} + \Delta t$, $\Delta \mathbf{x} - \Delta t$, $\Delta \mathbf{x} \times \Delta t$, $\frac{\Delta t}{\Delta \mathbf{x}}$.

62. **Football** When solving physics problems, what must be true about the motion of a football in order for you to treat the football as if it were a particle?

63. **Figure 29** is a graph of two people running.

a. Describe the position of runner A relative to runner B at the y-intercept.

b. Which runner is faster?

c. What occurs at point P and beyond?

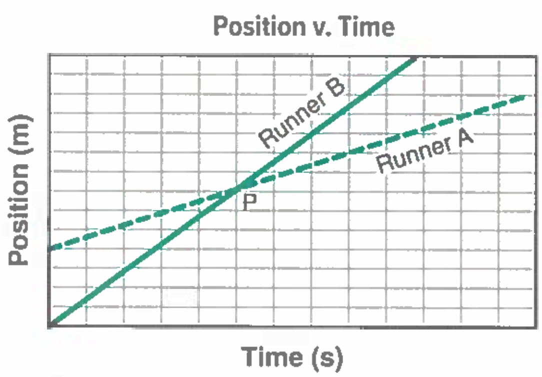


Figure 29

Mixed Review

64. **Cycling** A cyclist traveling along a straight path maintains a constant velocity of 5.0 m/s west. At time $t = 0.0$ s, the cyclist is 250 m west of point A.

a. Plot a position-time graph of the cyclist's location from point A at 10.0-s intervals for a total time of 60.0 s.

b. What is the cyclist's position from point A at 60.0 s?

c. What is the displacement from the starting position at 60.0 s?

65. **Figure 30** is a particle model diagram for a chicken casually walking across a road. Draw the corresponding position-time graph, and write an equation to describe the chicken's motion.

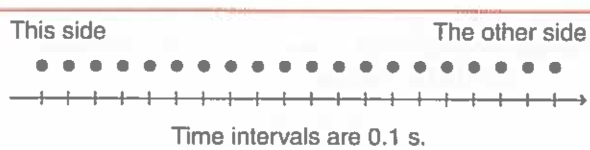


Figure 30

66. **Figure 31** shows position-time graphs for Nada and Samira paddling canoes in a local river.

a. At what time(s) are Nada and Samira in the same place?

b. How long does Nada paddle before passing Samira?

c. Where on the river does it appear that there might be a swift current?

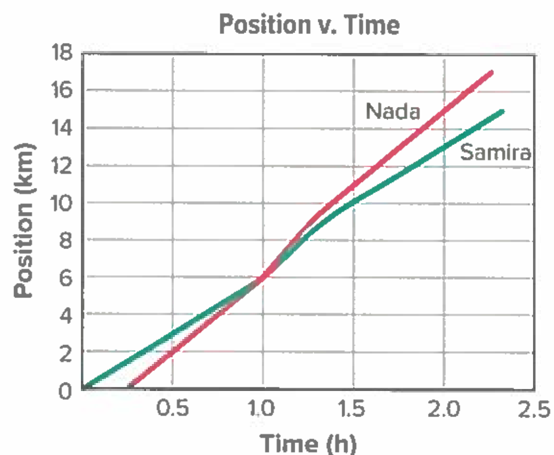


Figure 31

67. **Driving** Both car A and car B leave school when a stopwatch reads zero. Car A travels at a constant 75 km/h, and car B travels at a constant 85 km/h.

a. Draw a position-time graph showing the motion of both cars over 3 hours. How far are the two cars from school when the stopwatch reads 2.0 h? Calculate the distances and show them on your graph.

b. Both cars passed a gas station 120 km from the school. When did each car pass the gas station? Calculate the times and show them on your graph.

68. Draw a position-time graph for two cars traveling to a beach that is 50 km from school. At noon, car A leaves a store that is 10 km closer to the beach than the school is and moves at 40 km/h. Car B starts from school at 12:30 P.M. and moves at 100 km/h. When does each car get to the beach?

69. Two cars travel along a straight road. When a stopwatch reads $t = 0.00$ h, car A is at $\mathbf{x}_A = 48.0$ km moving at a constant speed of 36.0 km/h. Later, when the watch reads $t = 0.50$ h, car B is at $\mathbf{x}_B = 0.00$ km moving at 48.0 km/h. Answer the following questions, first graphically by creating a position-time graph and then algebraically by writing equations for the positions $\mathbf{x}_A$ and $\mathbf{x}_B$ as a function of the stopwatch time (t).

a. What will the watch read when car B passes car A?

b. At what position will car B pass car A?

c. When the cars pass, how long will it have been since car A was at the reference point?

70. The graph in **Figure 32** depicts Jamal's movement along a straight path. The origin is at one end of the path.

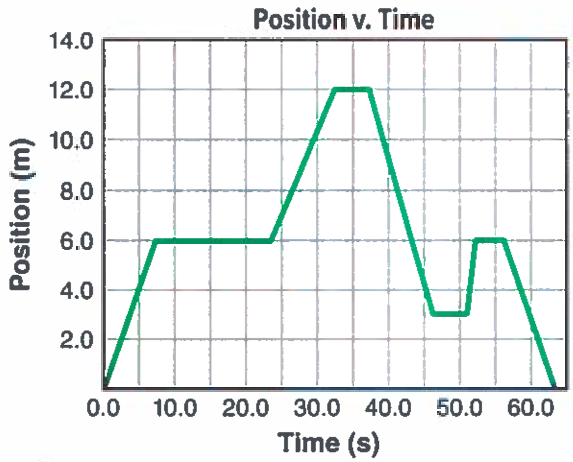


Figure 32

a. **Reverse Problem** Write a story describing Jamal's movements along the path that would correspond to the motion represented by the graph.

b. When is Jamal 6.0 m from the origin?

c. How much time passes between when Jamal starts moving and when he is 12.0 m from the origin?

d. What is Jamal's average velocity between 37.0 s and 46.0 s?

Thinking Critically

71. **Apply Calculators** Members of a physics class stood 25 m apart and used stopwatches to measure the time at which a car traveling on the highway passed each person. **Table 2** shows their data.

Table 2 Position v. Time

Time (s)	Position (m)
0.0	0.0
1.3	25.0
2.7	50.0
3.6	75.0
5.1	100.0
5.9	125.0
7.0	150.0
8.6	175.0
10.3	200.0

Use a graphing calculator to fit a line to a position-time graph of the data and to plot this line. Be sure to set the display range of the graph so that all the data fit on it. Find the line's slope. What was the car's speed?

72. **Apply Concepts** You want to average 90 km/h on a car trip. You cover the first half of the distance at an average speed of 48 km/h. What average speed must you have for the second half of the trip to meet your goal? Is this reasonable? Note that the velocities are based on half the distance, not half the time.

73. **Design an Experiment** Every time someone drives a particular red motorcycle past your friend's home, his father becomes angry. He thinks the motorcycle is going too fast for the posted 25 mph (40 km/h) speed limit. Describe a simple experiment you could do to determine whether the motorcycle is speeding the next time it passes your friend's house.

74. **Interpret Graphs** Is it possible for an object's position-time graph to be a horizontal line? A vertical line? If you answer yes to either situation, describe the associated motion in words.

Writing in Physics

75. Physicists have determined that the speed of light is 3.00×10^{8} m/s. How did they arrive at this number? Read about some of the experiments scientists have performed to determine light's speed. Describe how the experimental techniques improved to make the experiments' results more accurate.

76. Some species of animals have good endurance, while others have the ability to move very quickly, but only for a short amount of time. Use reference sources to find two examples of each quality, and describe how it is helpful to that animal.

Cumulative Review

77. Convert each of the following time measurements to its equivalent in seconds:

a. 58 ns
b. 0.046 Gs
c. 9270 ms
d. 12.3 ks

78. State the number of significant figures in the following measurements:

a. 3218 kg
b. 60.080 kg
c. 801 kg
d. 0.000534 kg

79. Using a calculator, Ahmed obtained the following results. Rewrite each answer using the correct number of significant figures.

a. 5.32 mm + 2.1 mm = 7.4200000 mm
b. 13.597 m × 3.65 m = 49.62905 m^2
c. 83.2 kg − 12.804 kg = 70.3960000 kg

MULTIPLE CHOICE

1. Which statement would be true about the particle model motion diagram for an airplane flying at a constant speed of 850 km/h?

A. The dots would start close together and get farther apart as the plane moved away from the airport.

B. The dots would be far apart at the beginning and get closer together as the plane moved away from the airport.

C. The dots would form an evenly spaced pattern.

D. The dots would start close together, get farther apart, and then get close together again as the airplane traveled away from the airport.

2. Which statement about drawing vectors is true?

A. The vector's length should be proportional to its magnitude.

B. You need a vector diagram to solve all physics problems properly.

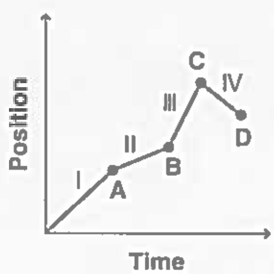
C. A vector is a quantity that has a magnitude but no direction.

D. All quantities in physics are vectors.

3. The figure below shows a simplified graph of a bicyclist's motion. (Speeding up and slowing down motion is ignored.) When is the person's velocity greatest?

A. section I **C.** point D

B. section III **D.** point B

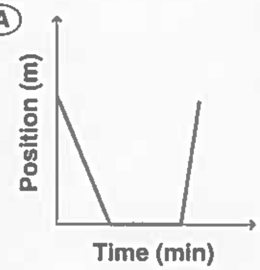


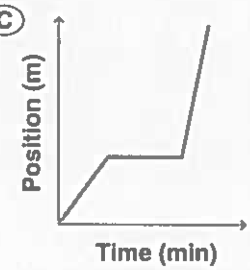
4. What is the average velocity of a train moving along a straight track if its displacement is 192 m east during a time period of 8.0 s?

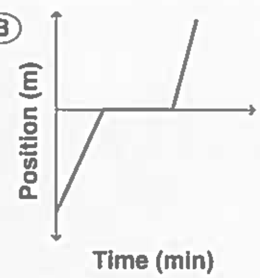
A. 12 m/s east **C.** 48 m/s east

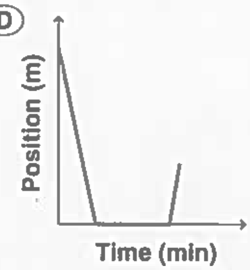
B. 24 m/s east **D.** 96 m/s east

5. A squirrel descends an 8 m tree at a constant speed in 1.5 min. It remains still at the base of the tree for 2.3 min. A loud noise then causes the squirrel to scamper back up the tree in 0.1 min to the exact position on the branch from which it started. Ignoring speeding up and slowing down motion, which graph most closely represents the squirrel's vertical displacement from the base of the tree?

Ⓐ


Ⓒ


Ⓑ


Ⓓ


FREE RESPONSE

6. A rat is moving along a straight path. Find the rat's position relative to its starting point if it moves 12.8 cm/s north for 3.10 s.

CHAPTER 3

Accelerated Motion

BIG IDEA **Acceleration is the rate of change in an object's velocity.**

SECTIONS

1 Acceleration

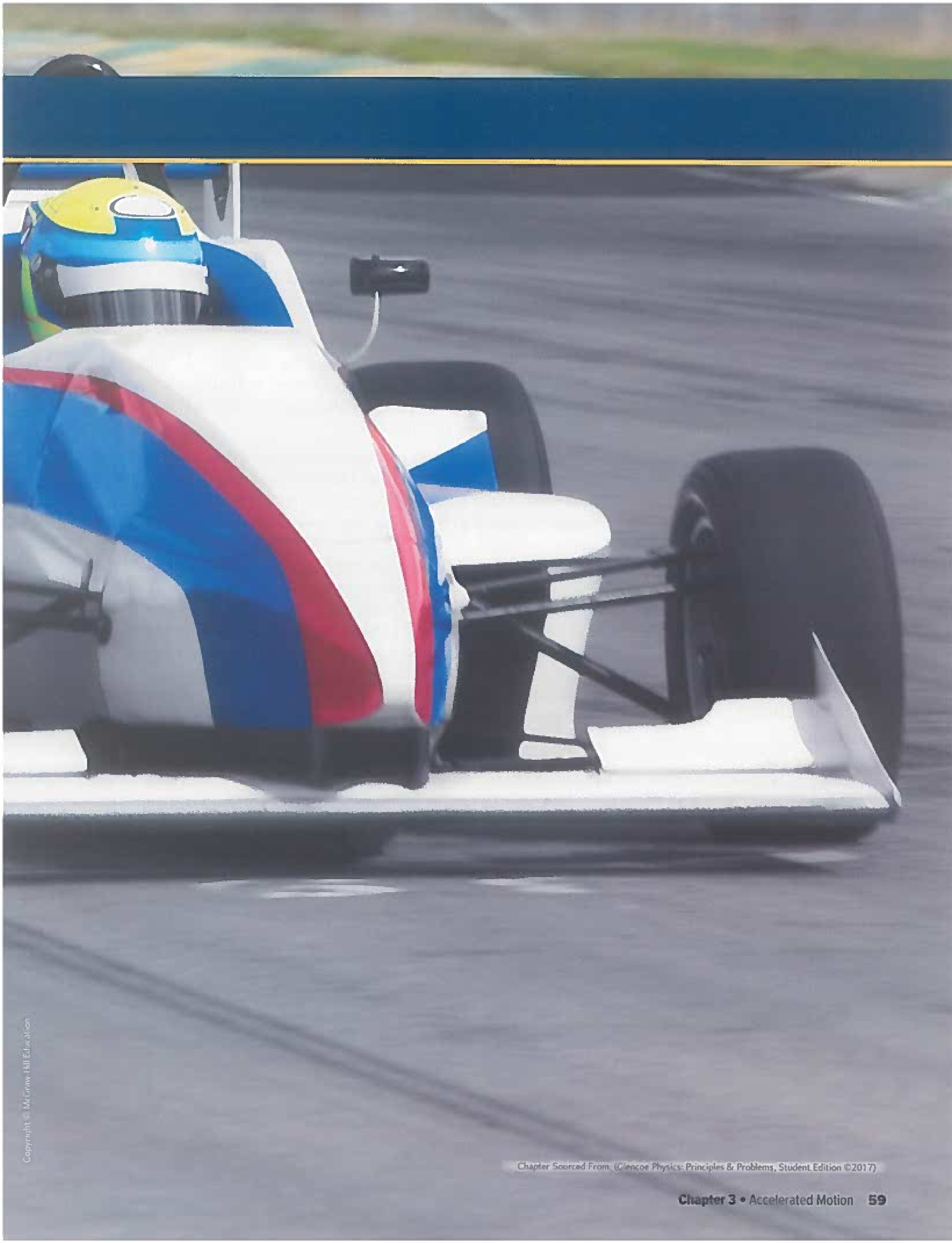
2 Motion with Constant Acceleration

3 Free Fall

LaunchLAB

GRAPHING MOTION

How does a graph showing constant speed compare to a graph of an object that is accelerating?



Chapter Sourced From: (Glencoe Physics: Principles & Problems, Student Edition ©2017)

SECTION 1
Acceleration

MAIN IDEA

An object accelerates when its velocity changes—that is, when it speeds up, slows down, or changes direction.

Essential Questions

- What is acceleration?
- How is acceleration different from velocity?
- What information can you learn from velocity-time graphs?

Review Vocabulary

vector a quantity that has magnitude and direction

New Vocabulary

acceleration
velocity-time graph
average acceleration
instantaneous acceleration

PHYSICS 4 YOU As an airplane takes off, its speed changes from 5 m/s on the runway to nearly 300 m/s once it's in the air. If you've ever ridden on an airplane, you've felt the seat push against your back as the plane rapidly accelerates.

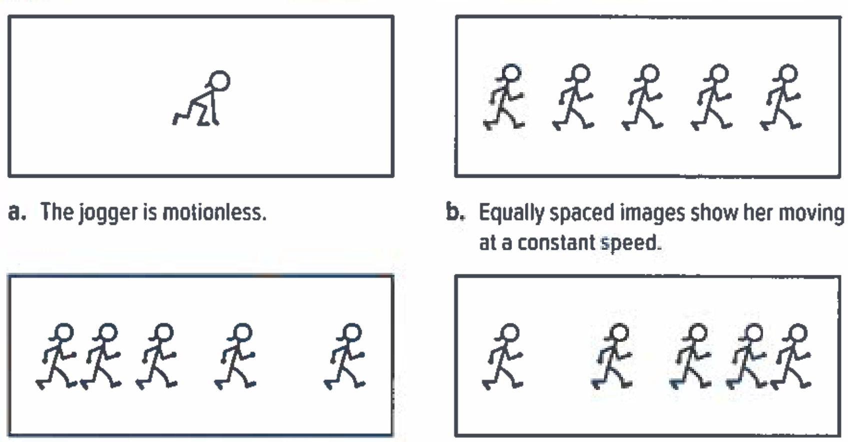
Nonuniform Motion Diagrams

An object in uniform motion moves along a straight line with an unchanging velocity, but few objects move this way all the time. More common is nonuniform motion, in which velocity is changing. In this chapter, you will study nonuniform motion along a straight line. Examples include balls rolling down hills, cars braking to a stop, and falling objects. In later chapters you will analyze nonuniform motion that is not confined to a straight line, such as motion along a circular path and the motion of thrown objects, such as baseballs.

Describing nonuniform motion You can feel a difference between uniform and nonuniform motion. Uniform motion feels smooth. If you close your eyes, it feels as if you are not moving at all. In contrast, when you move around a curve or up and down a roller coaster hill, you feel pushed or pulled.

How would you describe the motion of the jogger in **Figure 1**? In the first diagram, the jogger is motionless, but in the others, her position is changing in different ways. What information do the diagrams contain that could be used to distinguish the different types of motion? Notice the distances between successive positions. Because there is only one image of the jogger in the first diagram, you can conclude that she is at rest. The distances between images in the second diagram are the same because the jogger is in uniform motion; she moves at a constant velocity. In the remaining two diagrams, the distance between successive positions changes. The change in distance increases if the jogger speeds up. The change decreases if the jogger slows down.

Motion Diagram



a. The jogger is motionless.

b. Equally spaced images show her moving at a constant speed.

c. She is speeding up.

d. She is slowing down.

Figure 1 The distance the jogger moves in each time interval indicates the type of motion.

Particle model diagram What does a particle model motion diagram look like for an object with changing velocity? **Figure 2** shows particle model motion diagrams below the motion diagrams of the jogger when she is speeding up and slowing down. There are two major indicators of the change in velocity in this form of the motion diagram. The change in the spacing of the dots and the differences in the lengths of the velocity vectors indicate the changes in velocity. If an object speeds up, each subsequent velocity vector is longer, and the spacing between dots increases. If the object slows down, each vector is shorter than the previous one, and the spacing between dots decreases. Both types of motion diagrams indicate how an object's velocity is changing.

☑ **READING CHECK** **Analyze** What do increasing and decreasing lengths of velocity vectors indicate on a motion diagram?

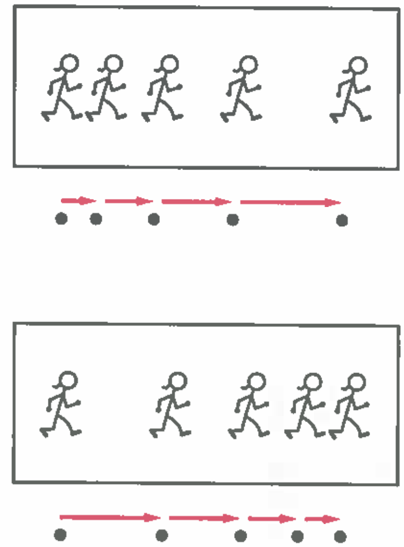


Figure 2 The change in length of the velocity vectors on these motion diagrams indicates whether the jogger is speeding up or slowing down.

Displaying acceleration on a motion diagram For a motion diagram to give a full picture of an object's movement, it should contain information about the rate at which the object's velocity is changing. The rate at which an object's velocity changes is called the **acceleration** of the object. By including acceleration vectors on a motion diagram, you can indicate the rate of change for the velocity.

Figure 3 shows a particle motion diagram for an object with increasing velocity. Notice that the lengths of the red velocity vectors get longer from left to right along the diagram. The figure also describes how to use the diagram to draw an acceleration vector for the motion. The acceleration vector that describes the increasing velocity is shown in violet on the diagram.

Notice in the figure that if the object's acceleration is constant, you can determine the length and direction of an acceleration vector by subtracting two consecutive velocity vectors and dividing by the time interval. That is, first find the change in velocity, $\Delta \boldsymbol{v} = \boldsymbol{v}_f - \boldsymbol{v}_i = \boldsymbol{v}_f + (-\boldsymbol{v}_i)$, where $\boldsymbol{v}_i$ and $\boldsymbol{v}_f$ refer to the velocities at the beginning and the end of the chosen time interval. Then divide by the time interval (Δt). The time interval between each dot in **Figure 3** is 1 s. You can draw the acceleration vector from the tail of the final velocity vector to the tip of the initial velocity vector.

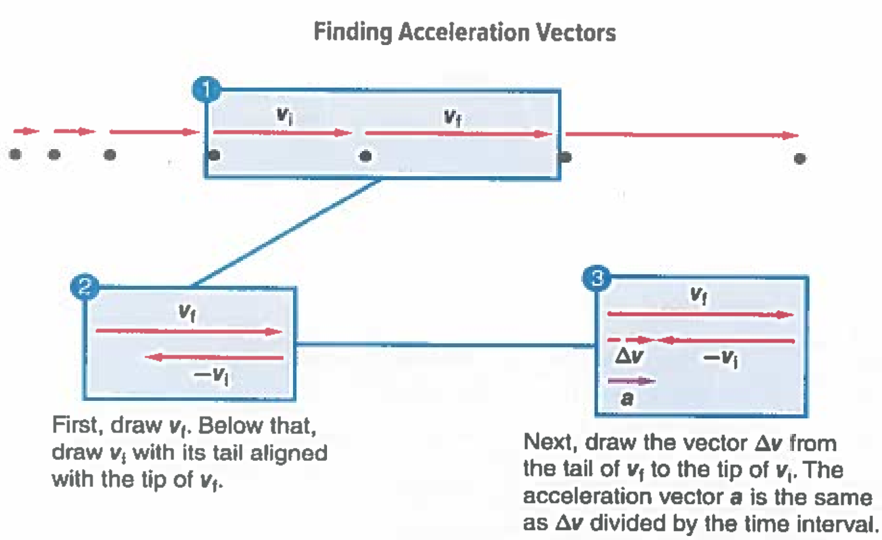


Figure 3 For constant acceleration, an acceleration vector on a particle model diagram is the difference in the two velocity vectors divided by the time interval within which the velocity changed: $a = \frac{\Delta v}{\Delta t}$.

Analyze Can you draw an acceleration vector for two successive velocity vectors that are the same length and direction? Explain.

COLOR CONVENTION

acceleration ⟷ violet
velocity ⟷ red

Direction of Acceleration

Consider the four situations shown in **Figure 4** in which an object can accelerate by changing speed. The first motion diagram shows the car moving in the positive direction and speeding up. The second motion diagram shows the car moving in the positive direction and slowing down. The third shows the car speeding up in the negative direction, and the fourth shows the car slowing down as it moves in the negative direction. The figure also shows the velocity vectors for the second time interval of each diagram, along with the corresponding acceleration vectors. Note that Δt is equal to 1 s.

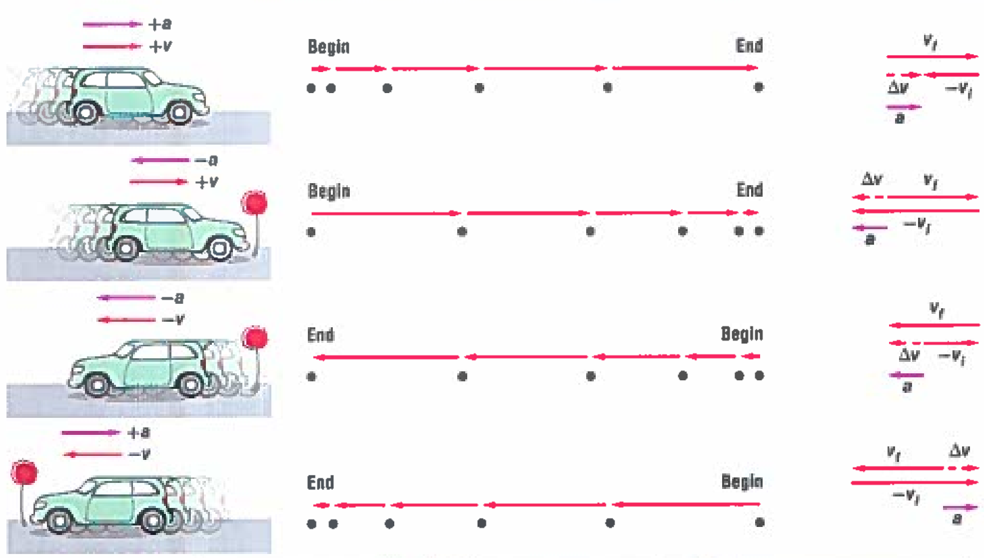
In the first and third situations, when the car is speeding up, the velocity and acceleration vectors point in the same direction. In the other two situations, in which the acceleration vector is in the opposite direction from the velocity vectors, the car is slowing down. In other words, when the car's acceleration and velocity are in the same direction, the car's speed increases. When they are in opposite directions, the speed of the car decreases.

Both the direction of an object's velocity and its direction of acceleration are needed to determine whether it is speeding up or slowing down. An object has a positive acceleration when the acceleration vector points in the positive direction and a negative acceleration when the acceleration vector points in the negative direction. It is important to notice that the sign of acceleration alone does not indicate whether the object is speeding up or slowing down.

☑ **READING CHECK** **Describe** the motion of an object if its velocity and acceleration vectors have opposite signs.

Figure 4 You need to know the direction of both the velocity and acceleration vectors in order to determine whether an object is speeding up or slowing down.

Velocity and Motion Diagram



Velocity	Δv	a
Increases	Positive Direction	Positive Direction
Increases	Negative Direction	Negative Direction
Decreases	Positive Direction	Negative Direction
Decreases	Negative Direction	Positive Direction

Velocity-Time Graphs

Just as it was useful to graph position versus time, it also is useful to plot velocity versus time. On a **velocity-time graph,** or *v-t* graph, velocity is plotted on the vertical axis and time is plotted on the horizontal axis.

Slope The velocity-time graph for a car that started at rest and sped up along a straight stretch of road is shown in **Figure 5.** The positive direction has been chosen to be the same as that of the car's motion. Notice that the graph is a straight line. This means the car sped up at a constant rate. The rate at which the car's velocity changed can be found by calculating the slope of the velocity-time graph.

The graph shows that the slope is 5.00 (m/s)/s, which is commonly written as 5 m/s^2. Consider the time interval between 4.00 s and 5.00 s. At 4.00 s, the car's velocity was 20.0 m/s in the positive direction. At 5.00 s, the car was traveling at 25.0 m/s in the same direction. Thus, in 1.00 s, the car's velocity increased by 5.0 m/s in the positive direction. When the velocity of an object changes at a constant rate, it has a constant acceleration.

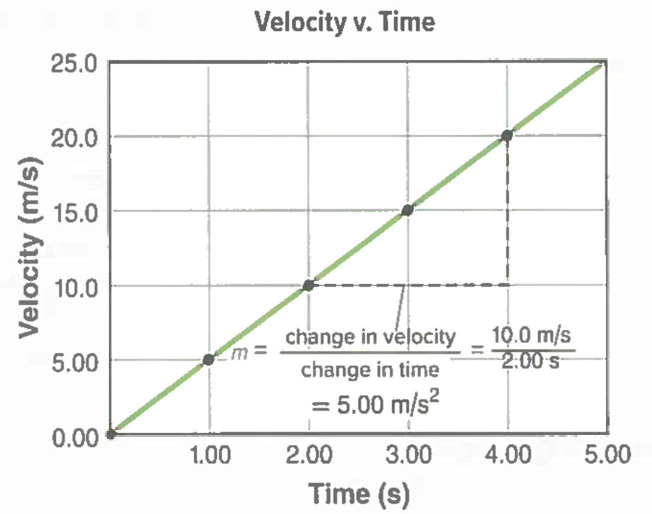


Figure 5 You can determine acceleration from a velocity-time graph by calculating the slope of the line. The slope is the rise divided by the run using any two points on the line.

Reading velocity-time graphs The motions of five runners are shown in **Figure 6.** Assume that the positive direction is east. The slopes of Graphs A and E are zero. Thus, the accelerations are zero. Both graphs show motion at a constant velocity—Graph A to the east and Graph E to the west. Graph B shows motion with a positive velocity eastward. Its slope indicates a constant, positive acceleration. You can infer that the speed increases because velocity and acceleration are positive. Graph C has a negative slope. It shows motion that begins with a positive velocity, slows down, and then stops. This means the acceleration and the velocity are in opposite directions. The point at which Graphs C and B cross shows that the runners' velocities are equal at that time. It does not, however, identify their positions.

Graph D indicates motion that starts out toward the west, slows down, for an instant has zero velocity, and then moves east with increasing speed. The slope of Graph D is positive. Because velocity and acceleration are initially in opposite directions, the speed decreases to zero at the time the graph crosses the *x*-axis. After that time, velocity and acceleration are in the same direction, and the speed increases.

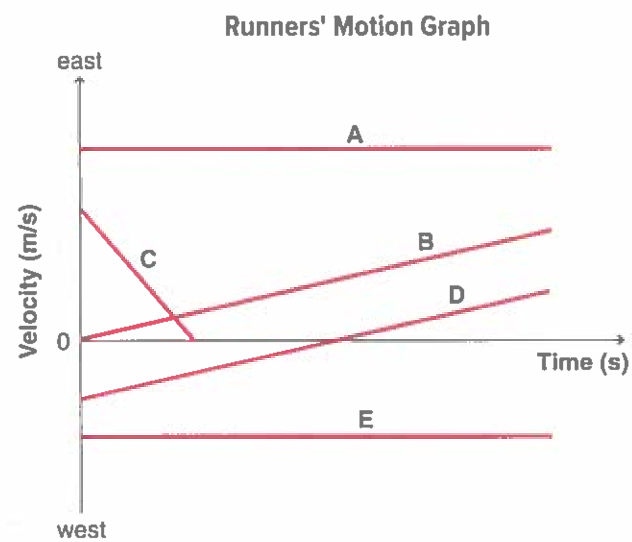


Figure 6 Because east is chosen as the positive direction on the graph, velocity is positive if the line is above the horizontal axis and negative if the line is below it. Acceleration is positive if the line is slanted upward on the graph. Acceleration is negative if the line is slanted downward on the graph. A horizontal line indicates constant velocity and zero acceleration.

READING CHECK **Describe** the meaning of a line crossing the *x*-axis in a velocity-time graph.

MiniLAB

STEEL BALL RACE

Does the height of a ramp affect the motion of a ball rolling down it?

PhysicsLABs

ACCELERATION

How can you use motion measurements to calculate the acceleration of a rolling ball?

TOSSED-BALL MOTION

PROBEWARE LAB What does the graph of ball tossed upward look like?

Average and Instantaneous Acceleration

How does it feel differently if the car you ride in accelerates a little or if it accelerates a lot? As with velocity, the acceleration of most moving objects continually changes. If you want to describe an object's acceleration, it is often more convenient to describe the overall change in velocity during a certain time interval rather than describing the continual change.

The **average acceleration** of an object is the change in its velocity during some measurable time interval divided by that time interval. Average acceleration is measured in meters per second per second (m/s/s), or simply meters per second squared (m/s^2). A car might accelerate quickly at times and more slowly at times. Just as average velocity depends only on the starting and ending displacement, average acceleration depends only on the starting and ending velocity during a time interval. **Figure 7** shows a graph of motion in which the acceleration is changing. The average acceleration during a certain time interval is determined just as it is in **Figure 5** for constant acceleration. Notice, however, that because the line is curved, the average acceleration in this graph varies depending on the time interval that you choose.

The change in an object's velocity at an instant of time is called **instantaneous acceleration.** You can determine the instantaneous acceleration of an object by drawing a tangent line on the velocity-time graph at the point of time in which you are interested. The slope of this line is equal to the instantaneous acceleration. Most of the situations considered in this textbook assume an ideal case of constant acceleration. When the acceleration is the same at all points during a time interval, the average acceleration and the instantaneous accelerations are equal.

READING CHECK **Contrast** How is instantaneous acceleration different from average acceleration?

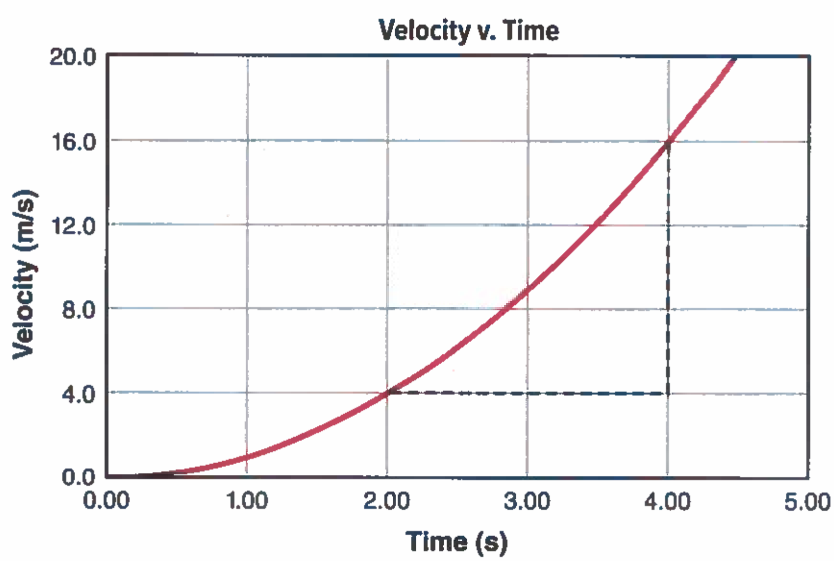


Figure 7 A curved line on a velocity-time graph shows that the acceleration is changing. The slope indicates the average acceleration during a time interval that you choose.

Calculate How large is the average acceleration between 0.00 s and 2.00 s?

Calculating Acceleration

How can you describe the acceleration of an object mathematically? Recall that the acceleration of an object is the slope of that object's velocity v. time graph. On a velocity v. time graph, slope equals $\Delta v/\Delta t$.

AVERAGE ACCELERATION

Average acceleration is defined as the change in velocity divided by the time it takes to make that change.

$$\bar{a} \equiv \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$$

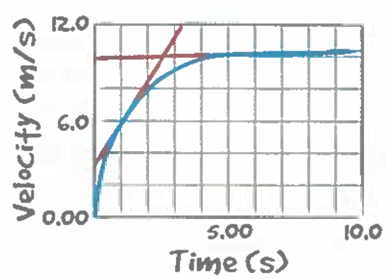
Suppose you run wind sprints back and forth across the gym. You first run at a speed of 4.0 m/s toward the wall. Then, 10.0 s later, your speed is 4.0 m/s as you run away from the wall. What is your average acceleration if the positive direction is toward the wall?

$$\bar{a} \equiv \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$$

$$= \frac{-4.0\text{ m/s} - 4.0\text{ m/s}}{10.0\text{ s}} = -0.80\text{ m/s}^2$$

EXAMPLE 1

VELOCITY AND ACCELERATION How would you describe the sprinter's velocity and acceleration as shown on the graph?



1 ANALYZE AND SKETCH THE PROBLEM

From the graph, note that the magnitude of the sprinter's velocity starts at zero, increases rapidly for the first few seconds, and then, after reaching about 10.0 m/s, remains almost constant.

KNOWN	UNKNOWN
v = varies	a = ?

2 SOLVE FOR THE UNKNOWN

Draw tangents to the curve at two points. Choose $t = 1.00$ s and $t = 5.00$ s. Solve for magnitude of the acceleration at 1.00 s:

$$a = \frac{\text{change in velocity}}{\text{change in time}}$$

◀ *The slope of the tangent at 1.00 s is equal to the acceleration at that time.*

$$= \frac{10.0\text{ m/s} - 6.0\text{ m/s}}{2.4\text{ s} - 1.00\text{ s}}$$

$$= 2.9\text{ m/s/s} = 2.9\text{ m/s}^2$$

Solve for the magnitude of the instantaneous acceleration at 5.0 s:

$$a = \frac{\text{change in velocity}}{\text{change in time}}$$

◀ *The slope of the tangent at 5.0 s is equal to the acceleration at that time.*

$$= \frac{10.3\text{ m/s} - 10.0\text{ m/s}}{10.0\text{ s} - 0.00\text{ s}}$$

$$= 0.030\text{ m/s/s} = 0.030\text{ m/s}^2$$

The acceleration is not constant because its magnitude changes from 2.9 m/s^2 at 1.0 s to 0.030 m/s^2 at 5.0 s.

The acceleration is in the direction chosen to be positive because both values are positive.

3 EVALUATE THE ANSWER

Are the units correct? Acceleration is measured in m/s^2.

APPLICATION

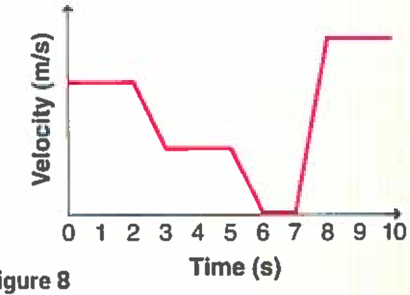


Figure 8

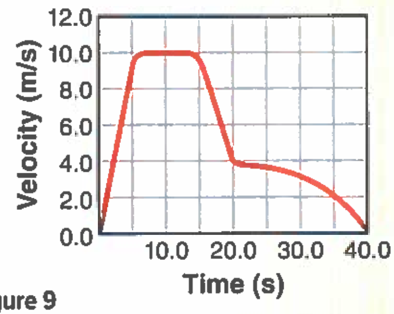


Figure 9

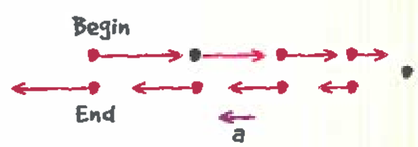
1. The velocity-time graph in **Figure 8** describes Hamad's motion as he walks along the midway at the Global Village in Dubai. Sketch the corresponding motion diagram. Include velocity vectors in your diagram.
2. Use the *v-t* graph of the toy train in **Figure 9** to answer these questions.
   - **a.** When is the train's speed constant?
   - **b.** During which time interval is the train's acceleration positive?
   - **c.** When is the train's acceleration most negative?
3. Refer to **Figure 9** to find the average acceleration of the train during the following time intervals.
   - **a.** 0.0 s to 5.0 s **b.** 15.0 s to 20.0 s **c.** 0.0 s to 40.0 s
4. **CHALLENGE** Plot a *v-t* graph representing the following motion: An elevator starts at rest from the ground floor of a three-story shopping mall. It accelerates upward for 2.0 s at a rate of 0.5 m/s^2, continues up at a constant velocity of 1.0 m/s for 12.0 s, and then slows down with a constant downward acceleration of 0.25 m/s^2 for 4.0 s as it reaches the third floor.

EXAMPLE 2

ACCELERATION Describe a ball's motion as it rolls up a slanted driveway. It starts at 2.50 m/s, slows down for 5.00 s, stops for an instant, and then rolls back down. The positive direction is chosen to be up the driveway. The origin is where the motion begins. What are the sign and the magnitude of the ball's acceleration as it rolls up the driveway?

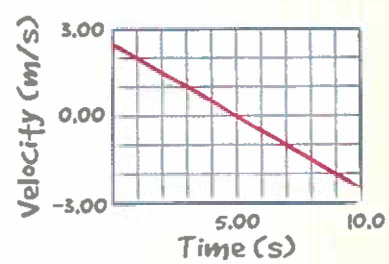
1 ANALYZE AND SKETCH THE PROBLEM

- Sketch the situation.
- Draw the coordinate system based on the motion diagram.



KNOWN
$v_i = +2.50$ m/s
$v_f = 0.00$ m/s at $t = 5.00$ s

UNKNOWN
$a = ?$



2 SOLVE FOR THE UNKNOWN

Find the acceleration from the slope of the graph.

Solve for the change in velocity and the time taken to make that change.

$\Delta v = v_f - v_i$

$= 0.00$ m/s $- 2.50$ m/s $= -2.50$ m/s ◀ Substitute v_f = 0.00 m/s at t_f = 5.00 s, v_i = 2.50 m/s at t_i = 0.00 s

$\Delta t = t_f - t_i$

$= 5.00$ s $- 0.00$ s $= 5.00$ s ◀ Substitute t_f = 5.00 s, t_i = 0.00 s

Solve for the acceleration.

$\bar{a} = \frac{\Delta v}{\Delta t} = (-2.50$ m/s$) / 5.00$ s ◀ Substitute Δv = -2.50 m/s, Δt = 5.00 s

$= -0.500$ m/s^2 or 0.500 m/s^2 down the driveway

3 EVALUATE THE ANSWER

- **Are the units correct?** Acceleration is measured in m/s^2.
- **Do the directions make sense?** As the ball slows down, the direction of acceleration is opposite that of velocity.

APPLICATION

5. A race car's forward velocity increases from 4.0 m/s to 36 m/s over a 4.0 s time interval. What is its average acceleration?

6. The race car in the previous problem slows from 36 m/s to 15 m/s over 3.0 s. What is its average acceleration?

7. A bus is moving west at 25 m/s when the driver steps on the brakes and brings the bus to a stop in 3.0 s.
   - **a.** What is the average acceleration of the bus while braking?
   - **b.** If the bus took twice as long to stop, how would the acceleration compare with what you found in part **a?**

8. A car is coasting backward downhill at a speed of 3.0 m/s when the driver gets the engine started. After 2.5 s, the car is moving uphill at 4.5 m/s. If uphill is chosen as the positive direction, what is the car's average acceleration?

9. Sultan has been jogging east toward the bus stop at 3.5 m/s when he looks at his watch and sees that he has plenty of time before the bus arrives. Over the next 10.0 s, he slows his pace to a leisurely 0.75 m/s. What was his average acceleration during this 10.0 s?

10. **CHALLENGE** If the rate of continental drift were to abruptly slow from 1.0 cm/y to 0.5 cm/y over the time interval of a year, what would be the average acceleration?

Acceleration with Constant Speed

Think again about running wind sprints across the gym. Notice that your speed is the same as you move toward the wall of the gym and as you move away from it. In both cases, you are running at a speed of 4.0 m/s. How is it possible for you to be accelerating?

Acceleration can occur even when speed is constant. The average acceleration for the entire trip you make toward the wall of the gym and back again is -0.80 m/s^2. The negative sign indicates that the direction of your acceleration is away from the wall because the positive direction was chosen as toward the wall. The velocity changes from positive to negative when the direction of motion changes. A change in velocity results in acceleration. Thus, acceleration can also be associated with a change in the direction of motion.

☑ **READING CHECK** **Explain** how it is possible for an object to accelerate when the object is traveling at a constant speed.

SECTION 1 REVIEW

11. **MAINIDEA** What are three ways an object can accelerate?

12. **Position-Time and Velocity-Time Graphs** Two joggers run at a constant velocity of 7.5 m/s east. **Figure 10** shows the positions of both joggers at time $t = 0$.
    - **a.** What would be the difference(s) in the position-time graphs of their motion?
    - **b.** What would be the difference(s) in their velocity-time graphs?

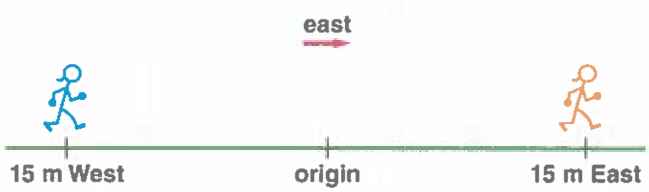


Figure 10

13. **Velocity-Time Graph** Sketch a velocity-time graph for a car that goes east at 25 m/s for 100 s, then west at 25 m/s for another 100 s.

14. **Average Velocity and Average Acceleration** A canoeist paddles upstream at a velocity of 2.0 m/s for 4.0 s and then floats downstream at 4.0 m/s for 4.0 s.
    - **a.** What is the average velocity of the canoe during the 8.0-s time interval?
    - **b.** What is the average acceleration of the canoe during the 8.0-s time interval?

15. **Critical Thinking** A police officer clocked a driver going 32 km/h over the speed limit just as the driver passed a slower car. When the officer stopped the car, the driver argued that the other driver should get a ticket as well. The driver said that the cars must have been going the same speed because they were observed next to each other. Is the driver correct? Explain with a sketch and a motion diagram.

SECTION 2 Motion with Constant Acceleration

PHYSICS 4 YOU **Suppose a car is moving along a road and suddenly the driver sees a fallen tree blocking the way ahead. Will the driver be able to stop in time? It all depends on how effectively the car's brakes can cause the car to accelerate in the direction opposite its motion.**

MAIN IDEA

For an object with constant acceleration, the relationships among position, velocity, acceleration, and time can be described by graphs and equations.

Essential Questions

- What do a position-time graph and a velocity-time graph look like for motion with constant acceleration?
- How can you determine the displacement of a moving object from its velocity-time graph?
- What are the relationships among position, velocity, acceleration, and time?

Review Vocabulary

displacement change in position having both magnitude and direction; it is equal to the final position minus the initial position

Position with Constant Acceleration

If an object experiences constant acceleration, its velocity changes at a constant rate. How does its position change? The positions at different times of a car with constant acceleration are graphed in **Figure 11.** The graph shows that the car's motion is not uniform. The displacements for equal time intervals on the graph get larger and larger. As a result, the slope of the line in **Figure 11** gets steeper as time goes on. For an object with constant acceleration, the position-time graph is a parabola.

The slopes from the position-time graph in **Figure 11** have been used to create the velocity-time graph on the left in **Figure 12.** For an object with constant acceleration, the velocity-time graph is a straight line.

A unique position-time graph cannot be created using a velocity-time graph because it does not contain information about position. It does, however, contain information about displacement. Recall that for an object moving at a constant velocity, the velocity is the displacement divided by the time interval. The displacement is then the product of the velocity and the time interval. On the right graph in **Figure 12** on the next page, $\boldsymbol{v}$ is the height of the plotted line above the horizontal axis, and Δt is the width of the shaded triangle. The area is $\left(\frac{1}{2}\right)\boldsymbol{v}\Delta t$, or $\Delta \boldsymbol{x}$. Thus, the area under the v-t graph equals the displacement.

☑ READING CHECK **Identify** What is the shape of a position-time graph of an object traveling with constant acceleration?

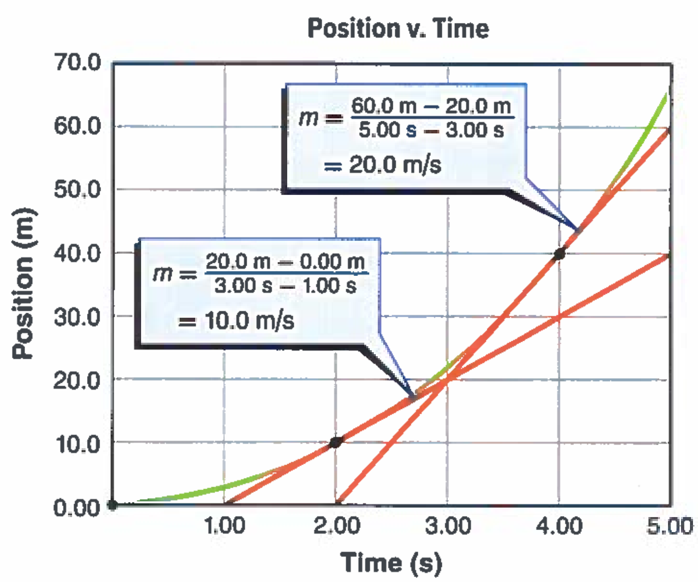
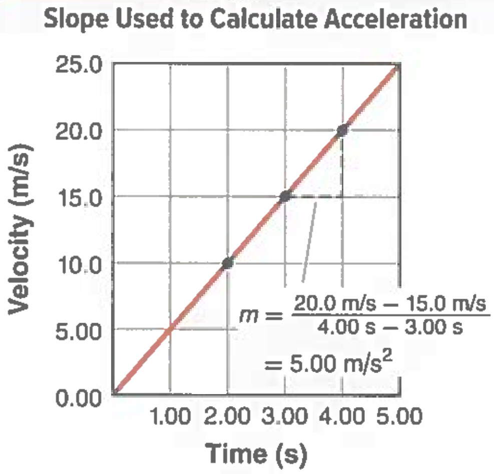


Figure 11 The slope of a position-time graph changes with time for an object with constant acceleration.



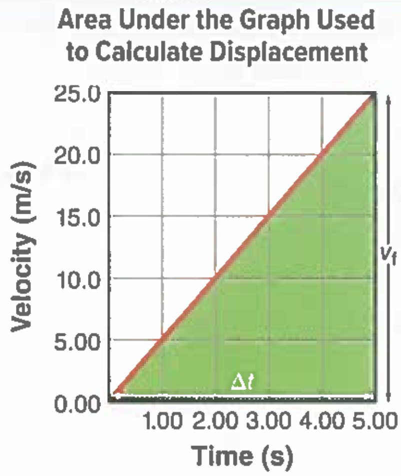


Figure 12 The slopes of the position-time graph in **Figure 11** are shown in these velocity-time graphs. The rise divided by the run gives the acceleration on the left. The area under the curve gives the displacement on the right.

Calculate What is the slope of the velocity-time graph on the left between $t = 2.00$ s and $t = 5.00$ s?

Velocity with Average Acceleration

You have read that the equation for average velocity can be algebraically rearranged to show the new position after a period of time, given the initial position and the average velocity. The definition of average acceleration can be manipulated similarly to show the new velocity after a period of time, given the initial velocity and the average acceleration.

If you know an object's average acceleration during a time interval, you can use it to determine how much the velocity changed during that time. You can rewrite the definition of average acceleration ($\overline{a} \equiv \frac{\Delta v}{\Delta t}$) as follows:

$$\Delta v = \overline{a}\Delta t$$
$$v_f - v_i = \overline{a}\Delta t$$

The equation for final velocity with average acceleration can be written:

FINAL VELOCITY WITH AVERAGE ACCELERATION

The final velocity is equal to the initial velocity plus the product of the average acceleration and the time interval.

$$v_f = v_i + \overline{a}\Delta t$$

In cases when the acceleration is constant, the average acceleration ($\overline{a}$) is the same as the instantaneous acceleration (a). This equation can be rearranged to find the time at which an object with constant acceleration has a given velocity. You can also use it to calculate the initial velocity of an object when both a velocity and the time at which it occurred are given.

PhysicsLAB

MEASURING ACCELERATION

PROBEWARE LAB What does a graph show about the motion of a cart?

APPLICATION

16. A golf ball rolls up a hill toward a miniature-golf hole. Assume the direction toward the hole is positive.

a. If the golf ball starts with a speed of 2.0 m/s and slows at a constant rate of 0.50 m/s^2, what is its velocity after 2.0 s?

b. What is the golf ball's velocity if the constant acceleration continues for 6.0 s?

c. Describe the motion of the golf ball in words and with a motion diagram.

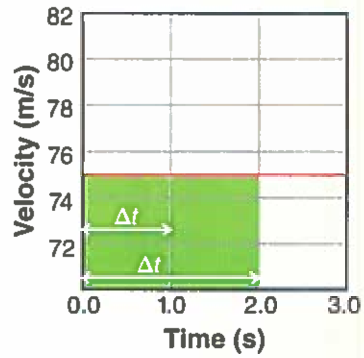
17. A bus traveling 30.0 km/h east has a constant increase in speed of 1.5 m/s^2. What is its velocity 6.8 s later?

18. If a car accelerates from rest at a constant rate of 5.5 m/s^2 north, how long will it take for the car to reach a velocity of 28 m/s north?

19. CHALLENGE A car slows from 22 m/s to 3.0 m/s at a constant rate of 2.1 m/s^2. How many seconds are required before the car is traveling at a forward velocity of 3.0 m/s?

EXAMPLE 3

FINDING DISPLACEMENT FROM A VELOCITY-TIME GRAPH The velocity-time graph at the right shows the motion of an airplane. Find the displacement of the airplane for Δt =1.0 s and for Δt = 2.0 s. Let the positive direction be forward.



1 ANALYZE AND SKETCH THE PROBLEM

- The displacement is the area under the *v-t* graph.
- The time intervals begin at t = 0.0 s.

KNOWN	UNKNOWN
v = +75 m/s	Δx = ?
Δt = 1.0 s	
Δt = 2.0 s	

2 SOLVE FOR THE UNKNOWN

Use the relationship among displacement, velocity, and time interval to find Δx during Δt = 1.0 s.

$\Delta x = v\Delta t$

$= (+75 \text{ m/s})(1.0 \text{ s})$ ◄ Substitute v = +75 m/s, Δt = 1.0 s.

$= +75 \text{ m}$

Use the same relationship to find Δx during Δt = 2.0 s.

$\Delta x = v\Delta t$

$= (+75 \text{ m/s})(2.0 \text{ s})$ ◄ Substitute v = +75 m/s, Δt = 2.0 s.

$= +150 \text{ m}$

3 EVALUATE THE ANSWER

- **Are the units correct?** Displacement is measured in meters.
- **Do the signs make sense?** The positive sign agrees with the graph.
- **Is the magnitude realistic?** Moving a distance of about one football field per second is reasonable for an airplane.

APPLICATION

20. The graph in **Figure 13** describes the motion of two bicyclists, Ibrahim and Basam, who start from rest and travel north, increasing their speed with a constant acceleration. What was the total displacement of each bicyclist during the time shown for each?
Hint: Use the area of a triangle: area = $\left(\frac{1}{2}\right)$*(base)(height).*

21. The motion of two people, moving south along a straight path is described by the graph in **Figure 14.** What is the total displacement of each person during the 4.0-s interval shown on the graph?

22. CHALLENGE A car, just pulling onto a straight stretch of highway, has a constant acceleration from 0 m/s to 25 m/s west in 12 s.

a. Draw a *v-t* graph of the car's motion.

b. Use the graph to determine the car's displacement during the 12.0 s time interval.

c. Another car is traveling along the same stretch of highway. It travels the same distance in the same time as the first car, but its velocity is constant. Draw a *v-t* graph for this car's motion.

d. Explain how you knew this car's velocity.

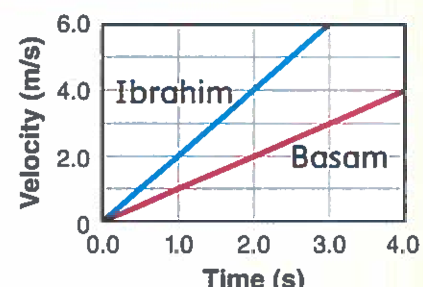


Figure 13

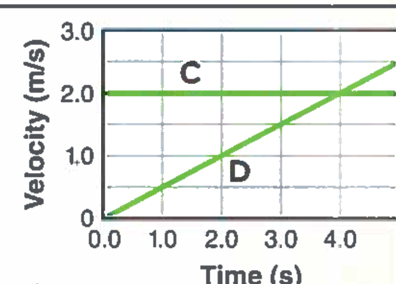


Figure 14

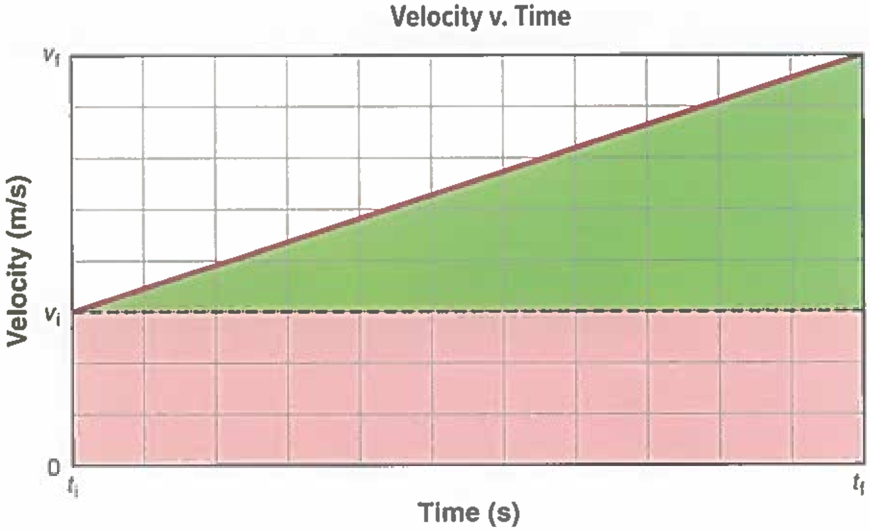


Figure 15 For motion with constant acceleration, if the initial velocity on a velocity-time graph is not zero, the area under the graph is the sum of a rectangular area and a triangular area.

Motion with an initial nonzero velocity The graph in **Figure 15** describes constant acceleration that started with an initial velocity of v_i. To determine the displacement, you can divide the area under the graph into a rectangle and a triangle. The total area is then:

$$\Delta x = \Delta x_{rectangle} + \Delta x_{triangle} = v_i(\Delta t) + \left(\frac{1}{2}\right)\Delta v \Delta t$$

Substituting $a\Delta t$ for the change in velocity in the equation yields:

$$\Delta x = \Delta x_{rectangle} + \Delta x_{triangle} = v_i(\Delta t) + \left(\frac{1}{2}\right)a(\Delta t)^2$$

When the initial or final position of the object is known, the equation can be written as follows:

$$x_f - x_i = v_i(\Delta t) + \left(\frac{1}{2}\right)a(\Delta t)^2 \text{ or } x_f = x_i + v_i(\Delta t) + \left(\frac{1}{2}\right)a(\Delta t)^2$$

If the initial time is $t_i = 0$, the equation then becomes the following.

POSITION WITH AVERAGE ACCELERATION

An object's final position is equal to the sum of its initial position, the product of the initial velocity and the final time, and half the product of the acceleration and the square of the final time.

$$x_f = x_i + v_i t_f + \left(\frac{1}{2}\right)a t_f^2$$

An Alternative Equation

Often, it is useful to relate position, velocity, and constant acceleration without including time. Rearrange the equation $v_f = v_i + at_f$ to solve for time: $t_f = \frac{v_f - v_i}{a}$.

You can then rewrite the position with average acceleration equation by substituting t_f to obtain the following:

$$x_f = x_i + v_i\left(\frac{v_f - v_i}{a}\right) + \left(\frac{1}{2}\right)a\left(\frac{v_f - v_i}{a}\right)^2$$

This equation can be solved for the velocity (v_f) at any position (x_f).

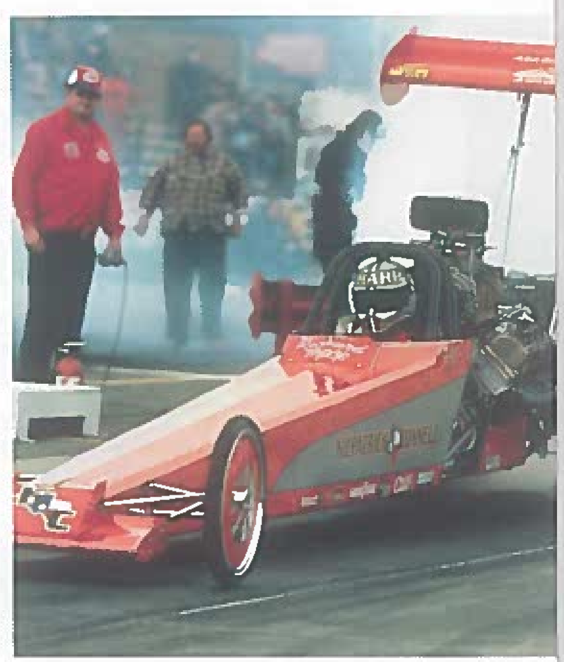
VELOCITY WITH CONSTANT ACCELERATION

The square of the final velocity equals the sum of the square of the initial velocity and twice the product of the acceleration and the displacement since the initial time.

$$v_f^2 = v_i^2 + 2a(x_f - x_i)$$

REAL-WORLD PHYSICS

DRAG RACING A dragster driver tries to obtain maximum acceleration over a course. The fastest U.S. National Hot Rod Association time on record for the 402-m course is 3.771 s. The highest final speed on record is 145.3 m/s (324.98 mph).

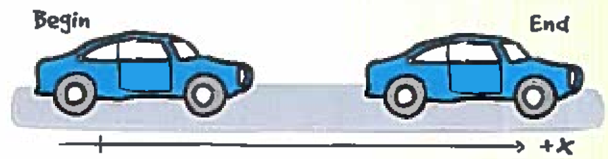


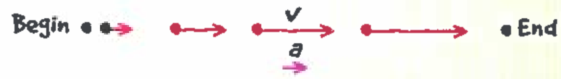
EXAMPLE 4

DISPLACEMENT An automobile starts at rest and accelerates at $3.5\ m/s^2$ after a traffic light turns green. How far will it have gone when it is traveling at 25 m/s?

1 ANALYZE AND SKETCH THE PROBLEM

- Sketch the situation.
- Establish coordinate axes. Let the positive direction be to the right.
- Draw a motion diagram.





KNOWN	UNKNOWN
$x_i = 0.00$ m	$x_f = ?$
$v_i = 0.00$ m/s	
$v_f = +25$ m/s	
$\bar{a} = a = +3.5\ m/s^2$	

2 SOLVE FOR THE UNKNOWN

Use the relationship among velocity, acceleration, and displacement to find x_f.

$$v_f^2 = v_i^2 + 2a(x_f - x_i)$$

$$x_f = x_i + \frac{v_f^2 - v_i^2}{2a}$$

$$= 0.00\ m + \frac{(+25\ m/s)^2 - (0.00\ m/s)^2}{2(+3.5\ m/s^2)}$$

◀ Substitute $x_i = 0.00$ m, $v_f = +25$ m/s, $v_i = 0.00$ m/s, $a = +3.5\ m/s^2$.

$$= +89\ m$$

3 EVALUATE THE ANSWER

- **Are the units correct?** Position is measured in meters.
- **Does the sign make sense?** The positive sign agrees with both the pictorial and physical models.
- **Is the magnitude realistic?** The displacement is almost the length of a football field. The result is reasonable because 25 m/s (about 55 mph) is fast.

APPLICATION

23. A skateboarder is moving at a constant speed of 1.75 m/s when she starts up an incline that causes her to slow down with a constant acceleration of $-0.20\ m/s^2$. How much time passes from when she begins to slow down until she begins to move back down the incline?

24. A race car travels on a straight racetrack with a forward velocity of 44 m/s and slows at a constant rate to a velocity of 22 m/s over 11 s. How far does it move during this time?

25. A car accelerates at a constant rate from 15 m/s to 25 m/s while it travels a distance of 125 m. How long does it take to achieve the final speed?

26. A bike rider pedals with constant acceleration to reach a velocity of 7.5 m/s north over a time of 4.5 s. During the period of acceleration, the bike's displacement is 19 m north. What was the initial velocity of the bike?

27. CHALLENGE The car in **Figure 16** travels west with a forward acceleration of $0.22\ m/s^2$. What was the car's velocity (v_i) at point x_i if it travels a distance of 350 m in 18.4 s?

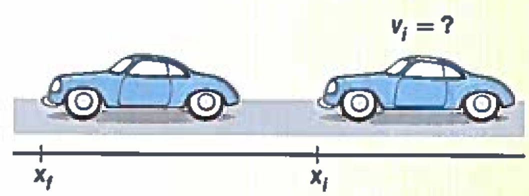


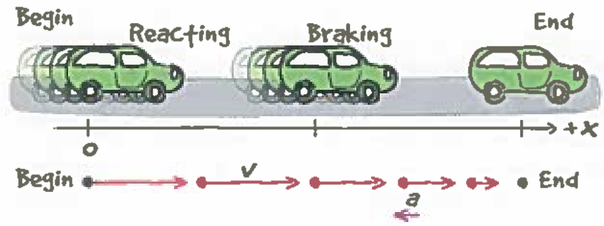
Figure 16

EXAMPLE 5

TWO-PART MOTION You are driving a car, traveling at a constant velocity of 25 m/s along a straight road, when you see a child suddenly run onto the road. It takes 0.45 s for you to react and apply the brakes. As a result, the car slows with a steady acceleration of 8.5 m/s^2 in the direction opposite your motion and comes to a stop. What is the total displacement of the car before it stops?

1 ANALYZE AND SKETCH THE PROBLEM

- Sketch the situation.
- Choose a coordinate system with the motion of the car in the positive direction.
- Draw the motion diagram, and label *v* and *a*.



KNOWN	UNKNOWN
$v_{reacting} = +25$ m/s	$x_{reacting} = ?$
$t_{reacting} = 0.45$ s	$x_{braking} = ?$
$a_{braking} = -8.5$ m/s^2	$x_{total} = ?$
$v_{i,\,braking} = +25$ m/s	
$v_{f,\,braking} = 0.00$ m/s	

2 SOLVE FOR THE UNKNOWN

Reacting:

Use the relationship among displacement, velocity, and time interval to find the displacement of the car as it travels at a constant speed.

$$x_{reacting} = v_{reacting}t_{reacting}$$

$$x_{reacting} = (+25 \text{ m/s})(0.45 \text{ s}) \qquad \blacktriangleleft \text{ Substitute } v_{reacting} = +25 \text{ m/s}, t_{reacting} = 0.45 \text{ s}.$$

$$= +11 \text{ m}$$

Braking:

Use the relationship among velocity, acceleration, and displacement to find the displacement of the car while it is braking.

$$v_{f,\,braking}{}^2 = v_{reacting}{}^2 + 2a_{braking}(x_{braking})$$

Solve for $x_{braking}$.

$$x_{braking} = \frac{v_{f,\,braking}{}^2 - v_{reacting}{}^2}{2a_{braking}}$$

$$= \frac{(0.00 \text{ m/s})^2 - (+25 \text{ m/s})^2}{2(-8.5 \text{ m/s}^2)} \qquad \blacktriangleleft \text{ Substitute } v_{f,\,braking} = 0.00 \text{ m/s}, v_{reacting} = +25 \text{ m/s}, a_{braking} = -8.5 \text{ m/s}^2.$$

$$= +37 \text{ m}$$

The total displacement is the sum of the reaction displacement and the braking displacement.

Solve for x_{total}.

$$x_{total} = x_{reacting} + x_{braking}$$

$$= +11 \text{ m} + 37 \text{ m} \qquad \blacktriangleleft \text{ Substitute } x_{reacting} = +11 \text{ m}, x_{braking} = +37 \text{ m}.$$

$$= +48 \text{ m}$$

3 EVALUATE THE ANSWER

- **Are the units correct?** Displacement is measured in meters.
- **Do the signs make sense?** Both $x_{reacting}$ and $x_{braking}$ are positive, as they should be.
- **Is the magnitude realistic?** The braking displacement is small because the magnitude of the acceleration is large.

APPLICATION

28. A car with an initial velocity of 24.5 m/s east has an acceleration of 4.2 m/s^2 west. What is its displacement at the moment that its velocity is 18.3 m/s east?

29. A man runs along the path shown in **Figure 17.** From point A to point B, he runs at a forward velocity of 4.5 m/s for 15.0 min. From point B to point C, he runs up a hill. He slows down at a constant rate of 0.050 m/s^2 for 90.0 s and comes to a stop at point C. What was the total distance the man ran?

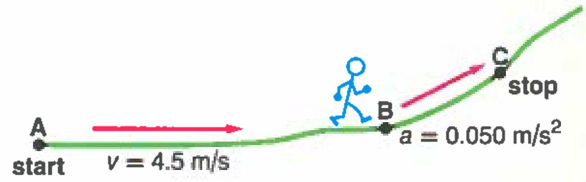


Figure 17

30. You start your bicycle ride at the top of a hill. You coast down the hill at a constant acceleration of 2.00 m/s^2. When you get to the bottom of the hill, you are moving at 18.0 m/s, and you pedal to maintain that speed. If you continue at this speed for 1.00 min, how far will you have gone from the time you left the hilltop?

31. Nora is training for a 5.0 km race. She starts out her training run by moving at a constant pace of 4.3 m/s for 19 min. Then she accelerates at a constant rate until she crosses the finish line 19.4 s later. What is her acceleration during the last portion of the training run?

32. **CHALLENGE** Kareem is learning to ride a bike without training wheels. His father pushes him with a constant acceleration of 0.50 m/s^2 east for 6.0 s. Kareem then travels at 3.0 m/s east for another 6.0 s before falling. What is Kareem's displacement? Solve this problem by constructing a velocity-time graph for Kareem's motion and computing the area underneath the graphed line.

SECTION 2 REVIEW

33. **MAINIDEA** If you were given initial and final velocities and the constant acceleration of an object, and you were asked to find the displacement, what mathematical relationship would you use?

34. **Acceleration** A woman driving west along a straight road at a speed of 23 m/s sees a deer on the road ahead. She applies the brakes when she is 210 m from the deer. If the deer does not move and the car stops right before it hits the deer, what is the acceleration provided by the car's brakes?

35. **Distance** The airplane in **Figure 18** starts from rest and accelerates east at a constant 3.00 m/s^2 for 30.0 s before leaving the ground.

a. What was the plane's displacement (Δx)?

b. How fast was the airplane going when it took off?

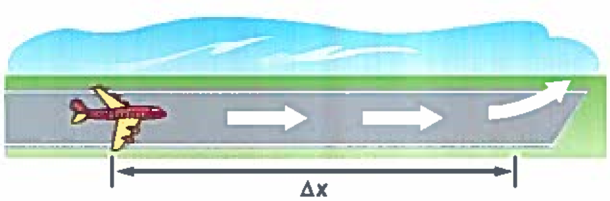


Figure 18

36. **Distance** An in-line skater first accelerates from 0.0 m/s to 5.0 m/s in 4.5 s, then continues at this constant speed for another 4.5 s. What is the total distance traveled by the in-line skater?

37. **Final Velocity** A plane travels a distance of 5.0×10^2 m north while being accelerated uniformly from rest at the rate of 5.0 m/s^2. What final velocity does it attain?

38. **Final Velocity** An airplane accelerated uniformly from rest at the rate of 5.0 m/s^2 south for 14 s. What final velocity did it attain?

39. **Graphs** A sprinter walks up to the starting blocks at a constant speed and positions herself for the start of the race. She waits until she hears the starting pistol go off and then accelerates rapidly until she attains a constant velocity. She maintains this velocity until she crosses the finish line, and then she slows to a walk, taking more time to slow down than she did to speed up at the beginning of the race. Sketch a velocity-time and a position-time graph to represent her motion. Draw them one above the other using the same time scale. Indicate on your position-time graph where the starting blocks and finish line are.

40. **Critical Thinking** Describe how you could calculate the acceleration of an automobile. Specify the measuring instruments and the procedures you would use.

SECTION 3

Free Fall

PHYSICS 4 YOU **Before their parachutes open, skydivers sometimes join hands to form a ring as they fall toward Earth. What happens if the skydivers have different masses? Do they fall at the same rate or different rates?**

MAIN IDEA

The acceleration of an object in free fall is due to gravity alone.

Essential Questions

- What is free-fall acceleration?
- How do objects in free fall move?

Review Vocabulary

origin the point at which both variables in a coordinate system have the value zero

New Vocabulary

free fall
free-fall acceleration

Galileo's Discovery

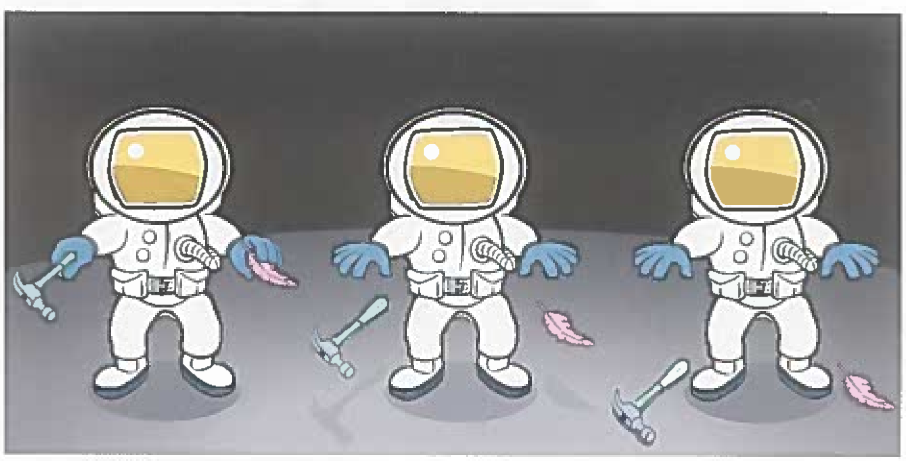
Which falls with more acceleration, a piece of paper or your physics book? If you hold one in each hand and release them, the book hits the ground first. Do heavier objects accelerate more as they fall? Try dropping them again, but first place the paper flat on the book. Without air pushing against it, the paper falls as fast as the book. For a lightweight object such as paper, collisions with particles of air have a greater effect than they do on a heavy book.

To understand falling objects, first consider the case in which air does not have an appreciable effect on motion. Recall that gravity is an attraction between objects. **Free fall** is the motion of an object when gravity is the only significant force acting on it.

About 400 years ago, Galileo Galilei discovered that, neglecting the effect of the air, all objects in free fall have the same acceleration. It doesn't matter what they are made of or how much they weigh. The acceleration of an object due only to the effect of gravity is known as **free-fall acceleration. Figure 19** depicts the results of a 1971 free-fall experiment on the Moon in which astronauts verified Galileo's results.

Near Earth's surface, free-fall acceleration is about 9.8 m/s^2 downward (which is equal to about 22 mph/s downward). Think about the skydivers above. Each second the skydivers fall, their downward velocity increases by 9.8 m/s. When analyzing free fall, whether you treat the acceleration as positive or negative depends on the coordinate system you use. If you define upward as the positive direction, then the free-fall acceleration is negative. If you decide that downward is the positive direction, then free-fall acceleration is positive.

Figure 19 In 1971 astronaut David Scott dropped a hammer and a feather at the same time from the same height above the Moon's surface. The hammer's mass was greater, but both objects hit the ground at the same time because the Moon has gravity but no air.



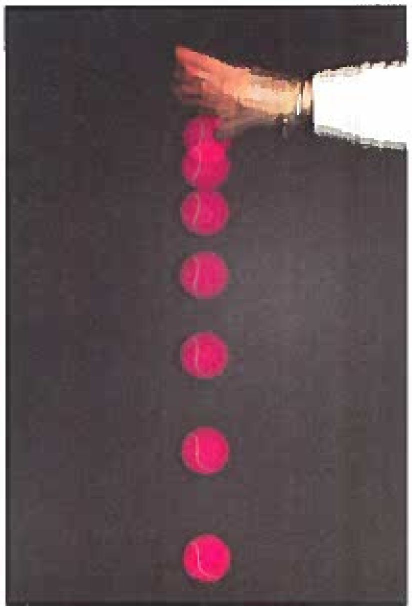


Figure 20 Because of free-fall acceleration, the speed of this falling ball increases 9.8 m/s each second.

Free-Fall Acceleration

Galileo's discovery explains why parachutists can form a ring in midair. Regardless of their masses, they fall with the same acceleration. To understand the acceleration that occurs during free fall, look at the multiflash photo of a dropped ball in **Figure 20.** The time interval between the images is 0.06 s. The distance between each pair of images increases, so the speed is increasing. If the upward direction is positive, then the velocity is becoming more and more negative.

Ball thrown upward Instead of a dropped ball, could this photo also illustrate a ball thrown upward? Suppose you throw a ball upward with a speed of 20.0 m/s. If you choose upward to be positive, then the ball starts at the bottom of the photo with a positive velocity. The acceleration is $\boldsymbol{a} = -9.8\ \mathrm{m/s^2}$. Because velocity and acceleration are in opposite directions, the speed of the ball decreases. If you think of the bottom of the photo as the start, this agrees with the multiflash photo.

Rising and falling motion After 1 s, the ball's velocity is reduced by 9.8 m/s, so it now is traveling at +10.2 m/s. After 2 s, the velocity is +0.4 m/s, and the ball still is moving upward. What happens during the next second? The ball's velocity is reduced by another 9.8 m/s and equals −9.4 m/s. The ball now is moving downward. After 4 s, the velocity is −19.2 m/s, meaning the ball is falling even faster.

Velocity-time graph The v-t graph for the ball as it goes up and down is shown in **Figure 21.** The straight line sloping downward does not mean that the speed is always decreasing. The speed decreases as the ball rises and increases as it falls. At around 2 s, the velocity changes smoothly from positive to negative. As the ball falls, its speed increases in the negative direction. The figure also shows a closer view of the v-t graph. At an instant of time, near 2.04 s, the velocity is zero.

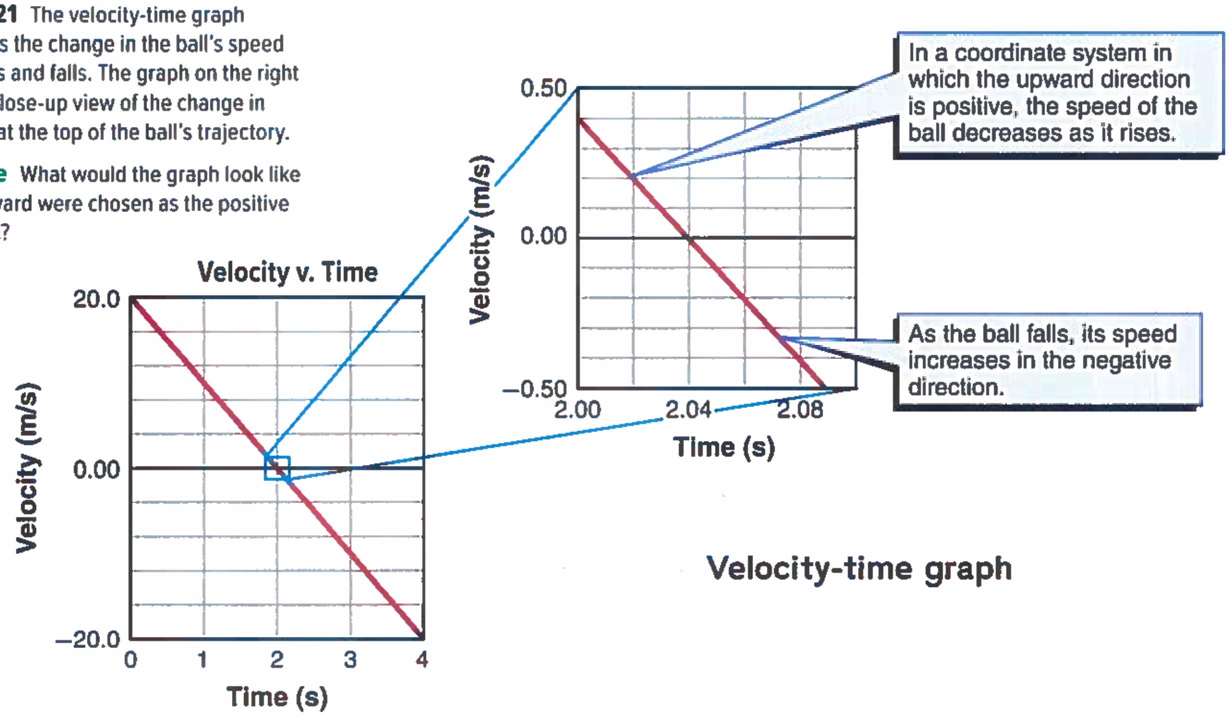
MiniLAB

FREE FALL

How can you use the motion of a falling object to estimate free-fall acceleration?

Figure 21 The velocity-time graph describes the change in the ball's speed as it rises and falls. The graph on the right gives a close-up view of the change in velocity at the top of the ball's trajectory.

Analyze What would the graph look like if downward were chosen as the positive direction?



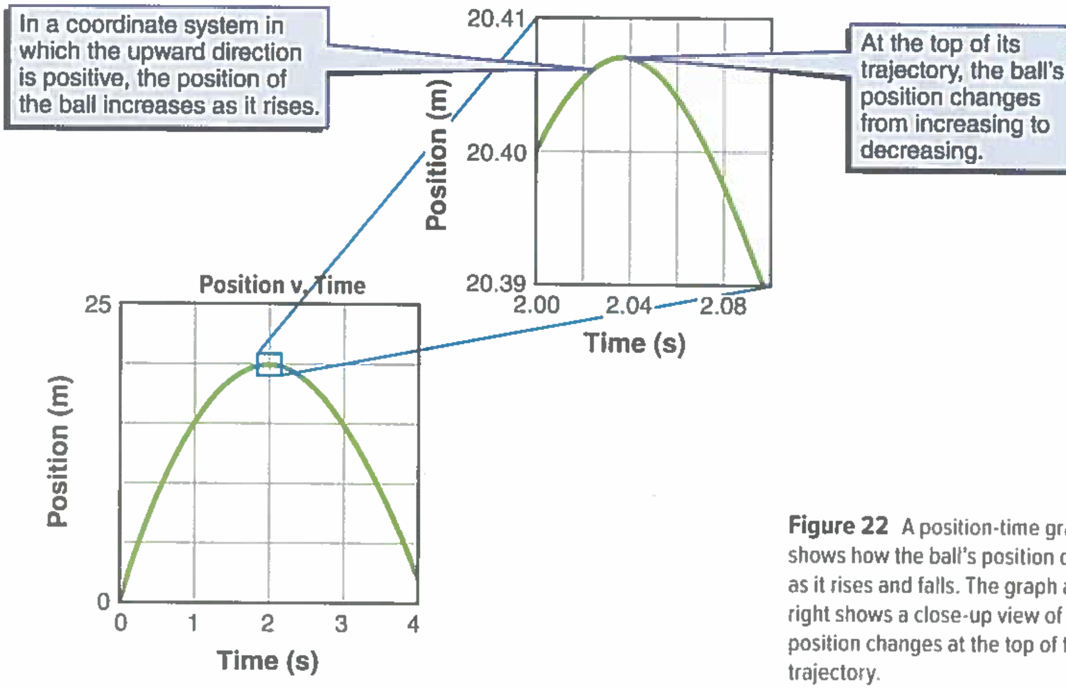


Figure 22 A position-time graph shows how the ball's position changes as it rises and falls. The graph at the right shows a close-up view of how the position changes at the top of the ball's trajectory.

Position-time graph Look at the position-time graphs in **Figure 22.** These graphs show how the ball's height changes as it rises and falls. If an object is moving with constant acceleration, its position-time graph forms a parabola. Because the ball is rising and falling, its graph is an inverted parabola. The shape of the graph shows the progression of time. It does not mean that the ball's path was in the shape of a parabola. The close-up graph on the right shows that at about 2.04 s, the ball reaches its maximum height.

Maximum height Compare the close-up graphs in **Figure 21** and **Figure 22.** Just before the ball reaches its maximum height, its velocity is decreasing in the positive direction. At the instant of time when its height is maximum, its velocity is zero. Just after it reaches its maximum height, the ball's velocity is increasing in the negative direction.

Acceleration The slope of the line on the velocity-time graph in **Figure 21** is constant at $-9.8\ m/s^2$. This shows that the ball's free-fall acceleration is $9.8\ m/s^2$ in the downward direction the entire time the ball is rising and falling.

It may seem that the acceleration should be zero at the top of the trajectory, but this is not the case. At the top of the flight, the ball's velocity is 0 m/s. If its acceleration were also zero, the ball's velocity would not change and would remain at 0 m/s. The ball would not gain any downward velocity and would simply hover in the air. Have you ever seen that happen? Objects tossed in the air on Earth always fall, so you know the acceleration of an object at the top of its flight must not be zero. Further, because the object falls down, you know the acceleration must be downward.

READING CHECK Analyze If you throw a ball straight up, what are its velocity and acceleration at the uppermost point of its path?

VOCABULARY

Science Usage v. Common Usage

Free fall

- **Science usage**
motion of a body when air resistance is negligible and the acceleration can be considered due to gravity alone
Acceleration during free fall is $9.8\ m/s^2$ downward.

- **Common usage**
a rapid and continuing drop or decline
The stock market's free fall in 1929 marked the beginning of the Great Depression.

PhysicsLAB

FREE-FALL ACCELERATION

INTERNET LAB How can you use motion data to calculate free-fall acceleration?

Free-fall rides Amusement parks use the concept of acceleration to design rides that give the riders the sensation of free fall. These types of rides usually consist of three parts: the ride to the top, momentary suspension, and the fall downward. Motors provide the force needed to move the cars to the top of the ride. When the cars are in free fall, the most massive rider and the least massive rider will have the same acceleration.

Suppose the free-fall ride shown in **Figure 23** starts from the top at rest and is in free fall for 1.5 s. What would be its velocity at the end of 1.5 s? Choose a coordinate system with a positive axis upward and the origin at the initial position of the car. Because the car starts at rest, v_i would be equal to 0.0 m/s. To calculate the final velocity, use the equation for velocity with constant acceleration.

$$\begin{aligned} v_f &= v_i + \bar{a}t_f \\ &= 0.0\ \text{m/s} + (-9.8\ \text{m/s}^2)(1.5\ \text{s}) \\ &= -15\ \text{m/s} \end{aligned}$$

How far do people on the ride fall during this time? Use the equation for displacement when time and constant acceleration are known.

$$\begin{aligned} x_f &= x_i + v_i t_f + \left(\frac{1}{2}\right)\bar{a}t_f^2 \\ &= 0.0\ \text{m} + (0.0\ \text{m/s})(1.5\ \text{s}) + \left(\frac{1}{2}\right)(-9.8\ \text{m/s}^2)(1.5\ \text{s})^2 \\ &= -11\ \text{m} \end{aligned}$$

Figure 23 The people on this amusement-park ride experience free-fall acceleration.

APPLICATION

41. A construction worker accidentally drops a brick from a high scaffold.

a. What is the velocity of the brick after 4.0 s?

b. How far does the brick fall during this time?

42. Suppose for the previous problem you choose your coordinate system so that the opposite direction is positive.

a. What is the brick's velocity after 4.0 s?

b. How far does the brick fall during this time?

43. A student drops a ball from a window 3.5 m above the sidewalk. How fast is it moving when it hits the sidewalk?

44. A tennis ball is thrown straight up with an initial speed of 22.5 m/s. It is caught at the same distance above the ground.

a. How high does the ball rise?

b. How long does the ball remain in the air? *Hint: The time it takes the ball to rise equals the time it takes to fall.*

45. You decide to flip a coin to determine whether to do your physics or English homework first. The coin is flipped straight up.

a. What are the velocity and acceleration of the coin at the top of its trajectory?

b. If the coin reaches a high point of 0.25 m above where you released it, what was its initial speed?

c. If you catch it at the same height as you released it, how much time did it spend in the air?

46. CHALLENGE A basketball player is holding a ball in her hands at a height of 1.5 m above the ground. She drops the ball, and it bounces several times. After the first bounce, the ball only returns to a height of 0.75 m. After the second bounce, the ball only returns to a height of 0.25 m.

a. Suppose downward is the positive direction. What would the shape of a velocity-time graph look like for the first two bounces?

b. What would be the shape of a position-time graph for the first two bounces?

Variations in Free Fall

When astronaut David Scott performed his free-fall experiment on the Moon, the hammer and the feather did not fall with an acceleration of magnitude 9.8 m/s². The value 9.8 m/s² is free-fall acceleration only near Earth's surface. The magnitude of free-fall acceleration on the Moon is approximately 1.6 m/s², which is about one-sixth its value on Earth.

When you study force and motion, you will learn about factors that affect the value of free-fall acceleration. One factor is the mass of the object, such as Earth or the Moon, that is responsible for the acceleration. Free-fall acceleration is not as great near the Moon as near Earth because the Moon has much less mass.

Free-fall acceleration also depends on the distance from the object responsible for it. The rings drawn around Earth in **Figure 24** show how free-fall acceleration decreases with distance from Earth. It is important to understand, however, that variations in free-fall acceleration at different locations on Earth's surface are very small, even with great variations in elevation. In the United Arab Emirates, for example, the magnitude of free-fall acceleration is about 9.792 m/s². For calculations in this book, a value of 9.8 m/s² will be used for free-fall acceleration.

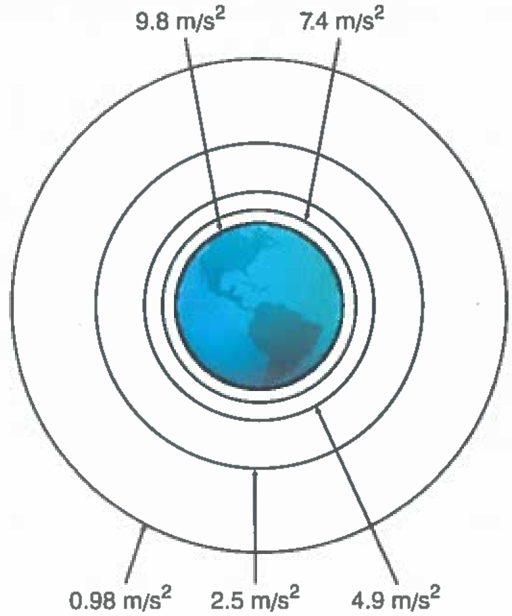


Figure 24 As the distance from Earth increases, the effect of free-fall acceleration decreases.

Analyze According to the diagram, what is the magnitude of free-fall acceleration a distance above Earth's surface equal to Earth's radius?

SECTION 3 REVIEW

47. MAINIDEA Suppose you hold a book in one hand and a flat sheet of paper in another hand. You drop them both, and they fall to the ground. Explain why the falling book is a good example of free fall, but the paper is not.

48. Final Velocity Your sister drops your house keys down to you from the second-floor window, as shown in **Figure 25**. What is the velocity of the keys when you catch them?

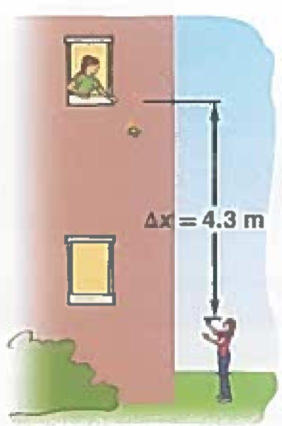


Figure 25

49. Free-Fall Ride Suppose a free-fall ride at an amusement park starts at rest and is in free fall. What is the velocity of the ride after 2.3 s? How far do people on the ride fall during the 2.3 s time period?

50. Maximum Height and Flight Time The free-fall acceleration on Mars is about one-third that on Earth. Suppose you throw a ball upward with the same velocity on Mars as on Earth.

a. How would the ball's maximum height compare to that on Earth?

b. How would its flight time compare?

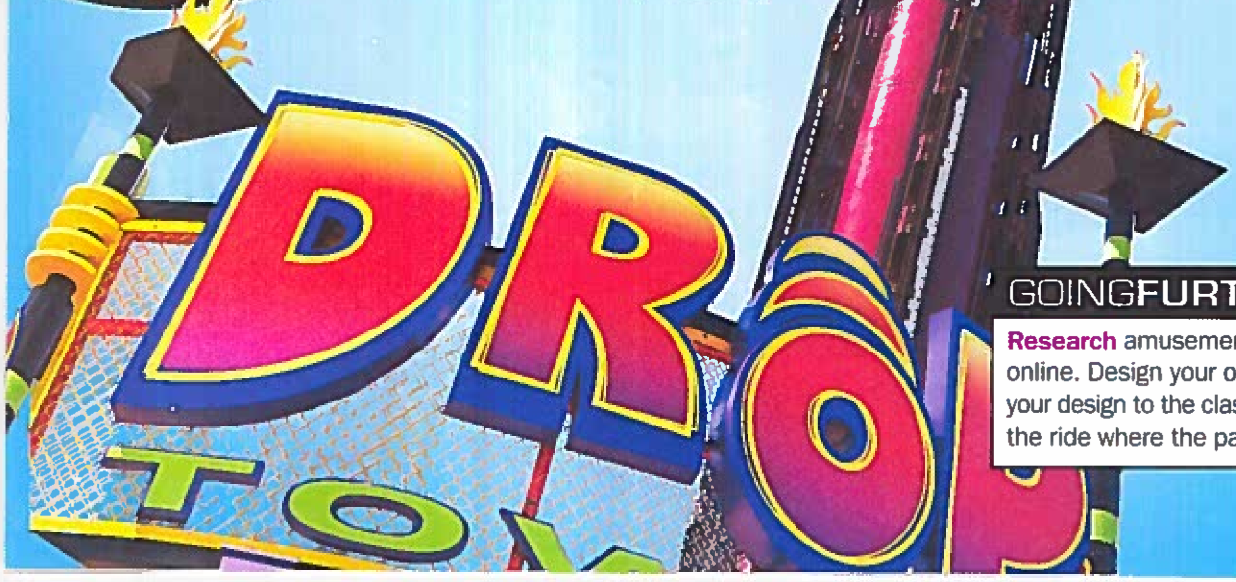
51. Velocity and Acceleration Suppose you throw a ball straight up into the air. Describe the changes in the velocity of the ball. Describe the changes in the acceleration of the ball.

52. Critical Thinking A ball thrown vertically upward continues upward until it reaches a certain position, and then falls downward. The ball's velocity is instantaneously zero at that highest point. Is the ball accelerating at that point? Devise an experiment to prove or disprove your answer.

Going Down?

Amusement-Park Thrill Rides

Your stomach jumps as you plummet 100 m downward. Just when you think you might smash into the ground, the breaks kick in and the amusement-park ride brings you to a slow and safe stop. "Let's go again!" cries your friend.



It's all about acceleration. Whether it's the 100-m plunge of a drop tower or the gentle up-and-down action of a carousel ride, the thrills of many amusement-park rides are based on the same principle—changes in velocity are exciting. Thrill rides take advantage of accelerations due to both changes in speed and changes in direction. A roller coaster is exciting because of accelerations produced by hills, loops, and banked turns, as shown in **Figure 1.**

Rides that use free-fall acceleration Many rides use free-fall acceleration to generate thrills. Drop-tower rides let passengers experience free fall and then carefully slow their descent just before they reach the ground. Pendulum rides, such as the one in **Figure 2,** act like giant swings. Passengers experience a stomach-churning moment as the pendulum reaches the top of its swing and begins to move downward. Passengers on a roller coaster experience a similar moment at the top of a hill.

FIGURE 2 Passengers sit in the pendulum of this pirate ship–themed ride, which swings back and forth like the pendulum on a grandfather clock.

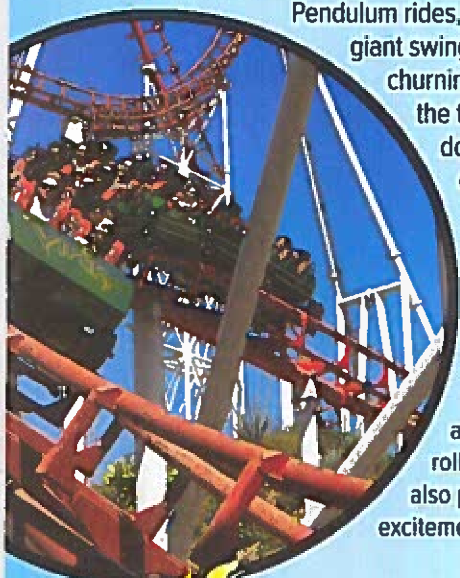


FIGURE 1 Passengers accelerate as they move around a banked turn of a roller coaster. Acceleration is also part of what provides the excitement in a series of loops.

GOINGFURTHER >>>

Research amusement-park ride design online. Design your own ride and present your design to the class. Identify points during the ride where the passengers accelerate.

CHAPTER 3

STUDY GUIDE

BIG IDEA Acceleration is the rate of change in an object's velocity.

VOCABULARY
- acceleration
- velocity-time graph
- average acceleration
- instantaneous acceleration

SECTION 1 Acceleration

MAIN IDEA An object accelerates when its velocity changes—that is, when it speeds up, slows down, or changes direction.

- Acceleration is the rate at which an object's velocity changes.
- Velocity and acceleration are not the same thing. An object moving with constant velocity has zero acceleration. When the velocity and the acceleration of an object are in the same direction, the object speeds up; when they are in opposite directions, the object slows down.
- You can use a velocity-time graph to find the velocity and the acceleration of an object.
- The average acceleration of an object is the slope of its velocity-time graph.

$$\bar{a} \equiv \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$$

SECTION 2 Motion with Constant Acceleration

MAIN IDEA For an object with constant acceleration, the relationships among position, velocity, acceleration, and time can be described by graphs and equations.

- If an object is moving with constant acceleration, its position-time graph is a parabola, and its velocity-time graph is a straight line.
- The area under an object's velocity-time graph is its displacement.
- In motion with constant acceleration, position, velocity, acceleration, and time are related:

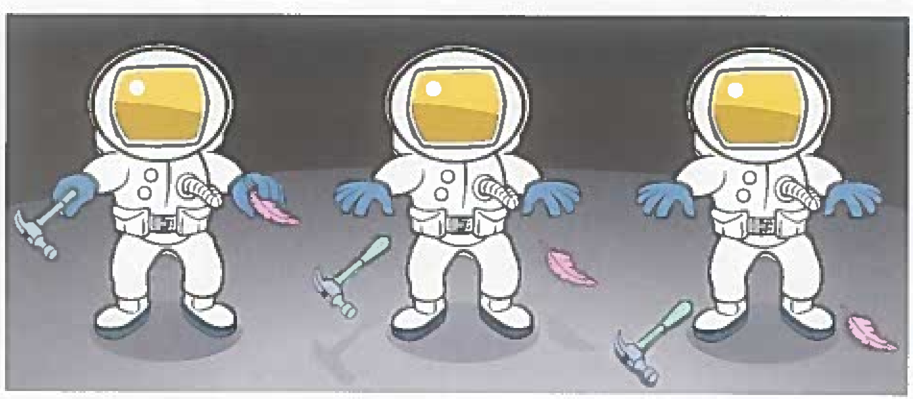
$$v_f = v_i + \bar{a}\Delta t$$
$$x_f = x_i + v_i t_f + \frac{1}{2}\bar{a}t_f^2$$
$$v_f^2 = v_i^2 + 2\bar{a}(x_f - x_i)$$

VOCABULARY
- free fall
- free-fall acceleration

SECTION 3 Free Fall

MAIN IDEA The acceleration of an object in free fall is due to gravity alone.

- Free-fall acceleration on Earth is about 9.8 m/s^2 downward. The sign associated with free-fall acceleration in equations depends on the choice of the coordinate system.
- When an object is in free fall, gravity is the only force acting on it. Equations for motion with constant acceleration can be used to solve problems involving objects in free fall.



SECTION 1 Acceleration

Mastering Concepts

53. BIGIDEA How are velocity and acceleration related?

54. Give an example of each of the following:

a. an object that is slowing down but has a positive acceleration

b. an object that is speeding up but has a negative acceleration

c. an object that is moving at a constant speed but has an acceleration

55. Figure 26 shows the velocity-time graph for an automobile on a test track. Describe how the velocity changes with time.

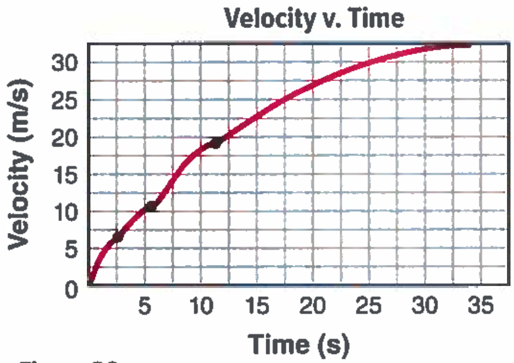


Figure 26

56. If the velocity-time graph of an object moving on a straight path is a line parallel to the horizontal axis, what can you conclude about its acceleration?

Mastering Problems

57. Ranking Task Rank the following objects according to the magnitude of the acceleration, from least to greatest. Specifically indicate any ties.

A. A falling acorn accelerates from 0.50 m/s to 10.3 m/s in 1.0 s.

B. A car accelerates from 20 m/s to rest in 1.0 s.

C. A centipede accelerates from 0.40 cm/s to 2.0 cm/s in 0.50 s.

D. While being hit, a golf ball accelerates from rest to 4.3 m/s in 0.40 s.

E. A jogger accelerates from 2.0 m/s to 1.0 m/s in 8.3 s.

58. Problem Posing Complete this problem so that it can be solved using the concept listed: "Mariam is playing basketball . . ."

a. acceleration

b. speed

59. The graph in **Figure 27** describes the motion of an object moving east along a straight path. Find the acceleration of the object at each of these times:

a. during the first 5.0 min of travel

b. between 5.0 min and 10.0 min

c. between 10.0 min and 15.0 min

d. between 20.0 min and 25.0 min

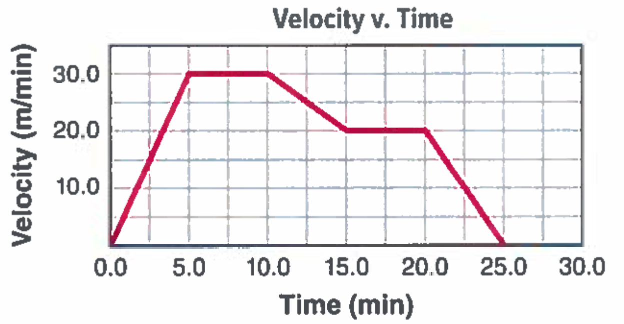


Figure 27

60. Plot a velocity-time graph using the information in **Table 1**, and answer the following questions:

a. During what time interval is the object speeding up? Slowing down?

b. At what time does the object reverse direction?

c. How does the average acceleration of the object between 0.0 s and 2.0 s differ from the average acceleration between 7.0 s and 12.0 s?

Table 1 Velocity v. Time

Time (s)	Velocity (m/s)
0.00	4.00
1.00	8.00
2.00	12.0
3.00	14.0
4.00	16.0
5.00	16.0
6.00	14.0
7.00	12.0
8.00	8.00
9.00	4.00
10.0	0.00
11.0	−4.00
12.0	−8.00

61. Determine the final velocity of a proton that has an initial forward velocity of 2.35×10^5 m/s and then is accelerated uniformly in an electric field at the rate of -1.10×10^{12} m/s^2 for 1.50×10^{-7} s.

62. Ranking Task Sami wants to buy the used sports car with the greatest acceleration. Car A can go from 0 m/s to 17.9 m/s in 4.0 s. Car B can accelerate from 0 m/s to 22.4 m/s in 3.5 s. Car C can go from 0 to 26.8 m/s in 6.0 s. Rank the three cars from greatest acceleration to least. Indicate if any are the same.

SECTION 2

Motion with Constant Acceleration

Mastering Concepts

63. What quantity does the area under a velocity-time graph represent?

64. Reverse Problem Write a physics problem with real-life objects for which the graph in **Figure 28** would be part of the solution.

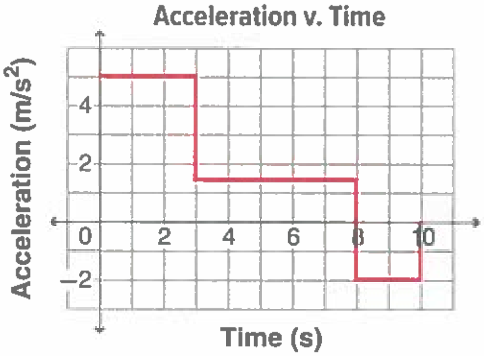


Figure 28

Mastering Problems

65. A car moves forward up a hill at 12 m/s with a uniform backward acceleration of 1.6 m/s^2.

a. What is its displacement after 6.0 s?

b. What is its displacement after 9.0 s?

66. Airplane Determine the displacement of a plane that experiences uniform acceleration from 66 m/s north to 88 m/s north in 12 s.

67. Race Car A race car is slowed with a constant acceleration of 11 m/s^2 opposite the direction of motion.

a. If the car is going 55 m/s, how many meters will it travel before it stops?

b. How many meters will it take to stop a car going twice as fast?

68. Refer to **Figure 29** to find the magnitude of the displacement during the following time intervals. Round answers to the nearest meter.

a. $t = 5.0$ min and $t = 10.0$ min

b. $t = 10.0$ min and $t = 15.0$ min

c. $t = 25.0$ min and $t = 30.0$ min

d. $t = 0.0$ min and $t = 25.0$ min

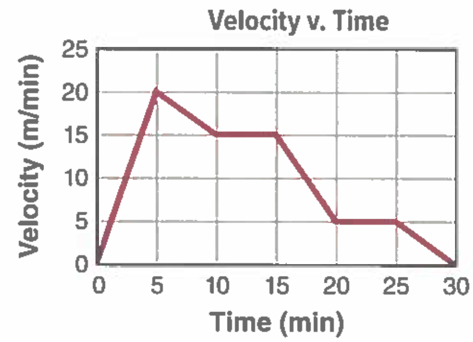


Figure 29

SECTION 3

Free Fall

Mastering Concepts

69. Explain why an aluminum ball and a steel ball of similar size and shape, dropped from the same height, reach the ground at the same time.

70. Give some examples of falling objects for which air resistance can and cannot be ignored.

Mastering Problems

71. Suppose an astronaut drops a feather from a height of 1.2 m above the surface of the Moon. If the free-fall acceleration on the Moon is 1.62 m/s^2 downward, how long does it take the feather to hit the Moon's surface?

72. A stone that starts at rest is in free fall for 8.0 s.

a. Calculate the stone's velocity after 8.0 s.

b. What is the stone's displacement during this time?

73. A bag is dropped from a hovering helicopter. The bag has fallen for 2.0 s. What is the bag's velocity? How far has the bag fallen? Ignore air resistance.

74. You throw a ball downward from a window at a speed of 2.0 m/s. How fast will it be moving when it hits the sidewalk 2.5 m below?

75. If you throw the ball in the previous problem up instead of down, how fast will it be moving when it hits the sidewalk?

76. **Beanbag** You throw a beanbag in the air and catch it 2.2 s later at the same place at which you threw it.
   a. How high did it go?
   b. What was its initial velocity?

Applying Concepts

77. **Croquet** A croquet ball, after being hit by a mallet, slows down and stops. Do the velocity and the acceleration of the ball have the same signs?

78. Explain how you would walk to produce each of the position-time graphs in **Figure 30.**

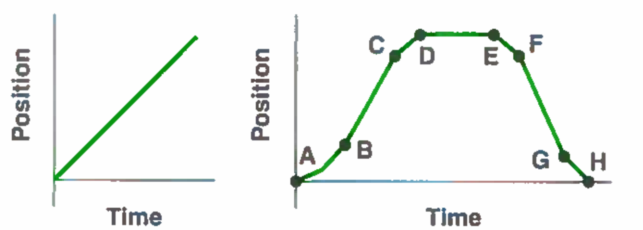


Figure 30

79. If you were given a table of velocities of an object at various times, how would you determine whether the acceleration was constant?

80. Look back at the graph in **Figure 26.** The three notches in the graph occur where the driver changed gears. Describe the changes in velocity and acceleration of the car while in first gear. Is the acceleration just before a gear change larger or smaller than the acceleration just after the change? Explain your answer.

81. An object shot straight up rises for 7.0 s before it reaches its maximum height. A second object falling from rest takes 7.0 s to reach the ground. Compare the displacements of the two objects during this time interval.

82. Draw a velocity-time graph for each of the graphs in **Figure 31.**

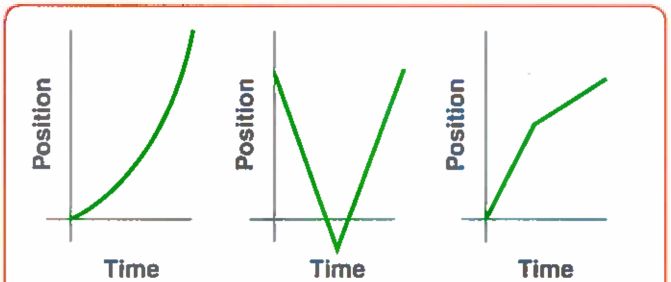


Figure 31

83. **The Moon** The value of free-fall acceleration on the Moon is about one-sixth of its value on Earth.
   a. Would a ball dropped by an astronaut hit the surface of the Moon with a greater, equal, or lesser speed than that of a ball dropped from the same height to Earth?
   b. Would it take the ball more, less, or equal time to fall?

84. **Jupiter** An object on the planet Jupiter has about three times the free-fall acceleration as on Earth. Suppose a ball could be thrown vertically upward with the same initial velocity on Earth and on Jupiter. Neglect the effects of Jupiter's atmospheric resistance, and assume that gravity is the only force on the ball.
   a. How would the maximum height reached by the ball on Jupiter compare to the maximum height reached on Earth?
   b. If the ball on Jupiter were thrown with an initial velocity that is three times greater, how would this affect your answer to part **a**?

85. Rock A is dropped from a cliff, and rock B is thrown upward from the same position.
   a. When they reach the ground at the bottom of the cliff, which rock has a greater velocity?
   b. Which has a greater acceleration?
   c. Which arrives first?

Mixed Review

86. Suppose a spaceship far from any star or planet had a uniform forward acceleration from 65.0 m/s to 162.0 m/s in 10.0 s. How far would the spaceship move?

87. **Figure 32** is a multiflash photo of a horizontally moving ball. What information about the photo would you need and what measurements would you make to estimate the acceleration?

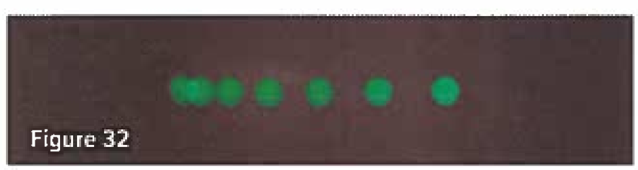


Figure 32

88. **Bicycle** A bicycle accelerates from 0.0 m/s to 4.0 m/s in 4.0 s. What distance does it travel?

89. A weather balloon is floating at a constant height above Earth when it releases a pack of instruments.
   a. If the pack hits the ground with a downward velocity of 73.5 m/s, how far did the pack fall?
   b. How long did it take for the pack to fall?

90. The total distance a steel ball rolls down an incline at various times is given in **Table 2.**

a. Draw a position-time graph of the motion of the ball. When setting up the axes, use five divisions for each 10 m of travel on the *x*-axis. Use five divisions for 1 s of time on the *t*-axis.

b. Calculate the distance the ball has rolled at the end of 2.2 s.

Table 2 Position v. Time

Time (s)	Position (m)
0.0	0.0
1.0	2.0
2.0	8.0
3.0	18.0
4.0	32.0
5.0	50.0

91. Engineers are developing new types of guns that might someday be used to launch satellites as if they were bullets. One such gun can give a small object a forward velocity of 3.5 km/s while moving it through a distance of only 2.0 cm.

a. What acceleration does the gun give this object?

b. Over what time interval does the acceleration take place?

92. Safety Barriers Highway safety engineers build soft barriers, such as the one shown in **Figure 33,** so that cars hitting them will slow down at a safe rate. Suppose a car traveling at 110 km/h hits the barrier, and the barrier decreases the car's velocity at a rate of 32 m/s^2. What distance would the car travel along the barrier before coming to a stop?

Figure 33

93. Baseball A baseball pitcher throws a fastball at a speed of 44 m/s. The ball has constant acceleration as the pitcher holds it in his hand and moves it through an almost straight-line distance of 3.5 m. Calculate the acceleration. Compare this acceleration to the free-fall acceleration on Earth.

94. Sleds Rocket-powered sleds are used to test the responses of humans to acceleration. Starting from rest, one sled can reach a speed of 444 m/s in 1.80 s and can be brought to a stop again in 2.15 s.

a. Calculate the acceleration of the sled when starting, and compare it to the magnitude of free-fall acceleration, 9.8 m/s^2.

b. Find the acceleration of the sled as it is braking, and compare it to the magnitude of free-fall acceleration.

95. The forward velocity of a car changes over an 8.0-s time period, as shown in **Table 3.**

a. Plot the velocity-time graph of the motion.

b. What is the car's displacement in the first 2.0 s?

c. What is the car's displacement in the first 4.0 s?

d. What is the displacement of the car during the entire 8.0 s?

e. Find the slope of the line between $t = 0.0$ s and $t = 4.0$ s. What does this slope represent?

f. Find the slope of the line between $t = 5.0$ s and $t = 7.0$ s. What does this slope indicate?

Table 3 Velocity v. Time

Time (s)	Velocity (m/s)
0.0	0.0
1.0	4.0
2.0	8.0
3.0	12.0
4.0	16.0
5.0	20.0
6.0	20.0
7.0	20.0
8.0	20.0

96. A truck is stopped at a stoplight. When the light turns green, the truck accelerates at 2.5 m/s^2. At the same instant, a car passes the truck going at a constant 15 m/s. Where and when does the truck catch up with the car?

97. Karate The position-time and velocity-time graphs of a player's fist breaking a wooden board during karate practice are shown in **Figure 34.**

a. Use the velocity-time graph to describe the motion of Belal's fist during the first 10 ms.

b. Estimate the slope of the velocity-time graph to determine the acceleration of his fist when it suddenly stops.

c. Express the acceleration as a multiple of the magnitude of free-fall acceleration, 9.8 m/s^2.

d. Determine the area under the velocity-time curve to find the displacement of the fist in the first 6 ms. Compare this with the position-time graph.

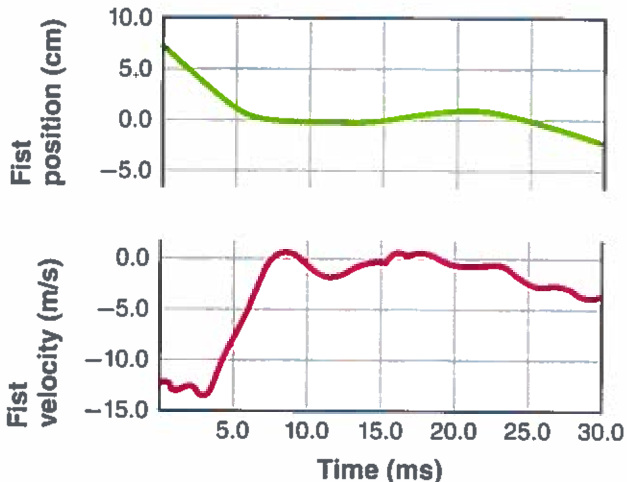


Figure 34

98. Cargo A helicopter is rising at 5.0 m/s when a bag of its cargo is dropped. The bag falls for 2.0 s.

a. What is the bag's velocity?

b. How far has the bag fallen?

c. How far below the helicopter is the bag?

Thinking Critically

99. Probeware Design a probeware lab to measure the distance an accelerated object moves over time. Use equal time intervals so that you can plot velocity over time as well as distance. A pulley at the edge of a table with a mass attached is a good way to achieve uniform acceleration. Suggested materials include a motion detector, lab cart, string, pulley, C-clamp, and masses. Generate position-time and velocity-time graphs using different masses on the pulley. How does the change in mass affect your graphs?

100. Analyze and Conclude Which (if either) has the greater acceleration: a car that increases its speed from 50 km/h to 60 km/h or a bike that goes from 0 km/h to 10 km/h in the same time? Explain.

101. Analyze and Conclude An express train traveling at 36.0 m/s is accidentally sidetracked onto a local train track. The express engineer spots a local train exactly 1.00×10^2 m ahead on the same track and traveling in the same direction. The local engineer is unaware of the situation. The express engineer jams on the brakes and slows the express train at a constant rate of 3.00 m/s^2. If the speed of the local train is 11.0 m/s, will the express train be able to stop in time, or will there be a collision? To solve this problem, take the position of the express train when the engineer first sights the local train as a point of origin. Next, keeping in mind that the local train has exactly a 1.00×10^2 m lead, calculate how far each train is from the origin at the end of the 12.0 s it would take the express train to stop (accelerate at –3.00 m/s^2 from 36 m/s to 0 m/s).

a. On the basis of your calculations, would you conclude that a collision will occur?

b. To check the calculations from part **a** and to verify your conclusion, take the position of the express train when the engineer first sights the local train as the point of origin and calculate the position of each train at the end of each second after the sighting. Make a table showing the distance of each train from the origin at the end of each second. Plot these positions on the same graph and draw two lines. Compare your graph to your answer to part **a**.

Writing in Physics

102. Research and describe Galileo's contributions to physics.

103. Research the maximum acceleration a human body can withstand without blacking out. Discuss how this impacts the design of three common entertainment or transportation devices.

Cumulative Review

104. Solve the following problems. Express your answers in scientific notation.

a. 6.2×10^{-4} m + 5.7×10^{-3} m

b. 8.7×10^{8} km – 3.4×10^{7} km

c. $(9.21\times10^{-5}\text{ cm})(1.83\times10^{8}\text{ cm})$

d. $\dfrac{2.63\times10^{-6}\text{ m}}{4.08\times10^{6}\text{ s}}$

105. The equation below describes an object's motion. Create the corresponding position-time graph and motion diagram. Then write a physics problem that could be solved using that equation. Be creative.

$$x = (35.0\text{ m/s})\,t - 5.0\text{ m}$$

MULTIPLE CHOICE

Use the following information to answer the first two questions.

A ball rolls down a hill with a constant acceleration of 2.0 m/s². The ball starts at rest and travels for 4.0 s before it reaches the bottom of the hill.

1. How far did the ball travel during this time?

A. 8.0 m **C.** 16 m
B. 12 m **D.** 20 m

2. What was the ball's speed at the bottom of the hill?

A. 2.0 m/s **C.** 12 m/s
B. 8.0 m/s **D.** 16 m/s

3. A driver of a car enters a new 110-km/h speed zone on the highway. The driver begins to accelerate immediately and reaches 110 km/h after driving 500 m. If the original speed was 80 km/h, what was the driver's forward acceleration?

A. 0.44 m/s² **C.** 8.4 m/s²
B. 0.60 m/s² **D.** 9.8 m/s²

4. A flowerpot falls off a balcony 85 m above the street. How long does it take to hit the ground?

A. 4.2 s **C.** 8.7 s
B. 8.3 s **D.** 17 s

5. A rock climber's shoe loosens a rock, and her climbing buddy at the bottom of the cliff notices that the rock takes 3.20 s to fall to the ground. How high up the cliff is the rock climber?

A. 15.0 m **C.** 50.0 m
B. 31.0 m **D.** 1.00×10^2 m

6. A car traveling at 91.0 km/h approaches the turnoff for a restaurant 30.0 m aheadxd. If the driver slams on the brakes with an acceleration of −6.40 m/s², what will be her stopping distance?

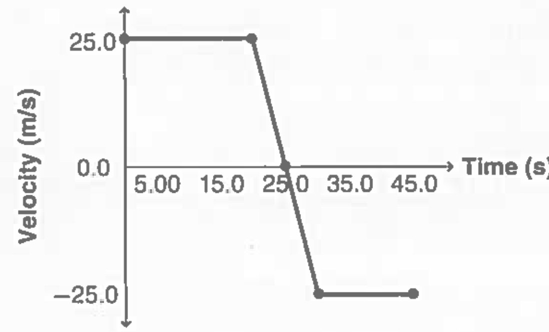
A. 14.0 m **C.** 50.0 m
B. 29.0 m **D.** 100.0 m

7. What is the correct formula manipulation to find acceleration when using the equation $v_f^2 = v_i^2 + 2ax$?

A. $\frac{v_f^2 - v_i^2}{x}$ **C.** $\frac{(v_f + v_i)^2}{2x}$
B. $\frac{v_f^2 + v_i^2}{2x}$ **D.** $\frac{v_f^2 - v_i^2}{2x}$

8. The graph below shows the motion of a farmer's truck. What is the truck's total displacement? Assume north is the positive direction.

A. 150 m south **C.** 300 m north
B. 125 m north **D.** 600 m south



9. How can the instantaneous acceleration of an object with varying acceleration be calculated?

A. by calculating the slope of the tangent on a position-time graph
B. by calculating the area under the graph on a position-time graph
C. by calculating the area under the graph on a velocity-time graph
D. by calculating the slope of the tangent on a velocity-time graph

FREE RESPONSE

10. Graph the following data, and then show calculations for acceleration and displacement after 12.0 s on the graph.

Time (s)	Velocity (m/s)
0.00	8.10
6.00	36.9
9.00	51.3
12.00	65.7

CHAPTER 4

Forces in One Dimension

BIGIDEA **Net forces cause changes in motion.**

SECTIONS

1 Force and Motion

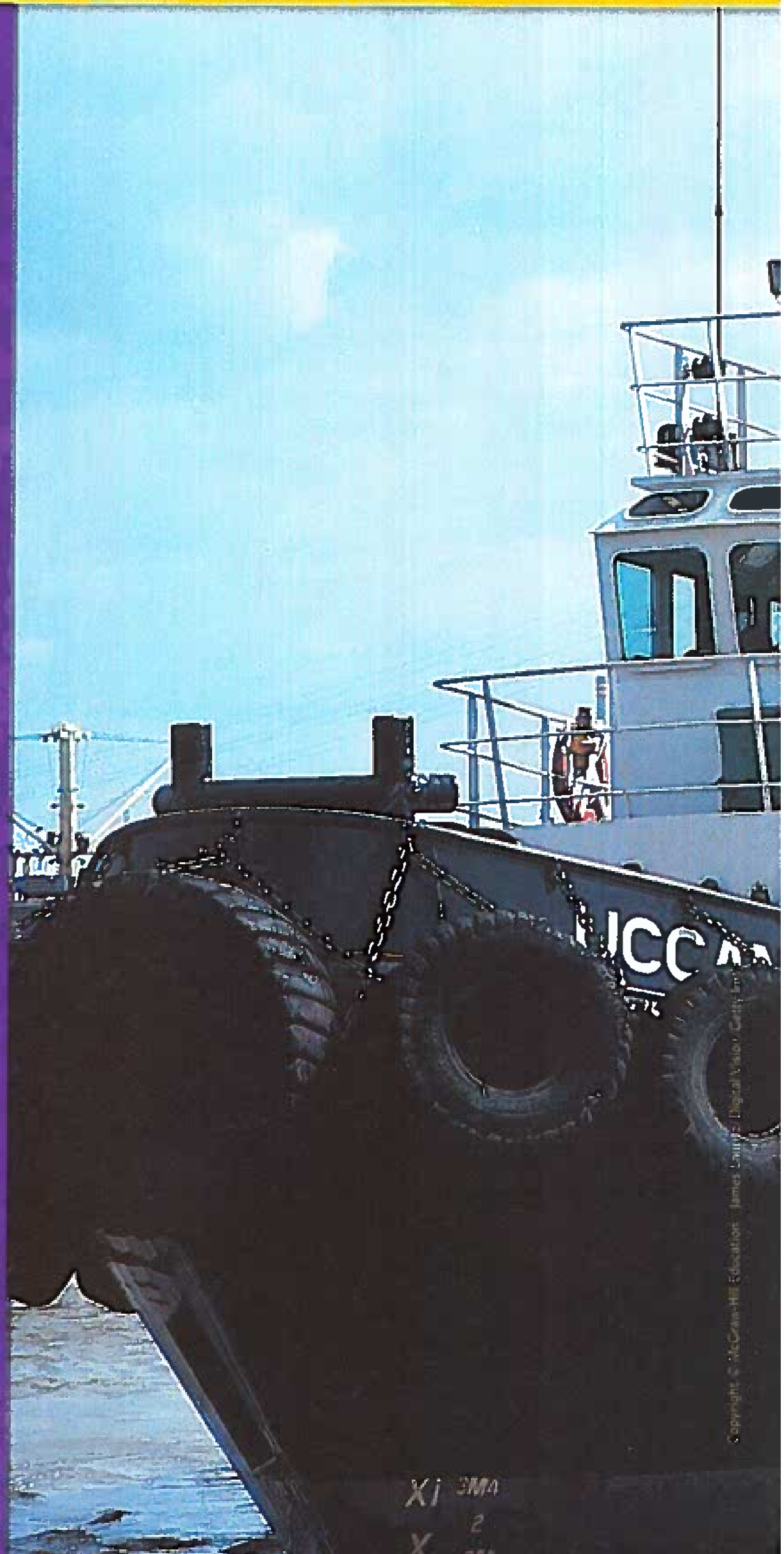
2 Weight and Drag Force

3 Newton's Third Law

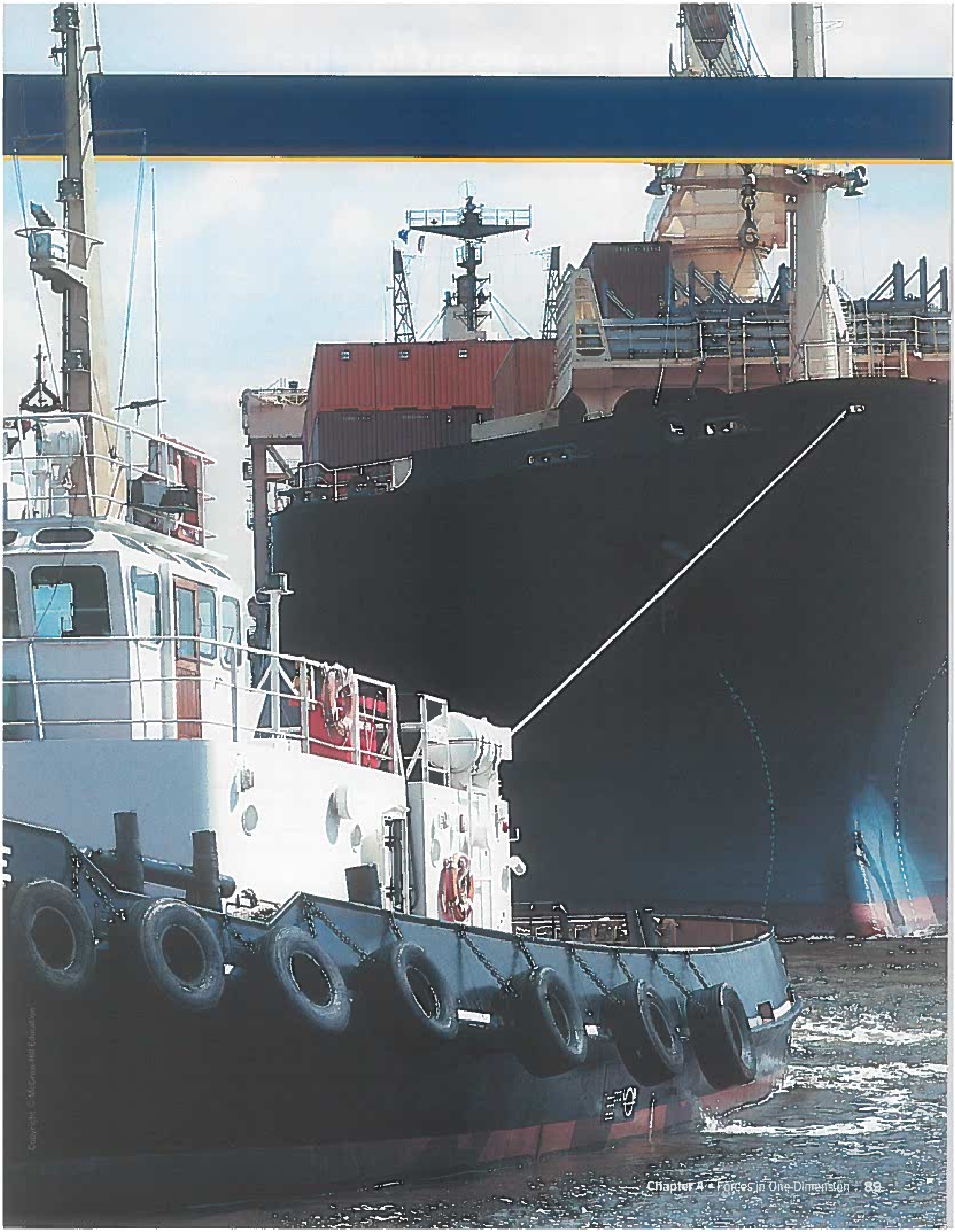
LaunchLAB

FORCES IN OPPOSITE DIRECTIONS

What happens when more than one force acts on an object?



James Lauritz/Digital Vision/Getty Images



SECTION 1

Force and Motion

PHYSICS 4 YOU **To start a skateboard moving on a level surface, you must push on the ground with your foot. If the skateboard is on a ramp, however, gravity will pull you down the slope. In both cases unbalanced forces change the skateboard's motion.**

MAIN IDEA
A force is a push or a pull.

Essential Questions

- What is a force?
- What is the relationship between force and acceleration?
- How does motion change when the net force is zero?

Review Vocabulary

acceleration the rate at which the velocity of an object changes

New Vocabulary

force
system
free-body diagram
net force
Newton's second law
Newton's first law
inertia
equilibrium

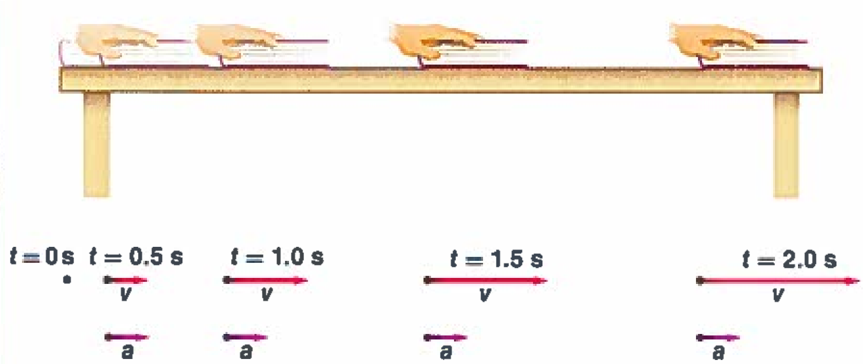
Force

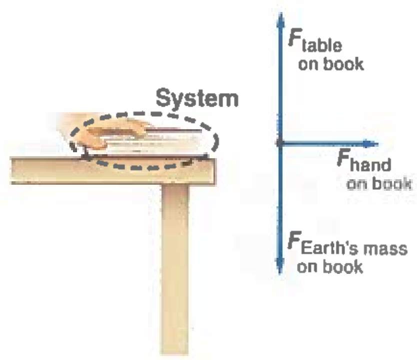
Consider a textbook resting on a table. To cause it to move, you could either push or pull on it. In physics, a push or a pull is called a **force.** If you push or pull harder on an object, you exert a greater force on the object. In other words, you increase the magnitude of the applied force. The direction in which the force is exerted also matters–if you push the resting book to the right, the book will start moving to the right. If you push the book to the left, it will start moving to the left. Because forces have both magnitude and direction, forces are vectors. The symbol $\boldsymbol{F}$ is vector notation that represents the size and direction of a force, while F represents only the magnitude. The magnitude of a force is measured in units called newtons (N).

Unbalanced forces change motion Recall that motion diagrams describe the positions of an object at equal time intervals. For example, the motion diagram for the book in **Figure 1** shows the distance between the dots increasing. This means the speed of the book is increasing. At $t = 0$, it is at rest, but after 2 seconds it is moving at 1.5 m/s. This change in speed means it is accelerating. What is the cause of this acceleration? The book was at rest until you pushed it, so the cause of the acceleration is the force exerted by your hand. In fact, all accelerations are the result of an unbalanced force acting on an object. What is the relationship between force and acceleration? By the end of this section, you will be able to answer that question as well as apply laws of motion to solve many different types of problems.

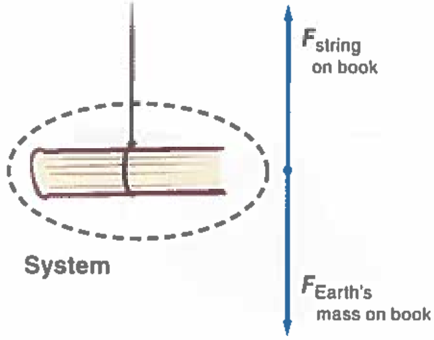
READING CHECK **Identify** the cause of all accelerations.

Figure 1 The hand pushing on the book exerts a force that causes the book to accelerate in the direction of the unbalanced force.

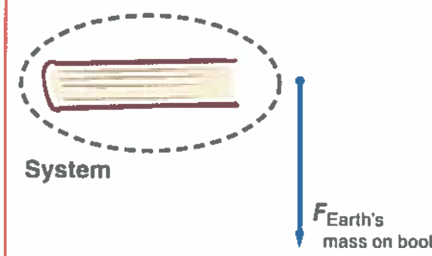




Identify the system.
Figure 2-1



Force exerted by string is a contact force.
Figure 2-2



Force exerted by Earth's mass is a field force.
Figure 2-3

Figure 2 The book is the system in each of these situations.

Classify each force in the first panel as either a contact force or a field force.

Systems and external world When considering how a force affects motion, it is important to identify the object or objects of interest, called the **system.** Everything around the system with which the system can interact is called the external world. In **Figure 2,** the book is the system. Your hand, Earth, string and the table are parts of the external world that interact with the book by pushing or pulling on it.

Contact forces Again, think about the different ways in which you could move a textbook. You could push or pull it by directly touching it, or you could tie a string around it and pull on the string. These are examples of contact forces. A contact force exists when an object from the external world touches a system, exerting a force on it. If you are holding this physics textbook right now, your hands are exerting a contact force on it. If you place the book on a table, you are no longer exerting a contact force on the book. The table, however, is exerting a contact force because the table and the book are in contact.

Field forces There are other ways in which the motion of the textbook can change. You could drop it, and as you learned in a previous chapter, it would accelerate as it falls to the ground. The gravitational force of Earth acting on the book causes this acceleration. This force affects the book whether or not Earth is actually touching it. Gravitational force is an example of a field force. Field forces are exerted without contact. Can you think of other kinds of field forces? If you have ever investigated magnets, you know that they exert forces without touching. You will investigate magnetism and other field forces in future chapters. For now, the only field force you need to consider is the gravitational force.

Agents Forces result from interactions; every contact and field force has a specific and identifiable cause, called the agent. You should be able to name the agent exerting each force as well as the system upon which the force is exerted. For example, when you push your textbook, your hand (the agent) exerts a force on the textbook (the system). If there are not both an agent and a system, a force does not exist. What about the gravitational force? The agent is the mass of Earth exerting a field force on the book. The labels on the forces in **Figure 2** are good examples of how to identify a force's agent and the system upon which the force acts.

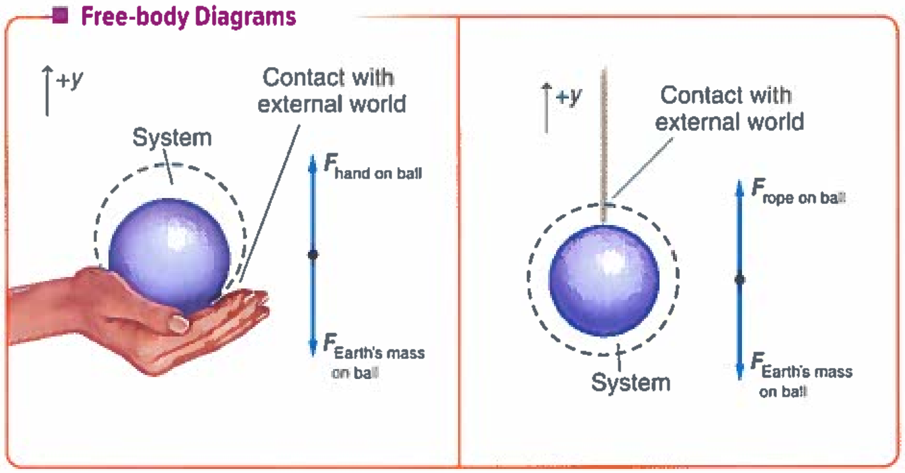
VOCABULARY
Science Use v. Common Use

Force

• Science usage
a push or a pull exerted on an object
The force of gravity exerted by the Sun on Earth pulls Earth into orbit around the Sun.

• Common usage
to compel by physical, moral, or intellectual means
Emi forced her younger brother to wash the dishes.

Figure 3 The drawings of the ball in the hand and the ball hanging from the string are both pictorial models. The free-body diagram for each situation is shown next to each pictorial model.



Free-body diagrams Just as pictorial representations and motion diagrams are useful in solving problems about motion, similar representations will help you analyze how forces affect motion. The first step is to sketch the situation, as shown in **Figure 3.** Circle the system, and identify every place where the system touches the external world. It is at these places that an agent exerts a contact force. Then identify any field forces on the system. This gives you the pictorial representation.

A **free-body diagram** is a physical representation that shows the forces acting on a system. Follow these guidelines when drawing a free-body diagram:

- The free-body diagram is drawn separately from the sketch of the problem situation.
- Apply the particle model, and represent the object with a dot.
- Represent each force with an arrow that points in the direction the force is applied. Always draw the force vectors pointing away from the particle, even when the force is a push.
- Make the length of each arrow proportional to the size of the force. Often you will draw these diagrams before you know the magnitudes of all the forces. In such cases, make your best estimate.
- Label each force. Use the symbol $\boldsymbol{F}$ with a subscript label to identify both the agent and the object on which the force is exerted.
- Choose a direction to be positive, and indicate this on the diagram.

Using free-body diagrams and motion diagrams Recall that all accelerations are the result of unbalanced forces. If a motion diagram shows that an object is accelerating, a free-body diagram of that object should have an unbalanced force in the same direction as the acceleration.

READING CHECK **Compare** the direction of an object's acceleration with the direction of the unbalanced force exerted on the object.

Combining Forces

What happens if you and a friend each push a table and exert 100 N of force on it? When you push together in the same direction, you give the table twice the acceleration that it would have if just one of you applied 100 N of force. When you push on the table in opposite directions with the same amount of force, as in **Figure 4,** there is no unbalanced force, so the table does not accelerate but remains at rest.

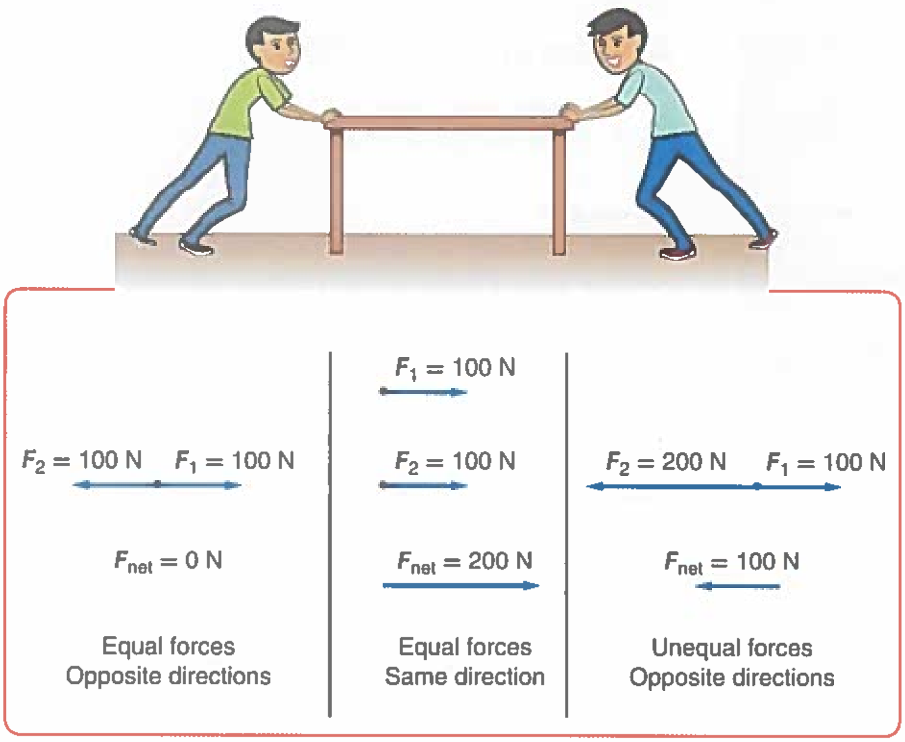


Figure 4 The net force acting on the table is the vector sum of all the forces acting on the table. This case only considers the horizontal forces acting on the table.

Net force The bottom portion of **Figure 4** shows free-body diagrams for these two situations. The third diagram in **Figure 4** shows the free-body diagram for a third situation in which your friend pushes on the table twice as hard as you in the opposite direction. Below each free-body diagram is a vector representing the resultant of the two forces. When the force vectors are in the same direction, they can be replaced by one vector with a length equal to their combined length. When the forces are in opposite directions, the resultant is the length of the difference between the two vectors. Another term for the vector sum of all the forces on an object is the **net force.**

You also can analyze the situation mathematically. Call the positive direction the direction in which you are pushing the table with a 100 N force. In the first case, your friend is pushing with a negative force of 100 N. Adding them together gives a total force of 0 N, which means there is no acceleration. In the second case, your friend's force is 100 N, so the total force is 200 N in the positive direction and the table accelerates in the positive direction. In the third case, your friend's force is −200 N, so the total force is −100 N and the table accelerates in the negative direction.

APPLICATION

For each of the following situations, specify the system and draw a motion diagram and a free-body diagram. Label all forces with their agents, and indicate the direction of the acceleration and of the net force. Draw vectors of appropriate lengths. Ignore air resistance unless otherwise indicated.

1. A skydiver falls downward through the air at constant velocity. (The air exerts an upward force on the person.)
2. You hold a baseball in the palm of your hand and toss it up. Draw the diagrams while the ball is still touching your hand.
3. After the ball leaves your hand, it rises, slowing down.
4. After the ball reaches its maximum height, it falls down, speeding up.
5. **CHALLENGE** You catch the ball in your hand and bring it to rest.

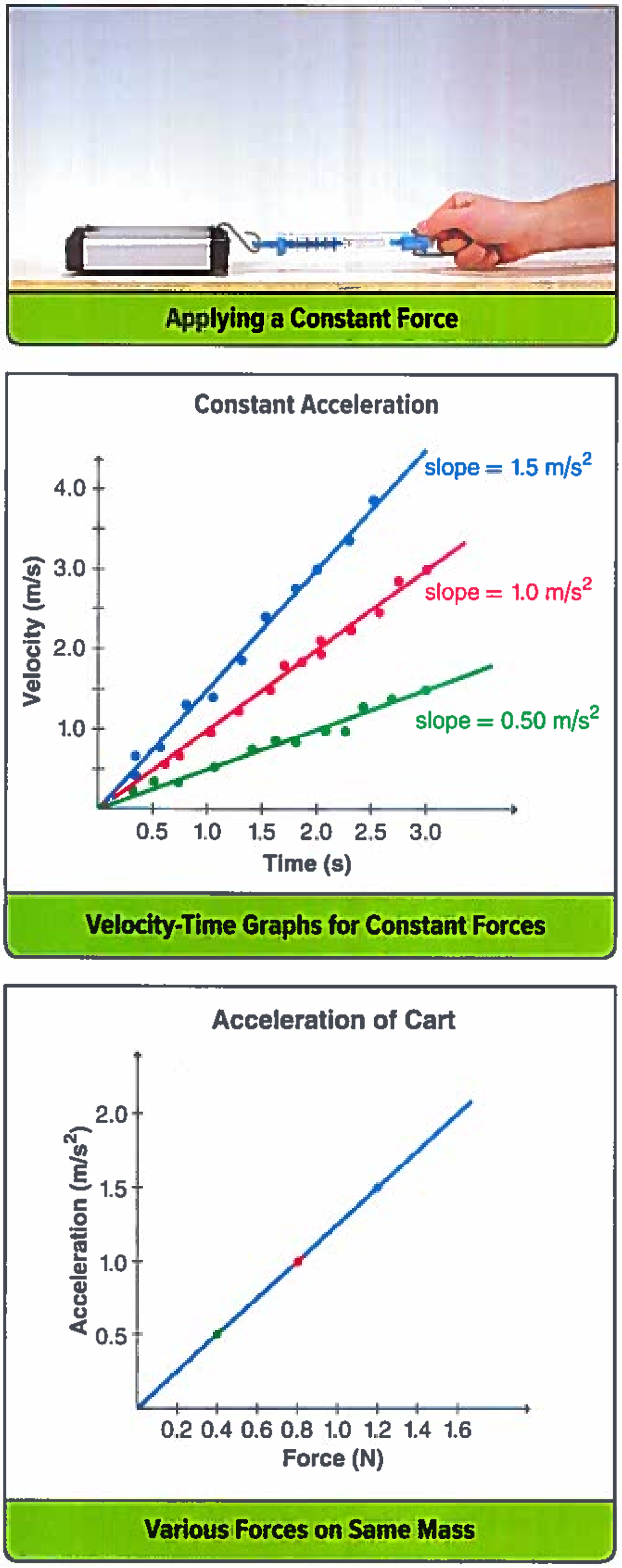


Figure 5 A spring scale exerts a constant unbalanced force on the cart. Repeating the investigation with different forces produces velocity-time graphs with different slopes.

Acceleration and Force

To explore how forces affect an object's motion, think about doing a series of investigations. Consider the simple situation shown in the top photo of **Figure 5** in which we exert one force horizontally on an object. Starting with the horizontal direction is helpful because gravity does not act horizontally. To reduce complications resulting from the object rubbing against the surface, the investigations should be done on a smooth surface, such as a well-polished table. We'll also use a cart with wheels that spin easily.

Apply constant force How can you exert a constant unbalanced force? One way is to use a device called a spring scale. Inside the scale is a spring that stretches proportionally to the magnitude of the applied force. The front of the scale is calibrated to read the force in newtons. If you pull on the scale so that the reading on the front stays constant, the applied force is constant. The top photo in **Figure 5** shows a spring scale pulling a low-resistance cart with a constant unbalanced force.

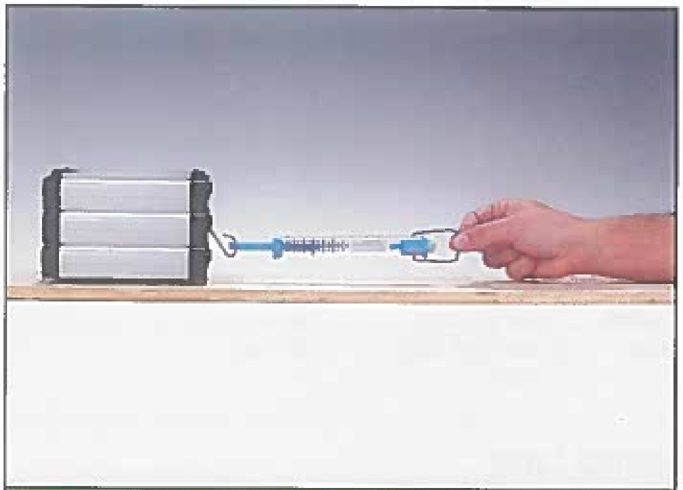
If you perform this investigation and measure the cart's velocity for a period of time, you could construct a graph like the green line shown in the velocity-time graphs for constant forces in the middle panel of **Figure 5.** The constant slope of the line in the velocity-time graph indicates the cart's velocity increases at a constant rate. The constant rate of change of velocity means the acceleration is constant. This constant acceleration is a result of the constant unbalanced force applied by the spring scale to the cart.

How does the acceleration depend on the force? Repeat the investigation with a larger constant force. Then repeat it again with an even greater force. For each force, plot a velocity-time graph like the red and blue lines in the middle panel of **Figure 5.** Recall that the line's slope is the cart's acceleration. Calculate the slope of each line and plot the results for each force to make an acceleration-force graph, as shown in the bottom panel of **Figure 5.**

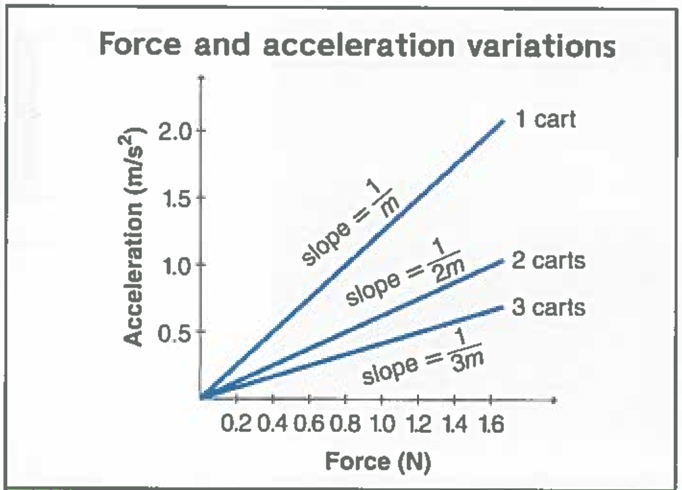
The graph indicates the relationship between force and acceleration is linear. Because the relationship is linear, you can apply the equation for a straight line:

$$y = kx + b$$

The y-intercept is 0, so the linear equation simplifies to $y = kx$. The y-variable is acceleration and the x-variable is force, so acceleration equals the slope of the line times the applied net force.



Changing the Mass of the System



Same Force on Different Masses

Figure 6 Changing an object's mass affects that object's acceleration when the applied force remains constant.

Compare the acceleration of one cart to the acceleration of two carts for an applied force of 1 N.

Interpreting slope What is the physical meaning of the slope of the acceleration-force graph? Does it describe something about the object that is accelerating? To see, change the mass of the object while applying the same force on it. Suppose that a second, identical cart is placed on top of the first, and then a third cart is added as in **Figure 6.** The spring scale would be pulling two carts and then three with the same force. A plot of the force versus acceleration for one, two, and three carts is shown in the graph in **Figure 6.**

The graph shows that if the same force is applied in each case, the acceleration of two carts is $\frac{1}{2}$ the acceleration of one cart, and the acceleration of three carts is $\frac{1}{3}$ the acceleration of one cart. This means that as the number of carts increases, the acceleration decreases. In other words, a greater force is needed to produce the same acceleration. The slopes of the lines in **Figure 6** depend upon the number of carts; that is, the slope depends on the total mass of the carts. In fact, the slope is the reciprocal of the mass (slope $= \frac{1}{\text{mass}}$). Using this value for slope, the mathematical equation $y = kx$ becomes the physics equation $a = \frac{F_{net}}{m}$.

What information is contained in the equation $a = \frac{F_{net}}{m}$? It tells you that a net force applied to an object causes that object to experience a change in motion–the force causes the object to accelerate. It also tells you that for the same object, if you double the force, you will double the object's acceleration. Lastly, if you apply the same force to objects with different masses, the one with the greater mass will have the smallest acceleration and the one with the least mass will have the greatest acceleration.

☑ **READING CHECK** **Determine** how the force exerted on an object must be changed to reduce the object's acceleration by half.

Recall that forces are measured in units called newtons. Because $F_{net} = ma$, a newton has the units of mass times the units of acceleration. So one newton is equal to one kg•m/s^2. To get an approximate idea of the size of 1 N, think about the downward force you feel when you hold an apple in your hand. The force exerted by the apple on your hand is approximately one newton. **Table 1** shows the magnitudes of some other common forces.

Table 1 Common Forces

Description	F (N)
Force of gravity on a coin (bronze)	0.05
Force of gravity on a 0.45-kg bag of sugar	4.5
Force of gravity on a 70-kg person	686
Force exerted by road on an accelerating car	3000
Force of a rocket engine	5,000,000

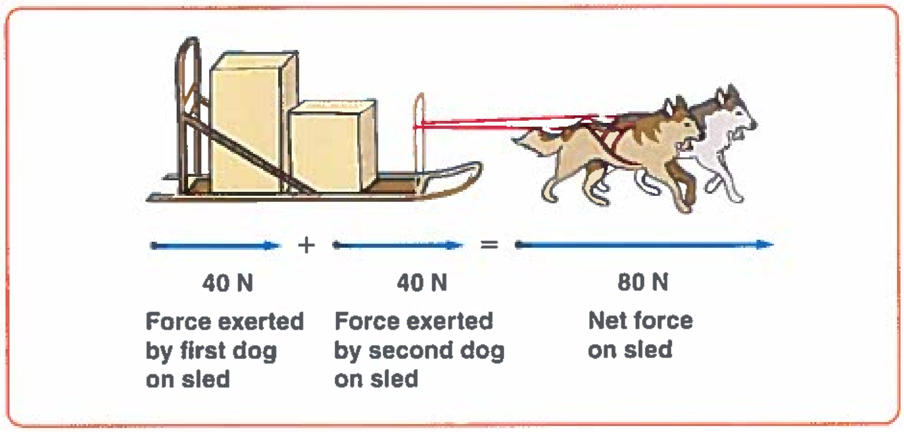


Figure 7 The net force acting on an object is the vector sum of all the forces acting on that object.

Newton's Second Law

Figure 7 shows two dogs pulling a sled. Each dog pulls with a force of 40 N. From the cart and spring-scale investigations, you know that the sled accelerates as a result of the unbalanced force acting on it. Would the acceleration change if instead of two dogs each exerting a 40-N force, there was one bigger, stronger dog exerting a single 80-N force on the sled, in the same direction? When considering forces and acceleration, it is important to find the sum of all forces, called the net force, acting on a system.

Newton's second law states that the acceleration of an object is proportional to the net force and inversely proportional to the mass of the object being accelerated. This law is based on observations of how forces affect masses and is represented by the following equation.

NEWTON'S SECOND LAW

The acceleration of an object is equal to the net force acting on the object divided by the mass of the object.

$$a = \frac{F_{net}}{m}$$

Solving problems using Newton's second law One of the most important steps in correctly applying Newton's second law is determining the net force acting on the object. Often, more than one force acts on an object, so you must add the force vectors to determine the net force. Draw a free-body diagram showing the direction and relative strength of each force acting on the system. Then, add the force vectors to find the net force. Next, use Newton's second law to calculate the acceleration. Finally, if necessary, you can use what you know about accelerated motion to find the velocity or position of the object.

APPLICATION

6. Two horizontal forces, 225 N and 165 N, are exerted on a canoe. If these forces are applied in the same direction, find the net horizontal force on the canoe.

7. If the same two forces as in the previous problem are exerted on the canoe in opposite directions, what is the net horizontal force on the canoe? Be sure to indicate the direction of the net force.

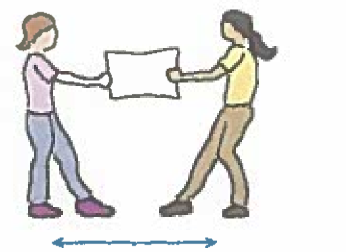
8. CHALLENGE Three confused sled dogs are trying to pull a sled across the Alaskan snow. One pulls east with a force of 35 N, another also pulls east but with a force of 42 N, and a big third dog pulls west with a force of 53 N. What is the net force on the sled?

EXAMPLE 1

FIGHTING OVER A PILLOW Mariam is holding a pillow with a mass of 0.30 kg when Sarah decides that she wants it and tries to pull it away from Mariam. If Sarah pulls horizontally on the pillow with a force of 10.0 N and Mariam pulls with a horizontal force of 11.0 N, what is the horizontal acceleration of the pillow?

1 ANALYZE AND SKETCH THE PROBLEM

- Sketch the situation.
- Identify the pillow as the system, and the direction in which Mariam pulls as positive.
- Draw the free-body diagram. Label the forces.



KNOWN	UNKNOWN
$m = 0.30$ kg	$a = ?$
$F_{\text{Mariam on pillow}} = 11.0$ N	
$F_{\text{Sarah on pillow}} = 10.0$ N	

2 SOLVE FOR THE UNKNOWN

$$F_{\text{net}} = F_{\text{Mariam on pillow}} + (-F_{\text{Sarah on pillow}})$$

Use Newton's second law.

$$a = \frac{F_{\text{net}}}{m}$$

$$= \frac{F_{\text{Mariam on pillow}} + (-F_{\text{Sarah on pillow}})}{m}$$

$$= \frac{11.0\text{ N} - 10.0\text{ N}}{0.30\text{ kg}}$$

◀ Substitute $F_{\text{Mariam on pillow}} = 11.0$ N, $F_{\text{Sarah on pillow}} = 10.0$ N, $m = 0.30$ kg.

$$= 3.3\text{ m/s}^2$$

$$a = 3.3\text{ m/s}^2 \text{ toward Mariam}$$

3 EVALUATE THE ANSWER

- **Are the units correct?** m/s^2 is the correct unit for acceleration.
- **Does the sign make sense?** The acceleration is toward Mariam because Mariam is pulling toward herself with a greater force than Sarah is pulling in the opposite direction.
- **Is the magnitude realistic?** The net force is 1 N and the mass is 0.3 kg, so the acceleration is realistic.

APPLICATION

9. A spring scale is used to exert a net force of 2.7 N on a cart. If the cart's mass is 0.64 kg, what is the cart's acceleration?

10. Kamaria is learning how to ice skate. She wants her mother to pull her along so that she has an acceleration of 0.80 m/s^2. If Kamaria's mass is 27.2 kg, with what force does her mother need to pull her? (Neglect any resistance between the ice and Kamaria's skates.)

11. CHALLENGE Two horizontal forces are exerted on a large crate. The first force is 317 N to the right. The second force is 173 N to the left.

a. Draw a force diagram for the horizontal forces acting on the crate.

b. What is the net force acting on the crate?

c. The box is initially at rest. Five seconds later, its velocity is 6.5 m/s to the right. What is the crate's mass?

Newton's First Law

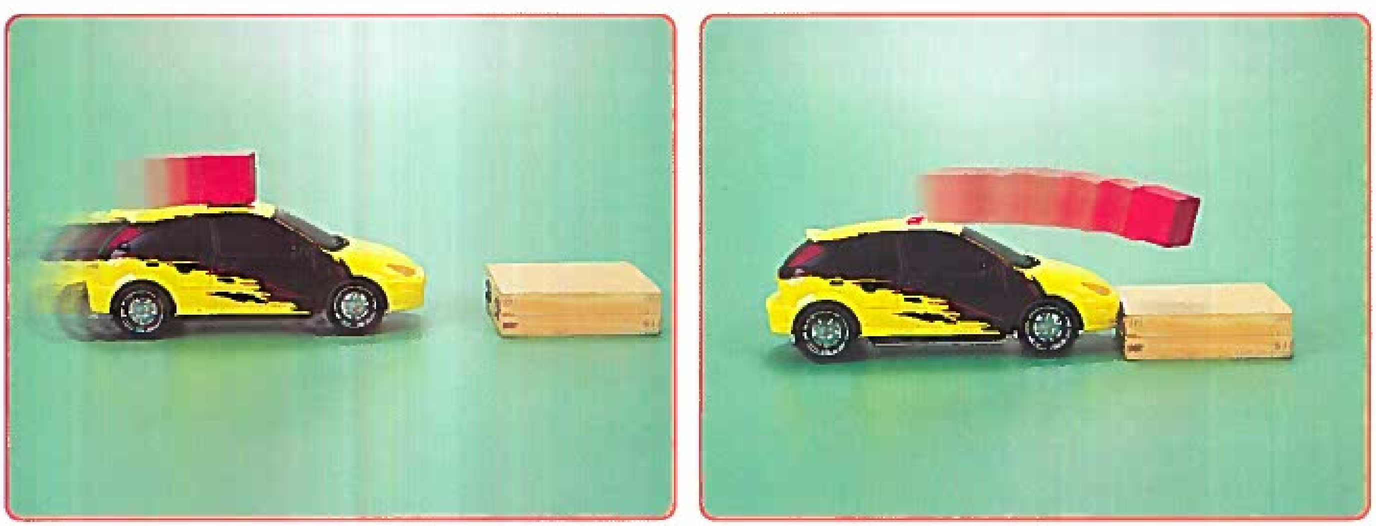
What is the motion of an object when the net force acting on it is zero? Newton's second law says that if $F_{net} = 0$, then acceleration equals zero. Recall that if acceleration equals zero, then velocity does not change. Thus a stationary object with no net force acting on it will remain at rest. What about a moving object, such as a ball rolling on a surface? How long will the ball continue to roll? It will depend on the surface. If the ball is rolled on a thick carpet that exerts a force on the ball, it will come to rest quickly. If it is rolled on a hard, smooth surface that exerts very little force, such as a bowling alley, the ball will roll for a long time with little change in velocity. Galileo did many experiments and he concluded that if he could remove all forces opposing motion, horizontal motion would never stop. Galileo was the first to recognize that the general principles of motion could be found by extrapolating experimental results to an ideal case.

In the absence of a net force, the velocity of the moving ball and the lack of motion of the stationary object do not change. Newton recognized this and generalized Galileo's results into a single statement. Newton's statement, "an object that is at rest will remain at rest, and an object that is moving will continue to move in a straight line with constant speed, if and only if the net force acting on that object is zero," is called **Newton's first law.**

Inertia Newton's first law is sometimes called the law of inertia because **inertia** is the tendency of an object to resist changes in velocity. The car and the red block in **Figure 8** demonstrate the law of inertia. In the left panel, both objects are moving to the right. In the right panel, the wooden box applies a force to the car, causing it to stop. The red block does not experience the force applied by the wooden box. It continues to move to the right with the same velocity as in the left panel.

Is inertia a force? No. Forces are results of interactions between two objects; they are not properties of single objects, so inertia cannot be a force. Remember that because velocity includes both the speed and direction of motion, a net force is required to change either the speed or the direction of motion. If the net force is zero, Newton's first law means the object will continue with the same speed and direction.

Figure 8 The car and the block approach the wooden box at the same speed. After the collision, the block continues on with the same horizontal speed.



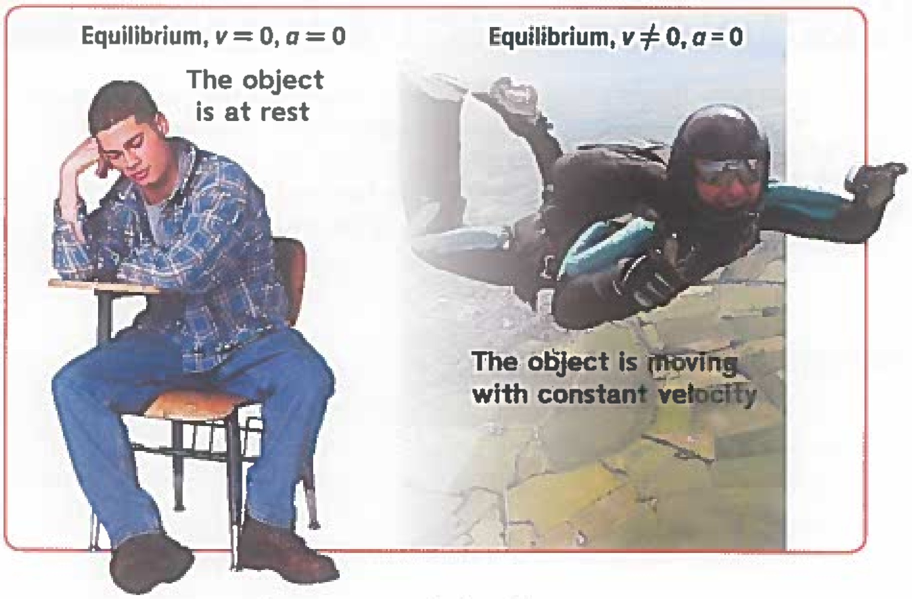


Figure 9 An object is in equilibrium if its velocity isn't changing. In both cases pictured here, velocity isn't changing, so the net force must be zero.

Equilibrium According to Newton's first law, a net force causes the velocity of an object to change. If the net force on an object is zero, then the object is in **equilibrium.** An object is in equilibrium if it is moving at a constant velocity. Note that being at rest is simply a special case of the state of constant velocity, $v = 0$. Newton's first law identifies a net force as something that disturbs a state of equilibrium. Thus, if there is no net force acting on the object, then the object does not experience a change in speed or direction and is in equilibrium. As **Figure 9** indicates, at least in terms of net forces, there is no difference between sitting in a chair and falling at a constant velocity while skydiving–velocity isn't changing, so the net force is zero.

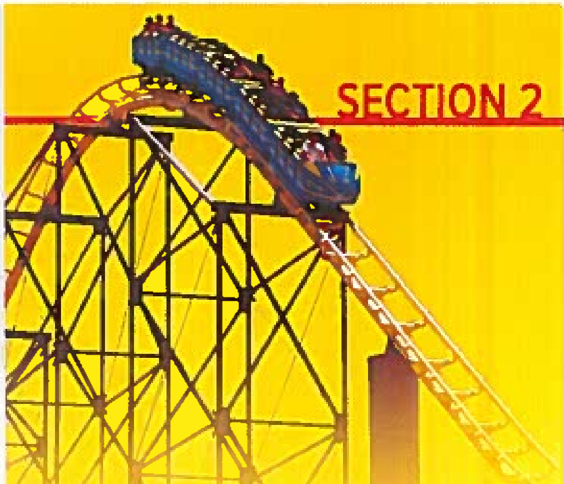
When analyzing forces and motion, it is important to keep in mind that the real world is full of forces that resist motion, called frictional forces. Newton's ideal, friction-free world is not easy to obtain. If you analyze a situation and find that the result is different from a similar experience that you have had, ask yourself whether this is because of the presence of frictional forces. For example, if you shove a textbook across a table, it will quickly come to a stop. At first thought, it might seem Newton's first law is violated in this case because the book's velocity changes even though there is no apparent force acting on the book. The net force acting on the book, however, is a frictional force between the table and the book in the direction opposite motion.

VOCABULARY
Science Use v. Common Use

Equilibrium
- **Science usage**
the condition in which the net force on an object is zero
When an object is in equilibrium, the object's velocity will be constant.
- **Common usage**
a state of balance
The pollution disturbed the ecosystem's equilibrium.

SECTION 1 REVIEW

12. **MAINIDEA** Identify each of the following as either **a, b,** or **c**: mass, inertia, the push of a hand, friction, air resistance, spring force, gravity, and acceleration.
    a. contact force
    b. a field force
    c. not a force
13. **Free-Body Diagram** Draw a free-body diagram of a bag of sugar being lifted by your hand at an increasing speed. Specifically identify the system. Use subscripts to label all forces with their agents. Remember to make the arrows the correct lengths.
14. **Free-Body Diagram** Draw a free-body diagram of a water bucket being lifted by a rope at a decreasing speed. Specifically identify the system. Label all forces with their agents and make the arrows the correct lengths.
15. **Critical Thinking** A force of 1 N is the only horizontal force exerted on a block, and the horizontal acceleration of the block is measured. When the same horizontal force is the only force exerted on a second block, the horizontal acceleration is three times as large. What can you conclude about the masses of the two blocks?



SECTION 2

Weight and Drag Force

PHYSICS 4 YOU **If you have ever ridden a roller coaster, you probably noticed that you felt weightless as you went over a hill. But the force of gravity at the top of the hill is virtually the same as the force of gravity at the bottom of the hill. So why do you feel weightless?**

MAIN IDEA
Newton's second law can be used to explain the motion of falling objects.

Essential Questions

- How are the weight and the mass of an object related?
- How do actual weight and apparent weight differ?
- What effect does air have on falling objects?

Review Vocabulary

viscosity a fluid's resistance to flowing

New Vocabulary

weight
gravitational field
apparent weight
weightlessness
drag force
terminal velocity

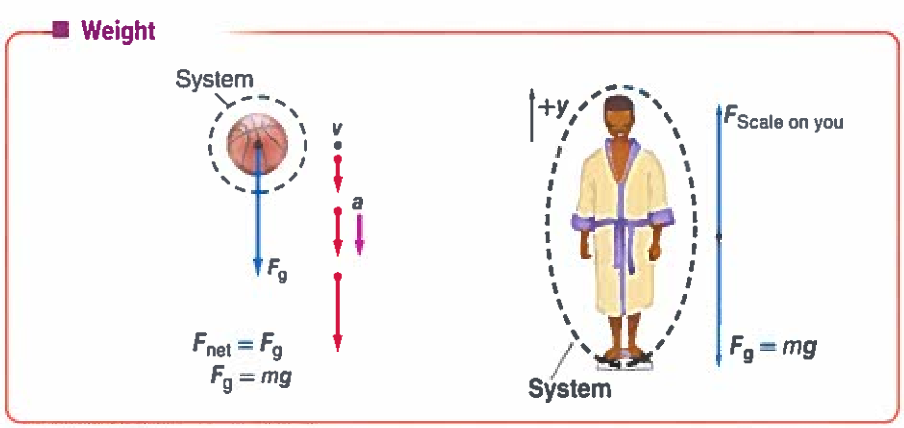
Weight

From Newton's second law, the fact that the ball in **Figure 10** is accelerating means there must be unbalanced forces acting on the ball. The only force acting on the ball is the gravitational force due to Earth's mass. An object's **weight** is the gravitational force experienced by that object. This gravitational force is a field force whose magnitude is directly proportional to the mass of the object experiencing the force. In equation form, the gravitational force, which equals weight, can be written $F_g = mg$. The mass of the object is m, and g, called the **gravitational field**, is a vector quantity that relates the mass of an object to the gravitational force it experiences at a given location. Near Earth's surface, g is 9.8 N/kg toward Earth's center. Objects near Earth's surface experience 9.8 N of force for every kilogram of mass.

Scales When you stand on a scale as shown in the right panel of **Figure 10,** the scale exerts an upward force on you. Because you are not accelerating, the net force acting on you must be zero. Therefore the magnitude of the force exerted by the scale ($F_{\text{scale on you}}$) pushing up must equal the magnitude of F_g pulling down on you. Inside the scale, springs provide the upward force necessary to make the net force equal zero. The scale is calibrated to convert the stretch of the springs to a weight. The measurement on the scale is affected by the gravitational field on Earth's surface. If you were on a different planet with a different g, the scale would exert a different force to keep you in equilibrium, and consequently, the scale's reading would be different. Because weight is a force, the proper unit used to measure weight is the newton.

Figure 10 The gravitational force exerted by Earth's mass on an object equals the object's mass times the gravitational field, ($F_g = mg$).

Identify the forces acting on you when you are in equilibrium while standing on a scale.

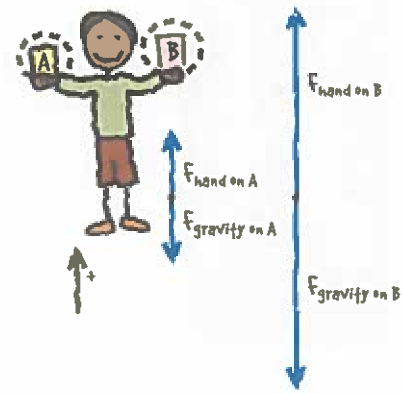


EXAMPLE 2

COMPARING WEIGHTS Amjad holds a brass cylinder in each hand. Cylinder A has a mass of 100.0 g and cylinder B has a mass of 300.0 g. What upward forces do his two hands exert to keep the cylinders at rest? If he then drops the two, with what acceleration do they fall? (Ignore air resistance.)

1 ANALYZE AND SKETCH THE PROBLEM

- Sketch the situation.
- Identify the two cylinders as the systems, and choose the upward direction as positive.
- Draw the free-body diagrams. Label the forces.



KNOWN	**UNKNOWNS**
$m_A = 0.1000$ kg	$F_{Hand\ on\ A} = ?$
$m_B = 0.3000$ kg	$F_{Hand\ on\ B} = ?$
$g = -9.8$ N/kg	$a_A = ?$ $a_B = ?$

2 SOLVE FOR THE UNKNOWNS

For cylinder A:

$$F_{Net\ on\ A} = F_{Hand\ on\ A} + F_{Gravity\ on\ A}$$
$$0 = F_{Hand\ on\ A} + F_{Gravity\ on\ A}$$
$$F_{Hand\ on\ A} = -F_{Gravity\ on\ A}$$
$$F_{Hand\ on\ A} = -m_A g$$
$$= -(0.1000\ \text{kg})(-9.8\ \text{N/kg})$$
$$= 0.98\ \text{N up}$$

For cylinder B:

$$F_{Net\ on\ B} = F_{Hand\ on\ B} + F_{Gravity\ on\ B}$$
$$0 = F_{Hand\ on\ B} + F_{Gravity\ on\ B}$$
$$F_{Hand\ on\ B} = -F_{Gravity\ on\ B}$$
$$F_{Hand\ on\ B} = -m_B g$$
$$= -(0.3000\ \text{kg})(-9.8\ \text{N/kg})$$
$$= 2.9\ \text{N up}$$

After the cylinders are dropped, the only force on each is the force of gravity. Use Newton's second law.

$$a_A = \frac{F_{Net\ on\ A}}{m_A} \qquad a_B = \frac{F_{Net\ on\ B}}{m_B}$$

$$a_A = \frac{m_A g}{m_A} = g \qquad a_B = \frac{m_B g}{m_B} = g$$ ◀ Substitute $F_{Net\ on\ A} = m_A g$ and $F_{Net\ on\ B} = m_B g$.

$$= -9.8\ \text{m/s}^2 \qquad = -9.8\ \text{m/s}^2$$ ◀ Substitute $g = -9.8$ N/kg $= -9.8$ m/s^2.

3 EVALUATE THE ANSWER

- **Are the units correct?** N is the correct unit for force. m/s^2 is the correct unit for acceleration.
- **Does the sign make sense?** The direction of the fall is downward, the negative direction, and the object is speeding up, so the acceleration should be negative.
- **Is the magnitude realistic?** Forces are 1–5 N, typical of that exerted by objects that have a mass of one kg or less. The accelerations are both equal to free fall acceleration.

APPLICATION

16. You place a watermelon on a spring scale calibrated to measure in newtons. If the watermelon's mass is 4.0 kg, what is the scale's reading?

17. You place a 22.50 kg television on a spring scale. If the scale reads 235.2 N, what is the gravitational field at that location?

18. A 0.50-kg stone is lifted up from the ground. What is the smallest force needed to lift it? Describe the particular motion resulting from this minimum force.

19. **CHALLENGE** A grocery sack can withstand a maximum of 230 N before it rips. Will a bag holding 15 kg of groceries that is lifted from the checkout counter at an acceleration of 7.0 m/s^2 hold?

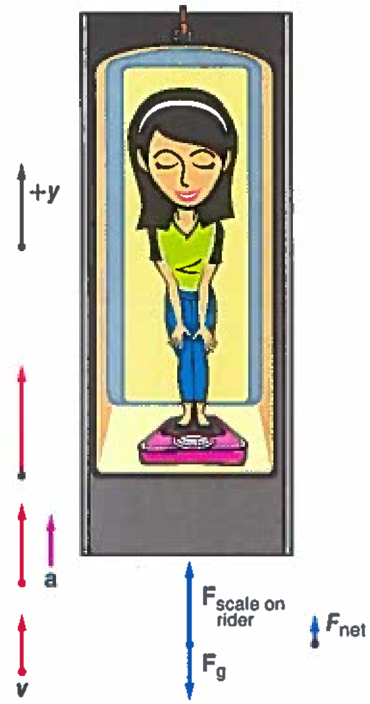


Figure 11 If you are accelerating upward, the net force acting on you must be upward. The scale must exert an upward force greater than the downward force of your weight.

Apparent weight What is weight? Because the weight force is defined as $F_g = mg$, F_g changes when g varies. On or near the surface of Earth, g is approximately constant, so an object's weight does not change appreciably as it moves around near Earth's surface. If a bathroom scale provides the only upward force on you, then it reads your weight. What would it read if you stood with one foot on the scale and one foot on the floor? What if a friend pushed down on your shoulders or lifted up on your elbows? Then there would be other contact forces on you, and the scale would not read your weight.

What happens if you stand on a scale in an elevator? As long as you are not accelerating, the scale will read your weight. What would the scale read if the elevator accelerated upward? **Figure 11** shows the pictorial and physical representations for this situation. You are the system, and upward is the positive direction. Because the acceleration of the system is upward, the net force must be upward. The upward force of the scale must be greater than the downward force of your weight. Therefore, the scale reading is greater than your weight.

If you ride in an elevator accelerating upward, you feel as if you are heavier because the floor presses harder on your feet. On the other hand, if the acceleration is downward, then you feel lighter, and the scale reads less than your weight. The force exerted by the scale is an example of **apparent weight**, which is the support force exerted on an object.

READING CHECK Describe the reading on the scale as the elevator accelerates upward from rest, reaches a constant speed, then comes to a stop.

Imagine that the cable holding the elevator breaks. What would the scale read then? The scale and you would both accelerate at $a = g$. According to this formula, the scale would read zero and your apparent weight would be zero. That is, you would be weightless. However, **weightlessness** does not mean that an object's weight is actually zero; rather, it means that there are no contact forces acting to support the object, and the object's *apparent weight* is zero. Similar to the falling elevator, astronauts experience weightlessness in orbit because they and their spacecraft are in free fall. You will study gravity and weightlessness in greater detail in a later chapter.

PhysicsLAB

FORCES IN AN ELEVATOR

How does apparent weight change when riding in an elevator?

MiniLAB

MASS AND WEIGHT

How are mass and weight related?

PROBLEM-SOLVING STRATEGIES

FORCE AND MOTION

When solving force and motion problems, use the following strategies.

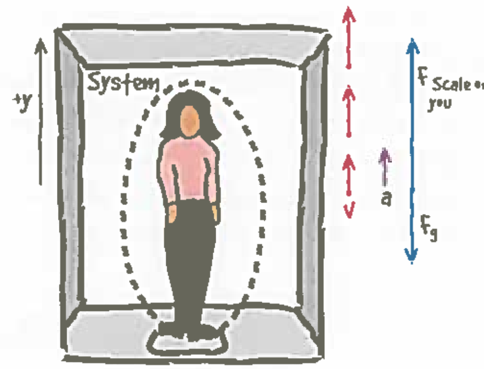
1. Read the problem carefully, and sketch a pictorial model.
2. Circle the system and choose a coordinate system.
3. Determine which quantities are known and which are unknown.
4. Create a physical model by drawing a motion diagram showing the direction of the acceleration.
5. Create a free-body diagram showing all the forces acting on the object.
6. Use Newton's laws to link acceleration and net force.
7. Rearrange the equation to solve for the unknown quantity.
8. Substitute known quantities with their units into the equation and solve.
9. Check your results to see whether they are reasonable.

EXAMPLE 3

REAL AND APPARENT WEIGHT Your mass is 75.0 kg, and you are standing on a bathroom scale in an elevator. Starting from rest, the elevator accelerates upward at 2.00 m/s^2 for 2.00 s and then continues at a constant speed. Is the scale reading during acceleration greater than, equal to, or less than the scale reading when the elevator is at rest?

1 ANALYZE AND SKETCH THE PROBLEM

- Sketch the situation.
- Choose a coordinate system with the positive direction as upward.
- Draw the motion diagram. Label v and a.
- Draw the free-body diagram. The net force is in the same direction as the acceleration, so the upward force is greater than the downward force.



KNOWN	UNKNOWN
$m = 75.0$ kg	$F_{scale} = ?$
$a = 2.00$ m/s^2	
$t = 2.00$ s	
$g = 9.8$ N/kg	

2 SOLVE FOR THE UNKNOWN

$F_{net} = ma$

$F_{net} = F_{scale} + (-F_g)$ ◀ F_g is negative because it is in the negative direction defined by the coordinate system.

Solve for F_{scale}.

$F_{scale} = F_{net} + F_g$

Elevator at rest:

$F_{scale} = F_{net} + F_g$ ◀ The elevator is not accelerating. Thus, $F_{net} = 0.00$ N.

$= F_g$ ◀ Substitute $F_{net} = 0.00$ N.

$= mg$ ◀ Substitute $F_g = mg$.

$= (75.0 \text{ kg})(9.8 \text{ N/kg})$ ◀ Substitute $m = 75.0$ kg, $g = 9.8$ N/kg.

$= 735$ N

Elevator accelerating upward:

$F_{scale} = F_{net} + F_g$

$= ma + mg$ ◀ Substitute $F_{net} = ma$, $F_g = mg$

$= (75.0 \text{ kg})(2.00 \text{ m/s}^2) + (75.0 \text{ kg})(9.8 \text{ N/kg})$ ◀ Substitute $m = 75.0$ kg, $a = 2.00$ m/s^2, $g = 9.8$ N/kg

$= 885$ N

The scale reading when the elevator is accelerating (885 N) is larger than the scale reading when the elevator is at rest (735 N).

3 EVALUATE THE ANSWER

- **Are the units correct?** kg·m/s^2 is the force unit, N.
- **Does the sign make sense?** The positive sign agrees with the coordinate system.
- **Is the magnitude realistic?** $F_{scale} = 885$ N is larger than it would be at rest when F_{scale} would be 735 N. The increase is 150 N, which is about 20 percent of the rest weight. The upward acceleration is about 20 percent of that due to gravity, so the magnitude is reasonable.

APPLICATION

20. On Earth, a scale shows that you weigh 585 N.

a. What is your mass?

b. What would the scale read on the Moon (g = 1.60 N/kg)?

21. **CHALLENGE** Use the results from Example Problem 3 to answer questions about a scale in an elevator on Earth. What force would be exerted by the scale on a person in the following situations?

a. The elevator moves upward at constant speed.

b. It slows at 2.0 m/s^2 while moving downward.

c. It speeds up at 2.0 m/s^2 while moving downward.

d. It moves downward at constant speed.

e. In what direction is the net force as the elevator slows to a stop as it is moving down?

Drag Force

It is true that the particles in the air around an object exert forces on that object. Air actually exerts huge forces, but in most cases, it exerts balanced forces on all sides, and therefore it has no net effect. Can you think of any experiences that help to prove that air can exert a force? One such example would be holding a piece of paper at arm's length and blowing hard at the paper. The paper accelerates in response to the air striking it, meaning the air exerts a net force on the paper.

So far, you have neglected the force of air on an object moving through the air. In actuality, when an object moves through any fluid, such as air or water, the fluid exerts a force on the moving object in the direction opposite the object's motion. A **drag force** is the force exerted by a fluid on an object opposing motion through the fluid. This force is dependent on the motion of the object, the properties of the object, and the properties of the fluid that the object is moving through. For example, as the speed of the object increases, so does the magnitude of the drag force. The size and shape of the object also affect the drag force. The fluid's properties, such as its density and viscosity, also affect the drag force.

PhysicsLAB

TERMINAL VELOCITY

PROBEWARE LAB How does air resistance affect objects in free fall?

MiniLAB

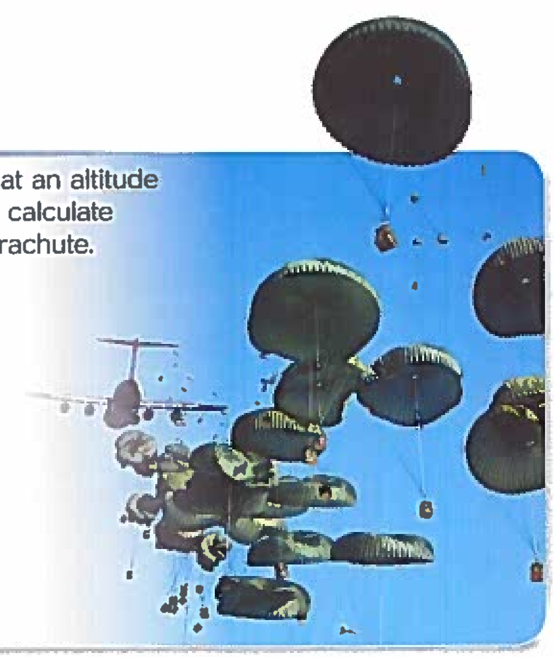
UPSIDE-DOWN PARACHUTE

How does terminal velocity depend on mass?

PHYSICS CHALLENGE

A 415-kg container of food and water is dropped from an airplane at an altitude of 300 m. First, consider the situation ignoring air resistance. Then calculate the more realistic situation involving a drag force provided by a parachute.

1. If you ignore air resistance, how long will it take the container to fall 300 m to the ground?
2. Again, ignoring air resistance, what is the speed of the container just before it hits the ground?
3. The container is attached to a parachute designed to produce a drag force that allows the container to reach a constant downward velocity of 6 m/s. What is the magnitude of the drag force when the container is falling at a constant 6 m/s down?



Terminal velocity If you drop a tennis ball, as in **Figure 12,** it has very little velocity at the start and thus only a small drag force. The downward force of gravity is much stronger than the upward drag force, so there is a downward acceleration. As the ball's velocity increases, so does the drag force. Soon the drag force equals the force of gravity. When this happens, there is no net force, and so there is no acceleration. The constant velocity that is reached when the drag force equals the force of gravity is called the **terminal velocity.**

When light objects with large surface areas are falling, the drag force has a substantial effect on their motion, and they quickly reach terminal velocity. Heavier, more-compact objects are not affected as much by the drag force. For example, the terminal velocity of a table-tennis ball in air is 9 m/s, that of a basketball is 20 m/s, and that of a baseball is 42 m/s. Competitive skiers increase their terminal velocities by decreasing the drag force on them. They hold their bodies in an egg shape and wear smooth clothing and streamlined helmets.

Skydivers can increase or decrease their terminal velocity by changing their body orientation and shape. A horizontal, spread-eagle shape produces the slowest terminal velocity, about 60 m/s. After opening up the parachute, the skydiver becomes part of a very large object with a correspondingly large drag force and a terminal velocity of about 5 m/s.

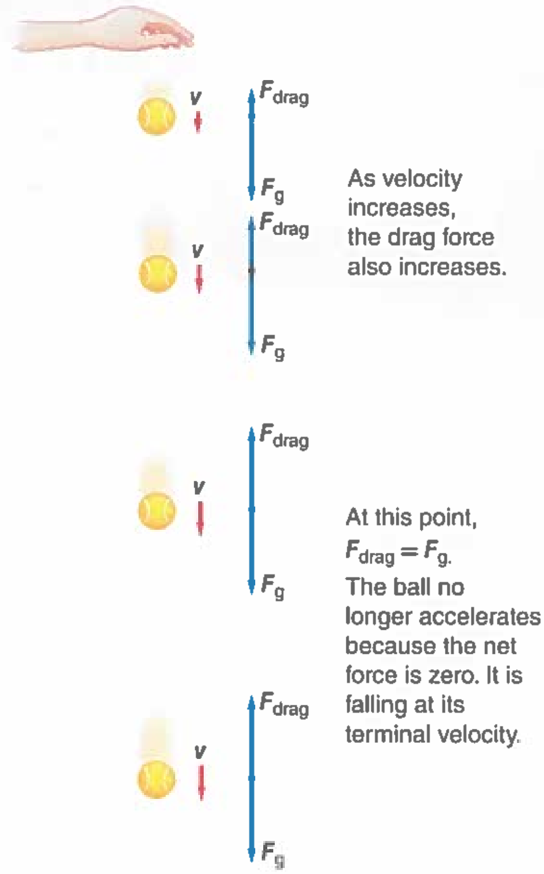


Figure 12 The drag force on an object increases as its velocity increases. When the drag force equals the gravitational force, the object is in equilibrium so it no longer accelerates.

SECTION 2 REVIEW

22. **MAINIDEA** The skydiver shown in **Figure 13** falls at a constant speed in the spread-eagle position. Immediately after opening the parachute, is the skydiver accelerating? If so, in which direction? Explain your answer using Newton's laws.

Figure 13

23. **Lunar Gravity** Compare the force holding a 10.0 kg rock on Earth and on the Moon. The gravitational field on the Moon is 1.6 N/kg.

24. **Motion of an Elevator** You are riding in an elevator holding a spring scale with a 1 kg mass suspended from it. You look at the scale and see that it reads 9.3 N. What, if anything, can you conclude about the elevator's motion at that time?

25. **Apparent Weight** You take a ride in a fast elevator to the top of a tall building and ride back down. During which parts of the ride will your apparent and real weights be the same? During which parts will your apparent weight be less than your real weight? More than your real weight? Sketch free-body diagrams to support your answers.

26. **Acceleration** Khalid, with a mass of 65.0 kg, is standing on an ice-skating rink. His friend applies a force of 9.0 N to him. What is Tecle's resulting acceleration?

27. **Critical Thinking** You have a job at a meat warehouse loading inventory onto trucks for shipment to grocery stores. Each truck has a weight limit of 10,000 N of cargo. You push each crate of meat along a low-resistance roller belt to a scale and weigh it before moving it onto the truck. One night, right after you weigh a 1000 N crate, the scale breaks. Describe a way in which you could apply Newton's laws to approximate the masses of the remaining crates.

SECTION 3 # Newton's Third Law

PHYSICS 4 YOU **If you push against a wall while sitting in a chair that has wheels, you will accelerate across the floor. What applies the unbalanced force that causes your acceleration? Newton's third law helps answer this question.**

MAINIDEA

All forces occur in interaction pairs.

Essential Questions

- What is Newton's third law?
- What is the normal force?

Review Vocabulary

symmetry correspondence of parts on opposite sides of a dividing line

New Vocabulary

interaction pair
Newton's third law
tension
normal force

Interaction Pairs

Figure 14 illustrates the idea of forces as interaction pairs. There is a force from the boy on the rope, and there is a force from the rope on the boy. Forces always come in pairs similar to this example. Consider the boy (A) as one system and the rope (B) as another. What forces act on each of the two systems? Looking at the force diagrams in **Figure 14,** you can see that each system exerts a force on the other. The two forces, $\boldsymbol{F}_{\text{A on B}}$ and $\boldsymbol{F}_{\text{B on A}}$, are the forces of interaction between the two. Notice the symmetry in the subscripts: A on B and B on A.

The forces $\boldsymbol{F}_{\text{A on B}}$ and $\boldsymbol{F}_{\text{B on A}}$ are an **interaction pair,** which is a set of two forces that are in opposite directions, have equal magnitudes, and act on different objects. Sometimes, an interaction pair is called an action-reaction pair. This might suggest that one causes the other; however, this is not true. For example, the force of the boy pulling on the rope doesn't cause the rope to pull on the boy. The two forces either exist together or not at all.

READING CHECK **Predict** the magnitude and direction of the force applied on you if you push against a tree with a force of 15 N directed to the left.

Definition of Newton's third law In **Figure 14,** the force exerted by the boy on the rope is equal in magnitude and opposite in direction to the force exerted by the rope on the boy. Such an interaction pair is an example of **Newton's third law,** which states that all forces come in pairs. The two forces in a pair act on different objects and are equal in strength and opposite in direction.

Figure 14 The force that the rope exerts on the boy and the force that the boy exerts on the rope are an interaction pair.

NEWTON'S THIRD LAW

The force of A on B is equal in magnitude and opposite in direction of the force of B on A.

$$F_{\text{A on B}} = -F_{\text{B on A}}$$

Using Newton's third law Consider the situation of holding a book in your hand. You can draw one free-body diagram for you and one for the book. Are there any interaction pairs? When identifying interaction pairs, keep in mind that they always occur in two different free-body diagrams, and they always will have the symmetry of subscripts noted on the previous page. In this case, the interaction pair is $F_{\text{book on hand}}$ and $F_{\text{hand on book}}$.

The ball in **Figure 15** interacts with the table and with Earth. First, analyze the forces acting on one system, the ball. The table exerts an upward force on the ball, and the mass of Earth exerts a downward gravitational force on the ball. Even though these forces are in opposite directions, they are not an interaction pair because they act on the same object. Now consider the ball and the table together. In addition to the upward force exerted by the table on the ball, the ball exerts a downward force on the table. This is an interaction pair.

Notice also that the ball has a weight. If the ball experiences a force due to Earth's mass, then there must be a force on Earth's mass due to the ball. In other words, they are an interaction pair.

$$F_{\text{Earth's mass on ball}} = -F_{\text{ball on Earth's mass}}$$

An unbalanced force on Earth would cause Earth to accelerate. But acceleration is inversely proportional to mass. Because Earth's mass is so huge in comparison to the masses of other objects that we normally consider, Earth's acceleration is so small that it can be neglected. In other words, Earth can be often treated as part of the external world rather than as a second system. The problem-solving strategies below summarize how to deal with interaction pairs.

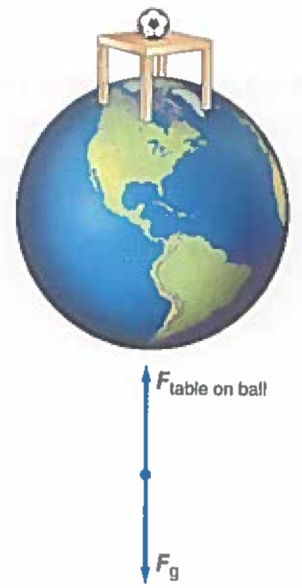
READING CHECK **Explain** why Earth's acceleration is usually very small compared to the acceleration of the object that Earth interacts with.

PROBLEM-SOLVING STRATEGIES

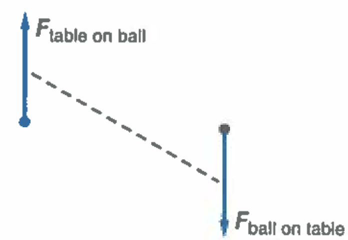
Use these strategies to solve problems in which there is an interaction between objects in two different systems.

1. Separate the system or systems from the external world.
2. Draw a pictorial model with coordinate systems for each system.
3. Draw a physical model that includes free-body diagrams for each system.
4. Connect interaction pairs by dashed lines.
5. To calculate your answer, use Newton's second law to relate the net force and acceleration for each system.
6. Use Newton's third law to equate the magnitudes of the interaction pairs and give the relative direction of each force.
7. Solve the problem and check the reasonableness of the answers' units, signs, and magnitudes.

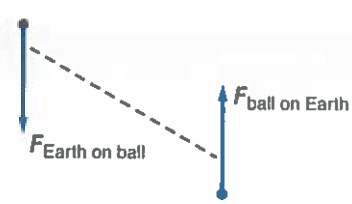
Newton's Third Law



The two forces acting on the ball are $F_{\text{table on ball}}$ and $F_{\text{Earth's mass on ball}}$. These forces are not an interaction pair.



Force interaction pair between ball and table.



Force interaction pair between ball and Earth.

Figure 15 A ball resting on a table is part of two interaction pairs.

EXAMPLE 4

EARTH'S ACCELERATION A softball has a mass of 0.18 kg. What is the gravitational force on Earth due to the ball, and what is Earth's resulting acceleration? Earth's mass is 6.0×10^{24} kg.

1 ANALYZE AND SKETCH THE PROBLEM

- Draw free-body diagrams for the two systems: the ball and Earth.
- Connect the interaction pair by a dashed line.

KNOWN	UNKNOWN
$m_{\text{ball}} = 0.18$ kg	$F_{\text{Earth on ball}} = ?$
$m_{\text{Earth}} = 6.0\times10^{24}$ kg	$a_{\text{Earth}} = ?$
$g = 9.8$ N/kg	

2 SOLVE FOR THE UNKNOWN

Use Newton's second law to find the weight of the ball.

$$F_{\text{Earth on ball}} = m_{\text{ball}}g$$
$$= (0.18\text{ kg})(-9.8\text{ N/kg})$$ ◀ Substitute $m_{\text{ball}} = 0.18$ kg, $g = -9.8$ N/kg.
$$= -1.8\text{ N}$$

Use Newton's third law to find $F_{\text{ball on Earth}}$.

$$F_{\text{ball on Earth}} = -F_{\text{Earth on ball}}$$
$$= -(-1.8\text{ N})$$ ◀ Substitute $F_{\text{Earth on ball}} = -1.8$ N.
$$= +1.8\text{ N}$$

Use Newton's second law to find a_{Earth}.

$$a_{\text{Earth}} = \frac{F_{\text{net}}}{m_{\text{Earth}}}$$
$$= \frac{1.8\text{ N}}{6.0\times10^{24}\text{ kg}}$$ ◀ Substitute $F_{\text{net}} = 1.8$ N, $m_{\text{Earth}} = 6.0\times10^{24}$ kg.
$$= 2.9\times10^{-25}\text{ m/s}^2 \text{ toward the softball}$$

3 EVALUATE THE ANSWER

- **Are the units correct?** Force is in N and acceleration is in m/s^2.
- **Do the signs make sense?** Force and acceleration should be positive.
- **Is the magnitude realistic?** It makes sense that Earth's acceleration should be so small because Earth is so massive.

APPLICATION

28. You lift a relatively light bowling ball with your hand, accelerating it upward. What are the forces on the ball? What forces does the ball exert? What objects are these forces exerted on?

29. A brick falls from a construction scaffold. Identify any forces acting on the brick. Also identify any forces the brick exerts and the objects on which these forces are exerted. (Air resistance may be ignored.)

30. A suitcase sits on a stationary airport luggage cart, as in **Figure 16.** Draw a free-body diagram for each object and specifically indicate any interaction pairs between the two.

31. CHALLENGE You toss a ball up in the air. Draw a free-body diagram for the ball after it has lost contact with your hand but while it is still moving upward. Identify any forces acting on the ball. Also identify any forces that the ball exerts and the objects on which these forces are exerted. Assume that air resistance is negligible.

Figure 16

Tension

Tension is simply a specific name for the force that a string or rope exerts. A simplification within this textbook is the assumption that all strings and ropes are massless. In **Figure 17**, the rope is about to break in the middle. If the rope breaks, the bucket will fall; before it breaks, there must be forces holding the rope together. The force that the top part of the rope exerts on the bottom part is $F_{\text{top on bottom}}$. Newton's third law states that this force must be part of an interaction pair. The other member of the pair is the force that the bottom part of the rope exerts on the top, $F_{\text{bottom on top}}$. These forces, equal in magnitude but opposite in direction, also are shown in **Figure 17.**

Think about this situation in another way. Before the rope breaks, the bucket is in equilibrium. This means that the force of its weight downward must be equal in magnitude but opposite in direction to the tension in the rope upward. Similarly, if you look at the point in the rope just above the bucket, it also is in equilibrium. Therefore, the tension of the rope below it pulling down must be equal to the tension of the rope above it pulling up. You can move up the rope, considering any point in the rope, and see that the tension forces at any point in the rope are pulling equally in both directions. Thus, the tension in the rope equals the weight of all objects below it.

Examine the tension forces shown in **Figure 18.** If team A is exerting a 500-N force and the rope does not accelerate, then team B also must be pulling with a force of 500 N. What is the tension in the rope? If each team pulls with 500 N of force, is the tension 1000 N? To decide, think of the rope as divided into two halves. The left side is not accelerating, so the net force on it is zero. Thus, $F_{\text{A on left side}} = F_{\text{right side on left side}} = 500$ N. Similarly, $F_{\text{B on right side}} = F_{\text{left side on right side}} = 500$ N. But the two tensions, $F_{\text{right side on left side}}$ and $F_{\text{left side on right side}}$, are an interaction pair, so they are equal and opposite. Thus, the tension in the rope equals the force with which each team pulls, or 500 N. To verify this, you could cut the rope in half and tie the ends to a spring scale. The scale would read 500 N.

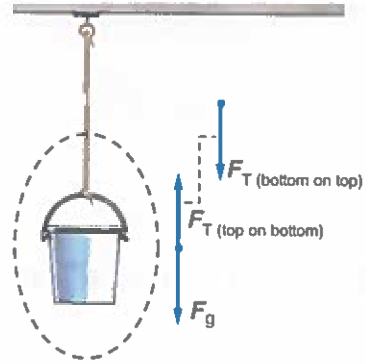


Figure 17 The tension in the rope is equal to the weight of all the objects hanging from it.

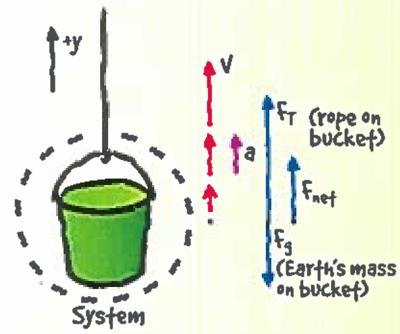
Figure 18 The rope is not accelerating, so the tension in the rope equals the force with which each side pulls.

EXAMPLE 5

LIFTING A BUCKET A 50.0 kg bucket is being lifted by a rope. The rope will not break if the tension is 525 N or less. The bucket started at rest, and after being lifted 3.0 m, it moves at 3.0 m/s. If the acceleration is constant, is the rope in danger of breaking?

1 ANALYZE AND SKETCH THE PROBLEM

- Draw the situation, and identify the forces on the system.
- Establish a coordinate system with the positive axis upward.
- Draw a motion diagram; include ***v*** and ***a***.
- Draw the free-body diagram, and label the forces.



KNOWN		UNKNOWN
$m = 50.0$ kg	$v_f = 3.0$ m/s	$F_T = ?$
$v_i = 0.0$ m/s	$d = 3.0$ m	

2 SOLVE FOR THE UNKNOWN

F_{net} is the sum of the positive force of the rope pulling up (F_T) and the negative weight force ($-F_g$) pulling down as defined by the coordinate system.

$$F_{net} = F_T + (-F_g)$$

$$F_T = F_{net} + F_g$$

$$= ma + mg$$ ◀ Substitute $F_{net} = ma$, $F_g = mg$

v_i, v_f, and d are known.

$$v_f^2 = v_i^2 + 2ad$$

$$a = \frac{v_f^2 - v_i^2}{2d}$$

$$= \frac{v_f^2}{2d}$$ ◀ Substitute $v_i = 0.0$ m/s.

$$F_T = ma + mg$$

$$= m\left(\frac{v_f^2}{2d}\right) + mg$$ ◀ Substitute $a = v_f^2 / (2d)$.

$$= (50.0\text{ kg})\left(\frac{(3.0\text{ m/s})^2}{2(3.0\text{ m})}\right) + (50.0\text{ kg})(9.8\text{ N/kg})$$ ◀ Substitute $m = 50.0$ kg, $v_f = 3.0$ m/s, $d = 3.0$ m, $g = 9.8$ N/kg.

$$= 560\text{ N}$$

The rope is in danger of breaking because the tension exceeds 525 N.

3 EVALUATE THE ANSWER

- **Are the units correct?** Dimensional analysis verifies kg·m/s^2, which is N.
- **Does the sign make sense?** The upward force should be positive.
- **Is the magnitude realistic?** The magnitude is a little larger than 490 N, which is the weight of the bucket. $F_g = mg = (50.0\text{ kg})(9.8\text{ N/kg}) = 490$ N

APPLICATION

32. Ali and Malik are trying to fix a tire on Ali's car, but they are having trouble getting the tire loose. When they pull together in the same direction, Malak with a force of 23 N and Ali with a force of 31 N, they just barely get the tire to move off the wheel. What is the magnitude of the force between the tire and the wheel?

33. CHALLENGE You are helping to repair a roof by loading equipment into a bucket that workers hoist to the rooftop. If the rope is guaranteed not to break as long as the tension does not exceed 450 N and you fill the bucket until it has a mass of 42 kg, what is the greatest acceleration that the workers can give the bucket as they pull it to the roof?

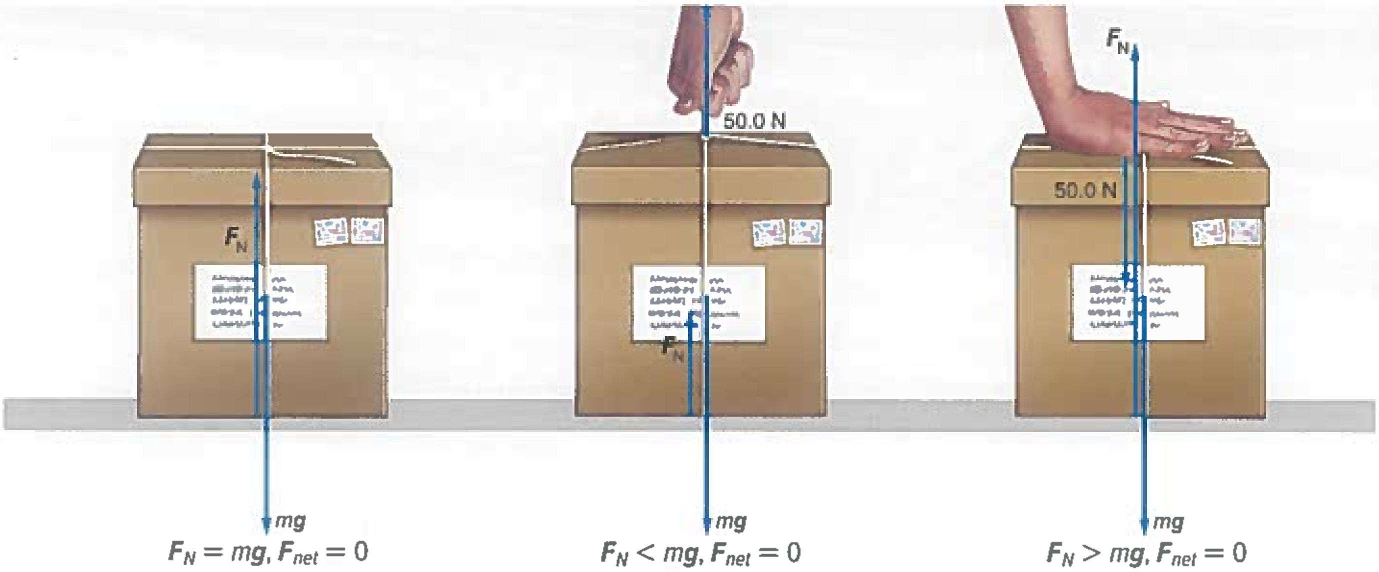


Figure 19 The normal force is not always equal to the object's weight.

The Normal Force

Any time two objects are in contact, they exert a force on each other. Think about a box sitting on a table. There is a downward force on the box due to Earth's gravitational attraction. There also is an upward force that the table exerts on the box. This force must exist because the box is in equilibrium. The **normal force** is the perpendicular contact force that a surface exerts on another surface.

The normal force always is perpendicular to the plane of contact between two objects, but is it always equal to the weight of an object? **Figure 19** shows three situations involving a box with the same weight. What if you tied a string to the box and pulled up on it a little bit, but not enough to accelerate the box, as shown in the middle panel in **Figure 19?** When you apply Newton's second law to the box and the forces acting on the box, you see $F_N + F_{\text{string on box}} - F_g = ma = 0$ N, which can be rearranged to show $F_N = F_g - F_{\text{string on box}}$.

You can see that in this case the normal force that the table exerts on the box is less than the box's weight (F_g). Similarly, if you pushed down on the box on the table as shown in the final panel in **Figure 19,** the normal force would be more than the box's weight. Finding the normal force will be important when you study friction in detail.

PhysicsLAB

NEWTON'S THIRD LAW

What are the interaction pairs between train cars?

SECTION 3 REVIEW

34. MAINIDEA Hold a ball motionless in your hand in the air as in **Figure 20.** Identify each force acting on the ball and its interaction pair.

Figure 20

35. Force Imagine lowering the ball in **Figure 20** at increasing speed. Do any of the forces or their interaction-pair partners change? Draw separate free-body diagrams for the forces acting on the ball and for each set of interaction pairs.

36. Tension A block hangs from the ceiling by a massless rope. A second block is attached to the first block and hangs below it on another piece of massless rope. If each of the two blocks has a mass of 5.0 kg, what is the tension in each rope?

37. Tension A block hangs from the ceiling by a massless rope. A 3.0 kg block is attached to the first block and hangs below it on another piece of massless rope. The tension in the top rope is 63.0 N. Find the tension in the bottom rope and the mass of the top block.

38. Critical Thinking A curtain prevents two tug-of-war teams from seeing each other. One team ties its end of the rope to a tree. If the other team pulls with a 500 N force, what is the tension in the rope? Explain.

SuperSonic?

On August 16, 1960, Joe Kittinger ascended 31.3 km into the stratosphere inside a capsule suspended from a helium balloon... and stepped out. He fell for 4 min 36 s, reaching 274 m/s before opening his parachute, landing safely 11 min later.

One small step Kittinger described the surreal experience of first stepping out of the capsule. He had the sensation that he was floating in space, but that was only because his eyes lacked a reference point to gauge his actual speed; in reality, he was dropping faster than anyone ever had before. The jump set records for fastest free fall, longest free fall, and highest parachute jump. Kittinger's jump set the stage for crewed space programs by proving that humans, with proper equipment, can survive the extreme conditions of such high altitudes.

Terminal velocity Terminal velocity is achieved when the upward drag force equals the downward gravitational force. Terminal velocity changes depending on the temperature and density of air at given altitudes. From a normal jump altitude of about 3500 m, the fastest speed a skydiver can achieve is around 90 m/s (nearly 200 mph). Due to the low air density a jumper will experience at extreme altitudes, they could reach speeds of 300 m/s (680 mph) or more.

Going supersonic Kittinger's maximum free-fall speed of 274 m/s (614 mph) was nearly fast enough to break the sound barrier. The speed of sound in air is not a constant but depends on the temperature of the air at a given altitude. At sea level, where the temperature is about 15°C, sound travels at 340 m/s. **Figure 1** shows that at much higher altitudes, where air is less dense and much colder, sound travels more slowly. Breaking the speed of sound during free fall is one of the goals of those attempting to beat Kittinger's records.

Altitude v. Speed of Sound

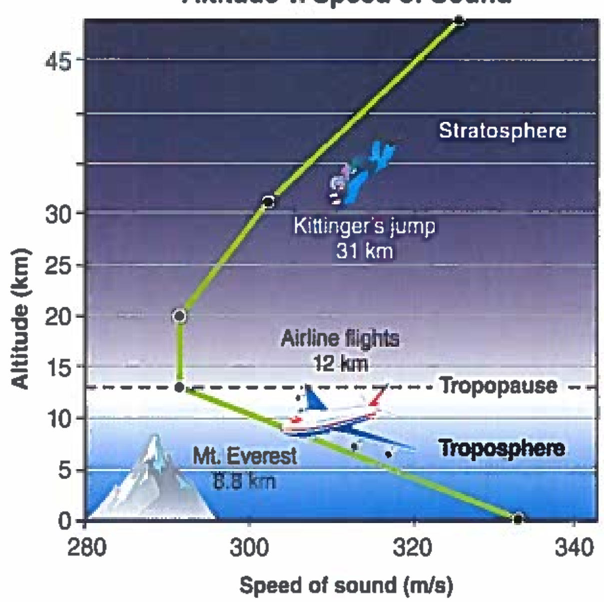


FIGURE 1 The speed of sound changes with altitude due to changes in air temperature and density. Suits similar to those worn by astronauts protect stunt skydivers attempting to break the sound barrier during free fall.

GOINGFURTHER >>>

Research Colonel Kittinger's involvement in Project Excelsior and Project Manhigh. Project Excelsior is especially interesting due to the technical problems during the Excelsior I and Excelsior III jumps.

CHAPTER 2 STUDY GUIDE

BIG IDEA Net forces cause changes in motion.

SECTION 1 Force and Motion

VOCABULARY
- force
- system
- free-body diagram
- net force
- Newton's second law
- Newton's first law
- inertia
- equilibrium

MAIN IDEA A force is a push or a pull.

- A force is a push or a pull. Forces have both direction and magnitude. A force might be either a contact force or a field force.
- Newton's second law states that the acceleration of a system equals the net force acting on it divided by its mass.

$$a = \frac{F_{net}}{m}$$

- Newton's first law states that an object that is at rest will remain at rest and an object that is moving will continue to move in a straight line with constant speed, if and only if the net force acting on that object is zero. An object with zero net force acting on it is in equilibrium.

SECTION 2 Weight and Drag Force

VOCABULARY
- weight
- gravitational field
- apparent weight
- weightlessness
- drag force
- terminal velocity

MAIN IDEA Newton's second law can be used to explain the motion of falling objects.

- The object's weight (F_g) depends on the object's mass and the gravitational field at the object's location.

$$F_g = mg$$

- An object's apparent weight is the magnitude of the support force exerted on it. An object with no apparent weight experiences weightlessness.
- A falling object reaches a constant velocity when the drag force is equal to the object's weight. The constant velocity is called the terminal velocity. The drag force on an object is determined by the object's weight, size, and shape as well as the fluid through which it moves.

SECTION 3 Newton's Third Law

VOCABULARY
- interaction pair
- Newton's third law
- tension
- normal force

MAIN IDEA All forces occur in interaction pairs.

- Newton's third law states that the two forces that make up an interaction pair of forces are equal in magnitude, but opposite in direction and act on different objects. In an interaction pair, $F_{A\ on\ B}$ does not cause $F_{B\ on\ A}$. The two forces either exist together or not at all.

$$F_{A\ on\ B} = -F_{B\ on\ A}$$

- The normal force is a support force resulting from the contact between two objects. It is always perpendicular to the plane of contact between the two objects.

SECTION 1 Force and Motion

Mastering Concepts

39. BIGIDEA You kick a soccer ball across a field. It slows down and comes to a stop. You ask your younger brother to explain what happened to the ball. He says, "The force of your foot was transferred to the ball, which made it move. When that force ran out, the ball stopped." Would Newton agree with that explanation? If not, explain how Newton's laws would describe it.

40. Cycling Imagine riding a single-speed bicycle. Why do you have to push harder on the pedals to start the bicycle moving than to keep it moving at a constant velocity?

Mastering Problems

41. What is the net force acting on a 1.0 kg ball moving at a constant velocity?

42. Skating Jamila and Wafa are skating. Jamila pushes Wafa, whose mass is 40.0 kg, with a force of 5.0 N. What is Wafa's resulting acceleration?

43. A 2300 kg car slows down at a rate of 3.0 m/s^2 when approaching a stop sign. What is the magnitude of the net force causing it to slow down?

44. Breaking the Collarbone After Eid Al Adha, Rashid and Osman use the collarbone of the sacrificed sheep as a toy. If Rashid pulls on it with a force 0.17 N larger than the force Osman pulls with in the opposite direction and the collarbone has a mass of 13 g, what is the collarbone's initial acceleration?

SECTION 2 Weight and Drag Force

Mastering Concepts

45. Suppose that the acceleration of an object is zero. Does this mean that there are no forces acting on the object? Give an example using an everyday situation to support your answer.

46. Basketball When a basketball player dribbles a ball, it falls to the floor and bounces up. Is a force required to make it bounce? Why? If a force is needed, what is the agent involved?

47. A cart has a net horizontal force acting on it to the right. Omar says that it must be moving to the right. Amir says no, it could be moving in either direction. Is either of these two correct? If so, explain and describe the velocity and acceleration (if any) of the cart.

48. Before a skydiver opens him parachute, he might be falling at a velocity higher than the terminal velocity that he will have after the parachute deploys.

a. Describe what happens to him velocity as he opens the parachute.

b. Describe the sky diver's velocity from when him parachute has been open for a time until he is about to land.

49. Three objects are dropped simultaneously from the top of a tall building: a shot put, an air-filled balloon, and a basketball.

a. Rank the objects in the order in which they will reach terminal velocity, from first to last.

b. Rank the objects according to the order in which they will reach the ground, from first to last.

c. What is the relationship between your answers to parts a and b?

Mastering Problems

50. What is your weight in newtons?

51. A rescue helicopter lifts two people using a winch and a rescue ring as shown in **Figure 21.**

a. The winch is capable of exerting a 2000 N force. What is the maximum mass it can lift?

b. If the winch applies a force of 1200 N, what is the rescuer's and victim's acceleration? Draw a free-body diagram for the people being lifted.

c. Using the acceleration from part b, how long does it take to pull the people up to the helicopter? Assume the people are initially at rest.

Figure 21

52. What force would a scale in an elevator on Earth exert on a 53 kg person standing on it during the following situations?

a. The elevator moves up at a constant speed.

b. It slows at 2.0 m/s^2 while moving upward.

c. It speeds up at 2.0 m/s^2 while moving downward.

d. The elevator moves down at a constant speed.

e. It slows to a stop while moving downward with a constant acceleration of 2.5 m/s^2.

53. **Astronomy** On the surface of Mercury, the gravitational field is 0.38 times its value on Earth.

a. What would a 6.0 kg mass weigh on Mercury?

b. If the gravitational field on the surface of Pluto is 0.08 times that of Mercury, what would a 7.0 kg mass weigh on Pluto?

54. A 65 kg diver jumps off of a 10.0 m tower. Assume that air resistance is negligible.

a. Find the diver's velocity when the diver hits the water.

b. The diver comes to a stop 2.0 m below the surface. Find the net force exerted by the water.

SECTION 3 Newton's Third Law

Mastering Concepts

55. A rock is dropped from a bridge. Earth pulls on the rock and accelerates it downward. According to Newton's third law, the rock also pulls on Earth, but Earth does not seem to accelerate. Explain.

56. Explain why the tension in a massless rope is constant throughout the rope.

57. Rami pushes on a bed as shown in **Figure 22.** Draw a free-body diagram for the bed and identify all the forces acting on it. Make a separate list of all the forces that the bed applies to other objects.

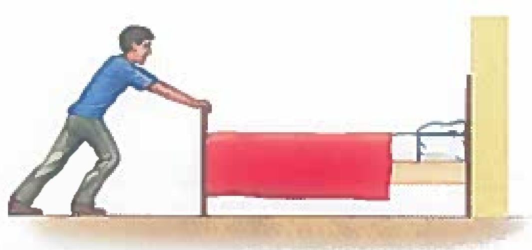


Figure 22

58. **Baseball** A batter swings a bat and hits a baseball. Draw free-body diagrams for the baseball and the bat at the moment of contact. Specifically indicate any interaction pairs between the two diagrams.

59. **Ranking Task Figure 23** shows a block in three different situations. Rank them according to the magnitude of the normal force between the block (or spring) and the floor, greatest to least. Specifically indicate any ties.

Figure 23

Mastering Problems

60. A 6.0 kg block rests on top of a 7.0 kg block, which rests on a horizontal table.

a. What is the force (magnitude and direction) exerted by the 7.0 kg block on the 6.0 kg block?

b. What is the force (magnitude and direction) exerted by the 6.0 kg block on the 7.0 kg block?

61. **Rain** A 2.45 mg raindrop falls to the ground. As it is falling, what magnitude of force does it exert on Earth?

62. Male lions and human sprinters can both accelerate at about 10.0 m/s^2. If a typical lion weighs 170 kg and a typical sprinter weighs 75 kg, what is the difference in the force exerted by the ground during a race between these two species? (Both the forward and normal forces should be calculated.)

63. A 4500 kg helicopter accelerates upward at 2.0 m/s^2. What lift force is exerted by the air on the propellers?

64. Three blocks are stacked on top of one another. The top block has a mass of 4.6 kg, the middle one has a mass of 1.2 kg, and the bottom one has a mass of 3.7 kg. Identify and calculate any normal forces between the objects.

Applying Concepts

65. **Whiplash** If you are in a car that is struck from behind, you can receive a serious neck injury called whiplash.

a. Using Newton's laws, explain what happens to cause such an injury.

b. How does a headrest reduce whiplash?

66. When you look at the label of the product in **Figure 24** to get an idea of how much the box contains, does it tell you its mass, weight, or both? Would you need to make any changes to this label to make it correct for consumption on the Moon?

Figure 24

67. From the top of a tall building, you drop two table-tennis balls, one filled with air and the other with water. Both experience air resistance as they fall. Which ball reaches terminal velocity first? Do both hit the ground at the same time?

68. It can be said that 1 kg is equivalent to 2.21 lb. What does this statement mean? What would be the proper way of making the comparison?

69. You toss a ball straight up into the air. Assume that air resistance is negligible.

   a. Draw a free-body diagram for the ball at three points: on the way up, at the very top, and on the way down. Specifically identify the forces and agents acting on the ball.

   b. What is the ball's velocity at the very top of the motion?

   c. What is the ball's acceleration at this point?

70. When receiving a basketball pass, a player doesn't hold his or her hands still but moves them in the direction of the moving ball. Explain in terms of acceleration and Newton's second law why the player moves his or hands in this manner.

Mixed Review

71. A dragster completed a 402.3 m (0.2500 mi) run in 5.023 s. If the car had a constant acceleration, what was its acceleration and final velocity?

72. **Space Station** Bassel weighs 588 N on Earth but is currently weightless in a space station. If she pushes off the wall with a vertical acceleration of 3.00 m/s^2, determine the force exerted by the wall during her push off.

73. **Jet** A 2.75×10^6-N jet plane is ready for takeoff. If the jet's engines supply a constant forward force of 6.35×10^6 N, how much runway will it need to reach its minimum takeoff speed of 285 km/h?

74. **Drag Racing** A 873 kg dragster, starting from rest, attains a speed of 26.3 m/s in 0.59 s.

   a. Find the average acceleration of the dragster.

   b. What is the magnitude of the average net force on the dragster during this time?

   c. What horizontal force does the seat exert on the driver if the driver has a mass of 68 kg?

75. The dragster in the previous problem completed a 402.3 m track in 4.936 s. It crossed the finish line going 126.6 m/s. Does the assumption of constant acceleration hold true? What information is needed to determine whether the acceleration was constant?

76. Suppose a 65 kg boy and a 45 kg boy use a massless rope in a tug-of-war on an icy, resistance-free surface as in **Figure 25**. If the acceleration of the boy on the right toward the other boy is 3.0 m/s^2, find the magnitude of the acceleration toward the boy on the right.

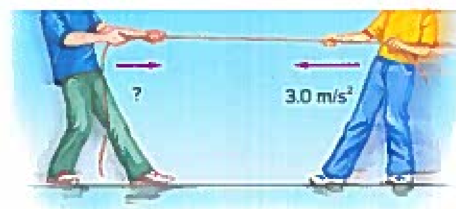


Figure 25

77. **Baseball** As a baseball is being caught, its speed goes from 30.0 m/s to 0.0 m/s in about 0.0050 s. The mass of the baseball is 0.145 kg.

   a. What is the baseball's acceleration?

   b. What are the magnitude and the direction of the force acting on it?

   c. What are the magnitude and the direction of the force acting on the player who caught it?

78. An automobile accelerates uniformly from 0 to 24 m/s in 6.0 s. If the car has a mass of 2.0×10^3 kg, what is the force accelerating it?

79. **Air Hockey** An air-hockey table works by pumping air through thousands of tiny holes in a table to support light pucks. This allows the pucks to move around on cushions of air with very little resistance. One of these pucks has a mass of 0.25 kg and is pushed along by a 12.0 N force for 0.90 s.

   a. What is the puck's acceleration?

   b. What is the puck's final velocity?

80. Weather Balloon The instruments attached to a weather balloon in **Figure 26** have a mass of 8.0 kg. The balloon is released and exerts an upward force of 98 N on the instruments.

a. What is the acceleration of the balloon and the instruments?

b. After the balloon has accelerated for 10.0 s, the instruments are released. What is the velocity of the instruments at the moment of their release?

c. What net force acts on the instruments after their release?

d. When does the direction of the instruments' velocity first become downward?

Figure 26

81. When a horizontal force of 4.5 N acts on a block on a resistance-free surface, it produces an acceleration of 2.5 m/s^2. Suppose a second 4.0 kg block is dropped onto the first. What is the magnitude of the acceleration of the combination if the same force continues to act? Assume that the second block does not slide on the first block.

82. Figure 27 shows two blocks, masses 4.3 kg and 5.4 kg, being pushed across a frictionless surface by a 22.5 N horizontal force applied to the 4.3 kg block.

a. What is the acceleration of the blocks?

b. What is the force of the 4.3 kg block on the 5.4 kg block?

c. What is the force of the 5.4 kg block on the 4.3 kg block?

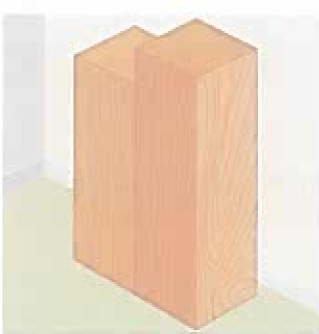


Figure 27

83. A student stands on a bathroom scale in an elevator at rest on the 64th floor of a building. The scale reads 836 N.

a. As the elevator moves up, the scale reading increases to 936 N. Find the acceleration of the elevator.

b. As the elevator approaches the 74th floor, the scale reading drops to 782 N. What is the acceleration of the elevator?

c. Using your results from parts a and b, explain which change in velocity, starting or stopping, takes the longer time.

84. Two blocks, one of mass 5.0 kg and the other of mass 3.0 kg, are tied together with a massless rope as in **Figure 28.** This rope is strung over a massless, resistance-free pulley. The blocks are released from rest. Find the following:

a. the tension in the rope

b. the acceleration of the blocks

Hint: You will need to solve two simultaneous equations.

Figure 28

Thinking Critically

85. Reverse Problem Write a physics problem with real-life objects for which the following equation would be part of the solution:

$F = (23\ \text{kg})(1.8\ \text{m/s}^2)$

86. Formulate Models A 2.0 kg mass (m_A) and a 3.0 kg mass (m_B) are connected to a lightweight cord that passes over a frictionless pulley. The pulley only changes the direction of the force exerted by the rope. The hanging masses are free to move. Choose coordinate systems for the two masses with the positive direction being up for m_A and down for m_B.

a. Create a pictorial model.

b. Create a physical model with motion and free-body diagrams.

c. What is the acceleration of the smaller mass?

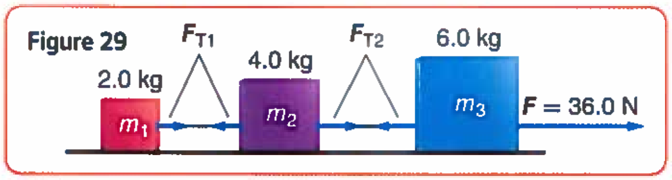
87. Use Models Suppose that the masses in the previous problem are now 1.00 kg and 4.00 kg. Find the acceleration of the larger mass.

88. Observe and Infer Three blocks that are connected by massless strings are pulled along a frictionless surface by a horizontal force, as shown in **Figure 29.**

a. What is the acceleration of each block?

b. What are the tension forces in each of the strings? *Hint: Draw a separate free-body diagram for each block.*

Figure 29



89. Critique Using the Example Problems in this chapter as models, write a solution to the following problem. A 3.46 kg block is suspended from two vertical ropes attached to the ceiling. What is the tension in each rope?

90. Think Critically You are serving as a scientific consultant for a new science-fiction TV series about space exploration. In episode 3, the heroine has been asked to be the first person to ride in a new interplanetary transport ship. She wants to be sure that the transport actually takes her to the planet she wants to get to, so she needs a device to measure the force of gravity when she arrives. To measure the force of gravity, the script writers would like the heroine to perform an experiment involving a scale. It is your job to design a quick experiment the heroine can conduct involving a scale to determine which planet she is on. Describe the experiment and include what the results would be for Venus ($g = 8.9$ N/kg), which is where she is supposed to go, and Mercury ($g = 3.7$ N/kg), which is where the transport takes her.

91. Apply Concepts Develop a lab that uses a motion detector and either a calculator or a computer program that graphs the distance a free-falling object moves over equal intervals of time. Also graph velocity versus time. Compare and contrast your graphs. Using your velocity graph, determine the gravitational field. Does it equal g?

92. Problem Posing Complete this problem so that it must be solved using the concept listed below: "A worker unloading a truck gives a 10 kg crate of oranges a push across the floor ..."

a. Newton's second law

b. Newton's third law

Writing in Physics

93. Research Newton's contributions to physics and write a one-page summary. Do you think his three laws of motion were his greatest accomplishments? Explain why or why not.

94. Review, analyze, and critique Newton's first law. Can we prove this law? Explain. Be sure to consider the role of resistance.

95. Physicists classify all forces into four fundamental categories: gravitational, electromagnetic, weak nuclear, and strong nuclear. Investigate these forces and describe the situations in which they are found.

Cumulative Review

96. Cross-Country Skiing Your friend is training for a cross-country skiing race, and you and some other friends have agreed to provide him with food and water along his training route. It is a bitterly cold day, so none of you wants to wait outside longer than you have to. Taro, whose house is the stop before yours, calls you at 8:25 A.M. to tell you that the skier just passed his house and is planning to move at an average speed of 8.0 km/h. If it is 5.2 km from Taro's house to yours, when should you expect the skier to pass your house?

97. Figure 30 is a position-time graph of the motion of two cars on a road.

a. At what time(s) does one car pass the other?

b. Which car is moving faster at 7.0 s?

c. At what time(s) do the cars have the same velocity?

d. Over what time interval is car B speeding up all the time?

e. Over what time interval is car B slowing down all the time?

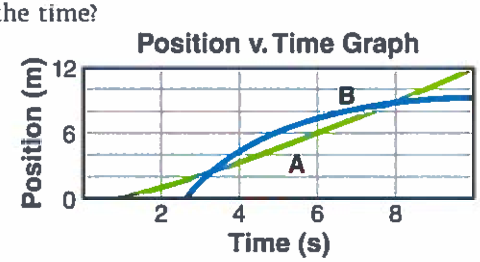


Figure 30

98. Refer to **Figure 30** to find the instantaneous speed for the following:

a. car B at 2.0 s

b. car B at 9.0 s

c. car A at 2.0 s

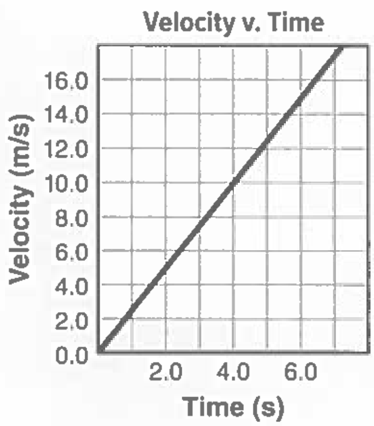
CHAPTER 4 STANDARDIZED TEST PRACTICE

MULTIPLE CHOICE

1. What is the acceleration of the car described by the graph below?

A. $0.20\ m/s^2$ **C.** $1.0\ m/s^2$

B. $0.40\ m/s^2$ **D.** $2.5\ m/s^2$



2. What distance will a sprinter travel in 4.0 s if his or her acceleration is $2.5\ m/s^2$? Assume the sprinter starts from rest.

A. 13 m **C.** 80 m

B. 20 m **D.** 90 m

3. If a motorcycle starts from rest and maintains a constant acceleration of $3\ m/s^2$, what will its velocity be after 10 s?

A. 10 m/s **C.** 90 m/s

B. 30 m/s **D.** 100 m/s

4. How does an object's acceleration change if the net force on the object is doubled?

A. The acceleration is cut in half.

B. The acceleration does not change.

C. The acceleration is doubled.

D. The acceleration is multiplied by four.

5. What is the weight of a 225 kg space probe on the Moon? The gravitational field on the Moon is 1.62 N/kg.

A. 139 N **C.** 1.35×10^3 N

B. 364 N **D.** 2.21×10^3 N

6. A 73 kg woman stands on a scale in an elevator. The scale reads 810 N. What is the magnitude and direction of the elevator's acceleration?

A. $0.23\ m/s^2$ up **C.** $6.5\ m/s^2$ down

B. $1.3\ m/s^2$ up **D.** $11\ m/s^2$ down

7. A 45 kg child sits on a 3.2 kg tire swing. What is the tension in the rope that hangs from a tree branch?

A. 310 N **C.** 4.5×10^2 N

B. 4.4×10^2 N **D.** 4.7×10^2 N

8. The tree branch in the previous problem sags, and the child's feet rest on the ground. If the tension in the rope is reduced to 220 N, what is the value of the normal force being exerted on the child's feet?

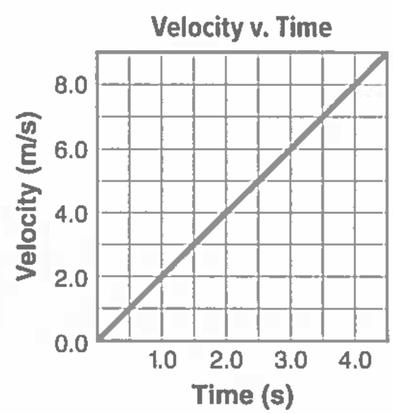
A. 2.2×10^2 N **C.** 4.3×10^2 N

B. 2.5×10^2 N **D.** 6.9×10^2 N

9. In the graph below, what is the force being exerted on the 16 kg cart?

A. 4 N **C.** 16 N

B. 8 N **D.** 32 N



FREE RESPONSE

10. Draw a free-body diagram of a cat sitting on a scale in an elevator. Using words and mathematical formulas, describe what happens to the apparent weight of the cat when the elevator accelerates upward, when the elevator travels at a constant speed downward, and when the elevator falls freely downward.

STUDENT RESOURCES

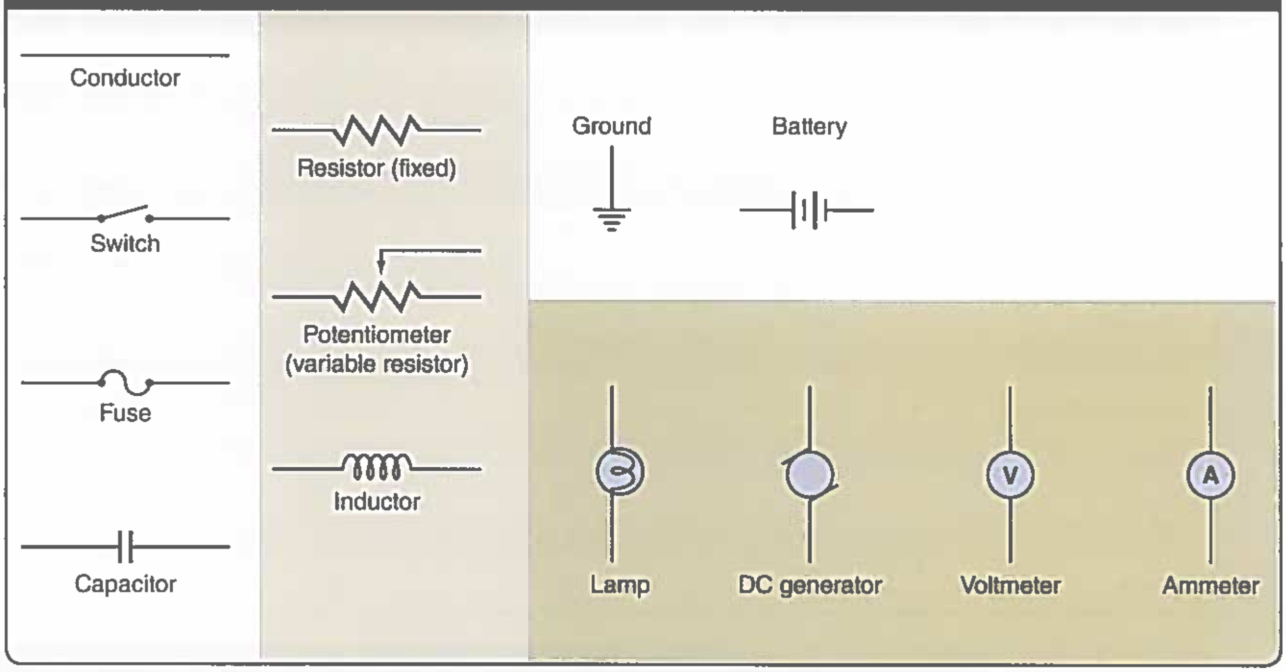
Reference Tables R-1

Chapter Sourced From: All Chapters from Glencoe Physics: Principles & Problems, Student Edition ©2017

Color Conventions

Displacement vector (*x*)		Negative charge	−
Velocity vector (*v*)		Positive charge	+
Acceleration vector (*a*)		Current direction	
Force vector (*F*)		Electron	
Momentum vector (*p*)		Proton	
Light ray		Neutron	
Object		Coordinate axes	
Image			
Electric field line (*E*)			
Magnetic field line (*B*)			

Electric Circuit Symbols



SI Base Units		
Quantity	Unit	Unit Abbreviation
Length	meter	m
Mass	kilogram	kg
Time	second	s
Temperature	kelvin	K
Amount of a substance	mole	mol
Electric current	ampere	A
Luminous intensity	candela	cd

SI Derived Units				
Quantity	Unit	Unit Symbol	Unit Expressed in Base Units	Unit Expressed in Other SI Units
Acceleration	meters per second squared	m/s^2	m/s^2	
Area	meters squared	m^2	m^2	
Capacitance	farad	F	$A^2{\cdot}s^4/(kg{\cdot}m^2)$	
Density	kilograms per meter cubed	kg/m^3	kg/m^3	
Electric charge	coulomb	C	A·s	
Electric field	newtons per coulomb	N/C	$kg{\cdot}m/(A{\cdot}s^3)$	V/m
Electric resistance	ohm	Ω	$kg{\cdot}m^2/(A^2{\cdot}s^3)$	V/A
EMF	volt	V	$kg{\cdot}m^2/(A^2{\cdot}s^3)$	
Energy, work	joule	J	$kg{\cdot}m^2/s^2$	N·m
Force	newton	N	$kg{\cdot}m/s^2$	
Frequency	hertz	Hz	s^{-1}	
Illuminance	lux	lx	cd/m^2	
Magnetic field	tesla	T	$kg/(A{\cdot}s^2)$	N·s/(C·m)
Potential difference	volt	V	$kg{\cdot}m^2/(A{\cdot}s^3)$	W/A or J/C
Power	watt	W	$kg{\cdot}m^2/s^3$	J/s
Pressure	pascal	Pa	$(kg/m)s^2$	N/m^2
Velocity	meters per second	m/s	m/s	
Volume	meters cubed	m^3	m^3	

Useful Conversions		
1 in = 2.54 cm	1 kg = 6.02×10^{26} u	1 atm = 101 kPa
1 mi = 1.61 km	1 oz = 28.4 g	1 cal = 4.184 J
1 mi^2 = 640 acres	1 kg = 2.21 lb	1 eV = 1.60×10^{-19} J
1 gal = 3.79 L	1 lb = 4.45 N	1 kWh = 3.60 MJ
1 m^3 = 264 gal	1 atm = 14.7 lb/in^2	1 hp = 746 W
1 knot = 1.15 mi/h	1 atm = 1.01×10^5 N/m^2	1 mol = 6.02×10^{23} particles

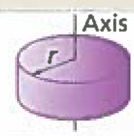
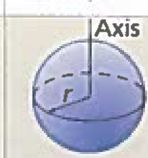
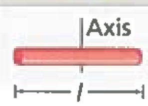
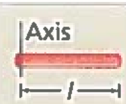
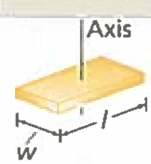
Physical Constants

Quantity	Symbol	Value	Approximate Value
Atomic mass unit	u	$1.660538782 \times 10^{-27}$ kg	1.66×10^{-27} kg
Avogadro's number	N_A	$6.02214179 \times 10^{23}$ mol^{-1}	6.022×10^{23} mol^{-1}
Boltzmann's constant	k	$1.3806504 \times 10^{-23}$ Pa·m^3/K	1.38×10^{-23} Pa·m^3/K
Coulomb's constant	K	$8.987551788 \times 10^{9}$ N·m^2/C^2	9.0×10^{9} N·m^2/C^2
Elementary charge	e	$1.60217653 \times 10^{-19}$ C	1.602×10^{-19} C
Gas constant	R	8.314472 Pa·m^3/mol·K	8.31 Pa·m^3/mol·K
Gravitational constant	G	6.67428×10^{-11} N·m^2/kg^2	6.67×10^{-11} N·m^2/kg^2
Mass of an electron	m_e	$9.10938215 \times 10^{-31}$ kg	9.11×10^{-31} kg
Mass of a proton	m_p	$1.672621637 \times 10^{-27}$ kg	1.67×10^{-27} kg
Mass of a neutron	m_n	$1.674927211 \times 10^{-27}$ kg	1.67×10^{-27} kg
Planck's constant	h	$6.62606896 \times 10^{-34}$ J·s	6.63×10^{-34} J·s
Speed of light in a vacuum	c	2.99792458×10^{8} m/s	3.00×10^{8} m/s

SI Prefix

Prefix	Symbol	Scientific Notation
femto	f	10^{-15}
pico	p	10^{-12}
nano	n	10^{-9}
micro	μ	10^{-6}
milli	m	10^{-3}
centi	c	10^{-2}
deci	d	10^{-1}
deka	da	10^{1}
hector	h	10^{2}
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}
tera	T	10^{12}
peta	P	10^{15}

Moments of Inertia for Various Objects

Object	Location of Axis	Diagram	Moment of Inertia
Thin hoop of radius r	through central diameter		mr^2
Solid, uniform cylinder of radius r	through center		$\frac{1}{2}mr^2$
Uniform sphere of radius r	through center		$\frac{2}{5}mr^2$
Long, uniform rod of length l	through center		$\frac{1}{12}ml^2$
Long, uniform rod of length l	through end		$\frac{1}{3}ml^2$
Thin, rectangular plate of length l and width w	through center		$\frac{1}{12}m(l^2 + w^2)$

Reference Tables

Densities of Some Common Substances	
Substance	Density (g/cm^3)
Aluminum	2.70
Cadmium	8.65
Copper	8.92
Germanium	5.32
Gold	19.32
Hydrogen	8.99×10^{-5}
Indium	7.31
Iron	7.87
Lead	11.34
Mercury	13.534
Oxygen	1.429×10^{-3}
Silicon	2.33
Silver	10.5
Water (4°C)	1.000
Zinc	7.14

Melting and Boiling Points		
Substance	Melting Point (°C)	Boiling Point (°C)
Aluminum	660.32	2519
Copper	1084.62	2562
Germanium	938.25	2833
Gold	1064.18	2856
Indium	156.60	2072
Iron	1538	2861
Lead	327.5	1749
Silicon	1414	3265
Silver	961.78	2162
Water	0.000	100.000
Zinc	419.53	907

Specific Heats			
Material	Specific Heat, C[J/(kg·K)]	Material	Specific Heat, C[J/(kg·K)]
Aluminum	897	Lead	130
Brass	376	Methanol	2450
Carbon	710	Silver	235
Copper	385	Water	4180
Glass	840	Water vapor	2020
Ice	2060	Zinc	388
Iron	450		

Heats of Fusion and Vaporization		
Material	Heat of Fusion, H_f (J/kg)	Heat of Vaporization, H_v (J/kg)
Copper	2.05×10^5	5.07×10^6
Gold	6.30×10^4	1.64×10^6
Iron	2.66×10^5	6.29×10^6
Lead	2.04×10^4	8.64×10^5
Mercury	1.15×10^4	2.72×10^5
Methanol	1.09×10^5	8.78×10^5
Silver	1.04×10^5	2.36×10^6
Water (solid)	3.34×10^5	2.26×10^6

Coefficients of Thermal Expansion at 20°C

Material	Coefficient of Linear Expansion α (°C^{-1})	Coefficient of Volume Expansion β (°C^{-1})
Solids		
Aluminum	23×10^{-6}	69×10^{-6}
Brass	19×10^{-6}	57×10^{-6}
Concrete	12×10^{-6}	36×10^{-6}
Copper	17×10^{-6}	51×10^{-6}
Glass (soft)	9×10^{-6}	27×10^{-6}
Glass (ovenproof)	3×10^{-6}	9×10^{-6}
Iron, steel	12×10^{-6}	35×10^{-6}
Platinum	9×10^{-6}	27×10^{-6}
Liquids		
Gasoline		950×10^{-6}
Mercury		180×10^{-6}
Methanol		1200×10^{-6}
Water		210×10^{-6}
Gases		
Air (and most other gases)		3400×10^{-6}

Wavelengths of Visible Light

Color	Wavelength, λ (nm)
Violet	380–430
Indigo	430–450
Blue	450–500
Cyan	500–520
Green	520–565
Yellow	565–590
Orange	590–625
Red	625–740

Speed of Sound in Various Mediums

Medium (0°C)	Speed (m/s)
Air (0°C)	331
Air (20°C)	343
Helium (0°C)	972
Hydrogen (27°C)	1310
Water (25°C)	1497
Seawater (25°C)	1533
Rubber	1600
Copper (25°C)	3560
Iron (25°C)	5130
Ovenproof glass	5640
Diamond	12,000

Dielectric Constants, *k* (20°C)

Vacuum	1.0000
Air (1 atm)	1.00059
Neon (1 atm)	1.00013
Glass	4–7
Quartz	4.3
Fused quartz	3.75
Water	80

Reference Tables

Solar System Data	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune
Mass (kg $\times 10^{24}$)	0.330	4.87	5.97	0.642	1899	569	86.8	102
Average radius (m $\times 10^{6}$)	2.44	6.05	6.38	3.40	71.5	60.3	25.6	24.8
Density (kg/m^3)	5427	5243	5515	3933	1326	687	1270	1638
Albedo	0.068	0.90	0.306	0.250	0.343	0.342	0.300	0.290
Average distance from the Sun (m $\times 10^{9}$)	57.91	108.2	149.6	227.9	778.4	1433.5	2872.5	4498.2
Orbital period (Earth days)	88.0	224.7	365.2	687.0	4332	10,759	30,685	60,189
Orbital inclination (degrees)	7.0	3.4	0.0	1.9	1.3	2.5	0.8	1.8
Orbital eccentricity	0.205	0.007	0.017	0.094	0.049	0.057	0.046	0.011
Rotational period (h)	1407.6	5832.5^R	23.9	24.6	9.9	10.7	17.2^R	16.1
Axial tilt (degrees)	0.03	177.4	23.4	25.2	3.1	26.7	97.8	28.3
Average surface temperature (K)	440	737	288	210	163	133	78	73
Gravitational field strength near the surface (N/kg)	3.7	8.9	9.8	3.7	20.9	10.4	8.4	10.7

R indicates retrograde motion.

The Moon	
Mass	0.073×10^{24} kg
Equatorial radius	1738 km
Mean density	3340 kg/m^3
Albedo	0.11
Average distance from Earth	384×10^{3} km
Orbital period	27.3 Earth days
Synodic period (lunar)	29.53 Earth days
Orbital inclination	5.1°
Orbital eccentricity	0.055
Rotational period	655.7 h
Gravitational field strength near the surface	1.6 N/kg

The Sun	
Mass	1.99×10^{30} kg
Equatorial radius	6.96×10^{8} m
Mean density	1408 kg/m^3
Absolute magnitude	+4.83
Luminosity	3.846×10^{26} J/s
Spectral type	G2 V
Rotational period (equatorial)	609.12 h
Mean energy production	0.1937×10^{-3} J/kg
Average surface temperature	5778 K

PERIODIC TABLE OF THE ELEMENTS

Element — Hydrogen
Atomic number — 1
Symbol — H
Atomic mass — 1.008
State of matter

Gas
Liquid
Solid
Synthetic

Metal
Metalloid
Nonmetal
Recently observed

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Hydrogen 1 H 1.008																	Helium 2 He 4.003
2	Lithium 3 Li 6.941	Beryllium 4 Be 9.012											Boron 5 B 10.811	Carbon 6 C 12.011	Nitrogen 7 N 14.007	Oxygen 8 O 15.999	Fluorine 9 F 18.998	Neon 10 Ne 20.180
3	Sodium 11 Na 22.990	Magnesium 12 Mg 24.305											Aluminum 13 Al 26.982	Silicon 14 Si 28.086	Phosphorus 15 P 30.974	Sulfur 16 S 32.066	Chlorine 17 Cl 35.453	Argon 18 Ar 39.948
4	Potassium 19 K 39.098	Calcium 20 Ca 40.078	Scandium 21 Sc 44.956	Titanium 22 Ti 47.867	Vanadium 23 V 50.942	Chromium 24 Cr 51.996	Manganese 25 Mn 54.938	Iron 26 Fe 55.847	Cobalt 27 Co 58.933	Nickel 28 Ni 58.693	Copper 29 Cu 63.546	Zinc 30 Zn 65.39	Gallium 31 Ga 69.723	Germanium 32 Ge 72.61	Arsenic 33 As 74.922	Selenium 34 Se 78.96	Bromine 35 Br 79.904	Krypton 36 Kr 83.80
5	Rubidium 37 Rb 85.468	Strontium 38 Sr 87.62	Yttrium 39 Y 88.906	Zirconium 40 Zr 91.224	Niobium 41 Nb 92.906	Molybdenum 42 Mo 95.94	Technetium 43 Tc (98)	Ruthenium 44 Ru 101.07	Rhodium 45 Rh 102.906	Palladium 46 Pd 106.42	Silver 47 Ag 107.868	Cadmium 48 Cd 112.411	Indium 49 In 114.82	Tin 50 Sn 118.710	Antimony 51 Sb 121.757	Tellurium 52 Te 127.60	Iodine 53 I 126.904	Xenon 54 Xe 131.290
6	Cesium 55 Cs 132.905	Barium 56 Ba 137.327	Lanthanum 57 La 138.905	Hafnium 72 Hf 178.49	Tantalum 73 Ta 180.948	Tungsten 74 W 183.84	Rhenium 75 Re 186.207	Osmium 76 Os 190.23	Iridium 77 Ir 192.217	Platinum 78 Pt 195.08	Gold 79 Au 196.967	Mercury 80 Hg 200.59	Thallium 81 Tl 204.383	Lead 82 Pb 207.2	Bismuth 83 Bi 208.980	Polonium 84 Po 208.982	Astatine 85 At 209.987	Radon 86 Rn 222.018
7	Francium 87 Fr (223)	Radium 88 Ra (226)	Actinium 89 Ac (227)	Rutherfordium 104 Rf (261)	Dubnium 105 Db (262)	Seaborgium 106 Sg (266)	Bohrium 107 Bh (264)	Hassium 108 Hs (277)	Meitnerium 109 Mt (268)	Darmstadtium 110 Ds (281)	Roentgenium 111 Rg (272)	Copernicium 112 Cn (285)	Ununtrium * 113 Uut (284)	Ununquadium * 114 Uuq (289)	Ununpentium * 115 Uup (288)	Ununhexium * 116 Uuh (291)		Ununoctium * 118 Uuo (294)

The number in parentheses is the mass number of the longest lived isotope for that element.

* The names and symbols for elements 113, 114, 115, 116, and 118 are temporary. Final names will be selected when the elements' discoveries are verified.

Lanthanide series	Cerium 58 Ce 140.115	Praseodymium 59 Pr 140.908	Neodymium 60 Nd 144.242	Promethium 61 Pm (145)	Samarium 62 Sm 150.36	Europium 63 Eu 151.965	Gadolinium 64 Gd 157.25	Terbium 65 Tb 158.925	Dysprosium 66 Dy 162.50	Holmium 67 Ho 164.930	Erbium 68 Er 167.259	Thulium 69 Tm 168.934	Ytterbium 70 Yb 173.04	Lutetium 71 Lu 174.967
Actinide series	Thorium 90 Th 232.038	Protactinium 91 Pa 231.036	Uranium 92 U 238.029	Neptunium 93 Np (237)	Plutonium 94 Pu (244)	Americium 95 Am (243)	Curium 96 Cm (247)	Berkelium 97 Bk (247)	Californium 98 Cf (251)	Einsteinium 99 Es (252)	Fermium 100 Fm (257)	Mendelevium 101 Md (258)	Nobelium 102 No (259)	Lawrencium 103 Lr (262)

Explore updates to the periodic table.

Periodic Table

The Elements

Element	Symbol	Atomic Number	Atomic Mass	Element	Symbol	Atomic Number	Atomic Mass
Actinium	Ac	89	(227)	Mendelevium	Md	101	(258)
Aluminum	Al	13	26.982	Mercury	Hg	80	200.59
Americium	Am	95	(243)	Molybdenum	Mo	42	95.96
Antimony	Sb	51	121.760	Neodymium	Nd	60	144.24
Argon	Ar	18	39.948	Neon	Ne	10	20.180
Arsenic	As	33	74.922	Neptunium	Np	93	(237)
Astatine	At	85	(210)	Nickel	Ni	28	58.693
Barium	Ba	56	137.327	Niobium	Nb	41	92.906
Berkelium	Bk	97	(247)	Nitrogen	N	7	14.007
Beryllium	Be	4	9.012	Nobelium	No	102	(259)
Bismuth	Bi	83	208.980	Osmium	Os	76	190.23
Bohrium	Bh	107	(272)	Oxygen	O	8	15.999
Boron	B	5	10.811	Palladium	Pd	46	106.42
Bromine	Br	35	79.904	Phosphorus	P	15	30.974
Cadmium	Cd	48	112.411	Platinum	Pt	78	195.078
Calcium	Ca	20	40.078	Plutonium	Pu	94	(244)
Californium	Cf	98	(251)	Polonium	Po	84	(209)
Carbon	C	6	12.011	Potassium	K	19	39.098
Cerium	Ce	58	140.116	Praseodymium	Pr	59	140.908
Cesium	Cs	55	132.905	Promethium	Pm	61	(145)
Chlorine	Cl	17	35.453	Protactinium	Pa	91	231.036
Chromium	Cr	24	51.996	Radium	Ra	88	(226)
Cobalt	Co	27	58.933	Radon	Rn	86	(222)
Copernicium	Cn	112	(285)	Rhenium	Re	75	186.207
Copper	Cu	29	63.546	Rhodium	Rh	45	102.906
Curium	Cm	96	(247)	Roentgenium	Rg	111	(280)
Darmstadtium	Ds	110	(281)	Rubidium	Rb	37	85.468
Dubnium	Db	105	(262)	Ruthenium	Ru	44	101.07
Dysprosium	Dy	66	162.500	Rutherfordium	Rf	104	(265)
Einsteinium	Es	99	(252)	Samarium	Sm	62	150.36
Erbium	Er	68	167.259	Scandium	Sc	21	44.956
Europium	Eu	63	151.964	Seaborgium	Sg	106	(271)
Fermium	Fm	100	(257)	Selenium	Se	34	78.96
Flerovium	Fl	114	(289)	Silicon	Si	14	28.086
Fluorine	F	9	18.998	Silver	Ag	47	107.868
Francium	Fr	87	(223)	Sodium	Na	11	22.990
Gadolinium	Gd	64	157.25	Strontium	Sr	38	87.62
Gallium	Ga	31	69.723	Sulfur	S	16	32.065
Germanium	Ge	32	72.63	Tantalum	Ta	73	180.948
Gold	Au	79	196.967	Technetium	Tc	43	(98)
Hafnium	Hf	72	178.49	Tellurium	Te	52	127.60
Hassium	Hs	108	(270)	Terbium	Tb	65	158.925
Helium	He	2	4.003	Thallium	Tl	81	204.383
Holmium	Ho	67	164.930	Thorium	Th	90	232.038
Hydrogen	H	1	1.008	Thulium	Tm	69	168.934
Indium	In	49	114.81	Tin	Sn	50	118.710
Iodine	I	53	126.904	Titanium	Ti	22	47.867
Iridium	Ir	77	192.217	Tungsten	W	74	183.84
Iron	Fe	26	55.847	Uranium	U	92	238.029
Krypton	Kr	36	83.798	Vanadium	V	23	50.942
Lanthanum	La	57	138.906	Xenon	Xe	54	131.293
Lawrencium	Lr	103	(262)	Ytterbium	Yb	70	173.04
Lead	Pb	82	207.2	Yttrium	Y	39	88.906
Lithium	Li	3	6.941	Zinc	Zn	30	65.38
Livermorium	Lv	116	(293)	Zirconium	Zr	40	91.224
Lutetium	Lu	71	174.967	Element 113*	Uut	113	(284)
Magnesium	Mg	12	24.305	Element 115*	Uup	115	(288)
Manganese	Mn	25	54.938	Element 117*	Uus	117	(294)
Meitnerium	Mt	109	(276)	Element 118*	Uuo	118	(294)

* Names have not yet been approved by IUPAC.

Safety Symbols	Hazard	Examples	Precaution	Remedy
Disposal	Special disposal procedures need to be followed.	Certain chemicals, living organisms	Do not dispose of these materials in the sink or trash can.	Dispose of wastes as directed by your teacher.
Biological	Organisms or other biological materials that might be harmful to humans	Bacteria, fungi, blood, unpreserved tissues, plant materials	Avoid skin contact with these materials. Wear mask and gloves.	Notify your teacher if you suspect contact with material. Wash hands thoroughly.
Extreme Temperature	Objects that can burn skin by being too cold or too hot	Boiling liquids, hot plates, dry ice, liquid nitrogen	Use proper protection when handling.	Go to your teacher for first aid.
Sharp Object	Use of tools or glassware that can easily puncture or slice skin	Razor blades, pins, scalpels, pointed tools, dissecting probes, broken glass	Practice common-sense behavior and follow guidelines for use of the tool.	Go to your teacher for first aid.
Fume	Possible danger to respiratory tract from fumes	Ammonia, acetone, nail polish remover, heated sulfur, moth balls	Be sure there is good ventilation. Never smell fumes directly. Wear a mask.	Leave foul area and notify your teacher immediately.
Electrical	Possible danger from electrical shock or burn	Improper grounding, liquid spills, short circuits, exposed wires	Double-check setup with teacher. Check condition of wires and apparatus.	Do not attempt to fix electrical problems. Notify your teacher immediately.
Irritant	Substances that can irritate the skin or mucous membranes of the respiratory tract	Pollen, moth balls, steel wool, fiberglass, potassium permanganate	Wear dust mask and gloves. Practice extra care when handling these materials.	Go to your teacher for first aid.
Chemical	Chemicals that can react with and destroy tissue and other materials	Bleaches such as hydrogen peroxide; acids such as sulfuric acid, hydrochloric acid; bases such as ammonia, sodium hydroxide	Wear goggles, gloves, and an apron	Immediately flush the affected area with water and notify your teacher.
Toxic	Substance may be poisonous if touched, inhaled, or swallowed.	Mercury, many metal compounds, iodine, poinsettia plant parts	Follow your teacher's instructions.	Always wash hands thoroughly after use. Go to your teacher for first aid.
Flammable	Flammable chemicals may be ignited by open flame, spark, or exposed heat.	Alcohol, kerosene, potassium permanganate	Avoid open flames and heat when using flammable chemicals.	Notify your teacher immediately. Use fire safety equipment if applicable.
Open Flame	Open flame in use, may cause fire.	Hair, clothing, paper, synthetic materials	Tie back hair and loose clothing. Follow teacher's instruction on lighting and extinguishing flames.	Notify your teacher immediately. Use fire safety equipment if applicable.

Eye Safety

Proper eye protection should be worn at all times by anyone performing or observing science activities.

Clothing Protection

This symbol appears when substances could stain or burn clothing.

Radioactivity

This symbol appears when radioactive materials are used.

Handwashing

After the lab, wash hands with soap and water before removing goggles.