

PHYSICAL

Science

SIXTH EDITION

Bill W. Tillery

Sixth Edition

Physical Science

Bill W. Tillery

Arizona State University



Higher Education

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PHYSICAL SCIENCE, SIXTH EDITION

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Preface

Physical Science is a straightforward, easy-to-read, but substantial introduction to the fundamental behavior of matter and energy. It is intended to serve the needs of nonscience majors who are required to complete one or more physical science courses. It introduces basic concepts and key ideas while providing opportunities for students to learn reasoning skills and a new way of thinking about their environment. No prior work in science is assumed. The language, as well as the mathematics, is as simple as can be practical for a college-level science course.

Organization

The *Physical Science* sequence of chapters is flexible, and the instructor can determine topic sequence and depth of coverage as needed. The materials are also designed to support a conceptual approach, or a combined conceptual and problem-solving approach. With laboratory studies, the text contains enough material for the instructor to select a sequence for a two-semester course. It can also serve as a text in a one-semester astronomy and earth science course, or in other combinations.

"The text is excellent. I do not think I could have taught the course using any other textbook. I think one reason I really enjoy teaching this course is because of the text. I could say for sure that this is one of the best textbooks I have seen in my career. . . I love this textbook for the following reasons: (1) it is comprehensive, (2) it is very well written, (3) it is easily readable and comprehensible, (4) it has good graphics."

—Ezat Heydari, Jackson State University

Meeting Student Needs

Physical Science is based on two fundamental assumptions arrived at as the result of years of experience and observation from teaching the course: (a) that students taking the course often have very limited background and/or aptitude in the natural sciences; and (b) that this type of student will better grasp the ideas and principles of physical science if they are discussed with minimal use of technical terminology and detail. In addition, it is critical for the student to see relevant applications of the material to everyday life. Most of these everyday-life applications, such as environmental concerns, are not isolated in an arbitrary chapter; they are discussed where they occur naturally throughout the text.



Each chapter presents historical background where appropriate, uses everyday examples in developing concepts, and follows a logical flow of presentation. The historical chronology, of special interest to the humanistically inclined nonscience major, serves to humanize the science being presented. The use of everyday examples appeals to the nonscience major, typically accustomed to reading narration, not scientific technical writing, and also tends to bring relevancy to the material being presented. The logical flow of presentation is helpful to students not accustomed to thinking about relationships between what is being read and previous knowledge learned, a useful skill in understanding the physical sciences. Worked examples help students to integrate concepts and understand the use of relationships called equations. They also serve as a model for problem solving; consequently, special attention is given to *complete* unit work and to the clear, fully expressed use of mathematics. Where appropriate, chapters contain one or more activities, called Concepts Applied, that use everyday materials rather than specialized laboratory equipment. These activities are intended to bring the science concepts closer to the world of the student. The activities are supplemental and can be done as optional student activities or as demonstrations.

"It is more readable than any text I've encountered. This has been my first experience teaching university physical science; I picked up the book and found it very user-friendly. The level of detail is one of this text's greatest strengths. It is well suited for a university course."

—Richard M. Woolheater, Southeastern Oklahoma State University

"The author's goals and practical approach to the subject matter is exactly what we are looking for in a textbook. . . . The practical approach to problem solving is very appropriate for this level of student."

—Martha K. Newchurch, Nicholls State University

"... the book engages minimal use of technical language and scientific detail in presenting ideas. It also uses everyday examples to illustrate a point. This approach bonds with the mindset of the nonscience major who is used to reading prose in relation to daily living."

—Ignatius Okafor, Jarvis Christian College

"I was pleasantly surprised to see that the author has written a textbook that seems well suited to introductory physical science at this level. . . . Physical Science seems to strike a nice balance between the two—avoiding unnecessary complications while still maintaining a rigorous viewpoint. I prefer a textbook that goes beyond what I am able to cover in class, but not too much. Tillery seems to have done a good job here."

—T. G. Heil, University of Georgia

New to This Edition

In general, there has been a concerted effort to make the text even more user-friendly and relevant for students:

- A new "Concepts Applied" feature was added throughout the text, adding applications of relevance for students.
- Where needed, Parallel Exercises were reorganized to make Group A and B exercises more physically, as well as conceptually, congruent.
- Then the Parallel Exercises were selectively "tuned" for the intended audience of nonscience majors by revising and replacing some exercises with new, more conceptual exercises.
- Text materials were made more conceptually oriented and student-friendly throughout.
- The overall size of the text was reduced by two chapters through reorganizing and condensing some of the historical background material.
- Old chapter 2, "Motion," and old chapter 3, "Patterns of Motion," were merged into one new chapter ("Motion") for a more intuitive presentation.
- Old chapter 9, "Atomic Structure," was substantially rewritten and merged with old chapter 10, "Elements and the Periodic Table," into one new chapter ("Atoms and Periodic Properties") with a more student-friendly approach.
- Old chapter 13, "Water and Solutions," (new chapter 11) was substantially rewritten to be more conceptual and relevant to students.

- The astronomy chapters were substantially rewritten to be more intuitive, contain less history, and update factual materials.
- To satisfy requests from current users of the text, new "Closer Look" features were added, for example: Freefall, Simple Machines, The Measurement Process, Doppler Radar, Lasers, Radiation and Food Preservation, Three Mile Island and Chernobyl, Dark Energy, Seismic Tomography, Estuary Pollution, and the Health of the Chesapeake Bay.
- Also to satisfy requests from current users of the text, additional "People Behind the Science" features were added, including biographies on Isaac Newton, Michael Faraday, Erwin Schrödinger, Robert Bunsen, Shirley Ann Jackson, Stephen Hawking, Jocelyn (Susan) Bell Burnell, and Carl Sagan.

The Learning System

Physical Science has an effective combination of innovative learning aids intended to make the student's study of science more effective and enjoyable. This variety of aids is included to help students clearly understand the concepts and principles that serve as the foundation of the physical sciences.

Overview

Chapter 1 provides an *overview* or orientation to what the study of physical science in general, and this text in particular, are all about. It discusses the fundamental methods and techniques used by scientists to study and understand the world around us. It also explains the problem-solving approach used throughout the text so that students can more effectively apply what they have learned.

Chapter Opening Tools

Chapter Outline

The chapter outline includes all the major topic headings and subheadings within the body of the chapter. It gives you a quick glimpse of the chapter's contents and helps you locate sections dealing with particular topics.

Chapter Overview

Each chapter begins with an introductory overview. The overview previews the chapter's contents and what you can expect to learn from reading the chapter. It adds to the general outline of the chapter by introducing you to the concepts to be covered, facilitating in the integration of topics, and helping you to stay focused and organized while reading the chapter for the first time. After reading the introduction, browse through the chapter, paying particular attention to the topic headings and illustrations so that you get a feel for the kinds of ideas included within the chapter.

OUTLINE

Electric Charge
 Electric Theory of Charge
 Electric Charge and Electrical Forces
 Electrostatic Charge
 Electrical Conductors and Insulators
 Measuring Electrical Charge
 Measuring Electrical Forces
 Force Fields
 Electric Potential
 Electric Current
 The Electric Circuit
 The Nature of Current
 Electrical Resistance
 A Closer Look: Household Circuits and Safety
 Electrical Power and Electrical Work
 Magnetism
 Magnetic Poles
 Magnetic Fields
 The Source of Magnetic Fields
 Permanent Magnets
 Earth's Magnetic Field
 Electric Currents and Magnetism
 Current Loops
 Applications of Electromagnets
 Electric Motors
 Electromagnetic Switches
 Transformers and Inductors
 Electromagnetic Induction
 Generators
 Transformers
 A Closer Look: Solar Cells
 People Behind the Science: Michael Faraday (1791–1867)



A thunderstorm produces an interesting display of electrical discharge. Each bolt can carry over 150,000 amperes of current with a voltage of 100 million volts.

CHAPTER

6

Electricity

Examples

Each topic discussed within the chapter contains one or more concrete, worked *Examples* of a problem and its solution as it applies to the topic at hand. Through careful study of these examples, students can better appreciate the many uses of problem solving in the physical sciences.

"I feel this book is written well for our average student. The images correlate well with the text, and the math problems make excellent use of the dimensional analysis method. While it was a toss-up between this book and another one, now that we've taught from the book for the last year, we are extremely happy with it."

—Alan Earhart, Three Rivers Community College

The previous chapters have been concerned with mechanical concepts, explanations of the motion of objects that exert forces on one another. These concepts were used to explain straight-line motion, the motion of free fall, and the circular motion of objects on the earth as well as the circular motion of planets and satellites. The mechanical concepts were based on Newton's laws of motion and are sometimes referred to as Newtonian physics. The mechanical explanations were then extended into the submicroscopic world of matter through the kinetic molecular theory. The objects of motion were now particles, molecules that exert force on one another, and concepts associated with heat were interpreted as the motion of these particles. In a further extension of Newtonian concepts, mechanical explanations were given for concepts associated with sound, a mechanical disturbance that follows the laws of motion as it moves through the molecules of matter.

You might wonder, as did the scientists of the 1800s, if mechanical interpretations would also explain other natural phenomena such as electricity, chemical reactions, and light. A mechanical model would be very attractive because it already explained so many other facts of nature, and scientists have always looked for basic, unifying theories. Mechanical interpretations were tried, as electricity was considered a moving fluid, and light was considered a mechanical wave moving through a material fluid. There were many unsolved puzzles with such a model, and gradually it was recognized that electricity, light, and chemical reactions could not be explained by mechanical interpretations. Gradually, the point of view changed from a study of particles to a study of the properties of the space around the particles. In this chapter you will learn about electric charge in terms of the space around particles. This model of electric charge, called the *field model*, will be used to develop concepts about electric current, the electric circuit, and electrical work and power. A relationship between electricity and the fascinating topic of magnetism is discussed next, including what magnetism is and how it is produced. The relationship is then used to explain the mechanical production of electricity (Figure 6.1), how electricity is measured, and how electricity is used in everyday technological applications.

Electric Charge

You are familiar with the use of electricity in many electrical devices such as lights, toasters, radios, and calculators. You are also aware that electricity is used for transportation and for heating and cooling places where you work and live. Many people accept electrical devices as part of their surroundings, with only a hazy notion of how they work. To many people electricity seems to be magical. Electricity is not magical, and it can be understood, just as we understand any other natural phenomenon. There are theories that explain observations, quantities that can be measured, and relationships between these quantities, or laws, that lead to understanding. All of the observations, measurements, and laws begin with an understanding of *electric charge*.

Electron Theory of Charge

It was a big mystery for thousands of years. No one could figure out why a rubbed piece of amber, which is fossilized tree resin, would attract small pieces of paper, thread, and hair. This unexplained attraction was called the "amber effect." Then about one hundred years ago, Joseph J. Thomson found the answer while experimenting with electric currents. From these experiments, Thomson was able to conclude that negatively charged particles were present in all matter, and in fact might be the stuff of which matter is made.

The amber effect was traced to the movement of these particles, so they were called *electrons* after the Greek word for amber. The word *electricity* is also based on the Greek word for amber.

Today, we understand that the basic unit of matter is the *atom*, which is made up of electrons and other particles such as *protons* and *neutrons*. The atom is considered to have a dense center part called a *nucleus* that contains the closely situated protons and neutrons. The electrons move around the nucleus at some relatively greater distance (Figure 6.2). Details on the nature of protons, neutrons, electrons, and models of how the atom is constructed will be considered in chapter 8. For understanding electricity, you need only consider the protons in the nucleus, the electrons that move around the nucleus, and the fact that electrons can be moved from an atom and cause to move to or from one object to another. Basically, the electrical, light, and chemical phenomena involve the *electrons* and not the more massive nucleus. The massive nuclei remain in a relatively fixed position in a solid, but some of the electrons can move about from atom to atom.

Electric Charge and Electrical Forces

Electrons and protons have a property called *electric charge*. Electrons have a *negative electric charge* and protons have a *positive electric charge*. The negative or positive description simply means that these two properties are opposite; it does not mean that one is better than the other. Charge is as fundamental to

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A Closer Look

Above It All

The super-speed magnetic levitation (maglev) train is a completely new technology based on magnetic repulsion. It is a train that travels along a magnetic field that travels along the monorail guides. The maglev train does not have friction between wheels and the rails since it

does not have wheels. This lack of resistance at the early manipulated magnetic fields makes very short acceleration distances possible. For example, a German maglev train can accelerate from 0 to 300 km/h (about 185 mi/h) over a distance of just 5 km (about 3 mi). A conventional train with wheels requires about 30 km (about 19 mi)

to reach the same speed from a standing start. The maglev is attractive for short runs because of its superior acceleration and braking abilities. It is also attractive for longer runs because of its high top speed—up to about 500 km/h (about 310 mi/h). Today, only an aircraft can match such a speed.

EXAMPLE 2.3

A bicycle moves from rest to 5 m/s in 5 s. What was the acceleration?

Solution

$$\begin{aligned} v_i &= 0 \text{ m/s} \\ v_f &= 5 \text{ m/s} \\ t &= 5 \text{ s} \\ a &= ? \\ a &= \frac{v_f - v_i}{t} \\ &= \frac{5 \text{ m/s} - 0 \text{ m/s}}{5 \text{ s}} \\ &= \frac{5 \text{ m/s}}{5 \text{ s}} \\ &= 1 \left(\frac{\text{m}}{\text{s}} \right) \left(\frac{1}{\text{s}} \right) \\ &= 1 \frac{\text{m}}{\text{s}^2} \end{aligned}$$

EXAMPLE 2.4

An automobile uniformly accelerates from rest at 15 ft/s² for 6 s. What is the final velocity in ft/s? (Answer: 90 ft/s)

So far, you have learned only about straight-line, uniform acceleration that results in an increased velocity. There are also other changes in the motion of an object that are associated with acceleration. One of the more obvious is a change that results in a decreased velocity. Your car's brakes, for example, can slow your car or bring it to a complete stop. This is *negative acceleration*, which is sometimes called *deceleration*. Another change in the motion of an object is a change of direction. Velocity encompasses both the rate of motion and direction, so

a change of direction is an acceleration. The satellite moving with a constant speed in a circular orbit around the earth is constantly changing its direction of movement. It is therefore constantly accelerating because of this constant change in its motion. Your automobile has three devices that could change the state of its motion. Your automobile therefore has three accelerations—the gas pedal (which can increase magnitude of velocity), the brakes (which can decrease magnitude of velocity), and the steering wheel (which can change direction of velocity). (See Figure 2.6.) The important thing to remember is that acceleration results from any change in the motion of an object.

The final velocity (v_f) and the initial velocity (v_i) are different variables than the average velocity (\bar{v}). You cannot use an initial or final velocity for an average velocity. You may, however, calculate an average velocity (\bar{v}) from the other two variables as long as the acceleration taking place between the initial and final velocities is uniform. An example of such a uniform change would be an automobile during a constant, straight-line acceleration. To find an average velocity during a uniform

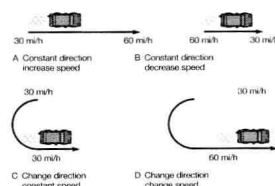


FIGURE 2.6 Four different ways (A–D) to accelerate a car.

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Chapter Two: Motion

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Applying Science to the Real World

Concepts Applied

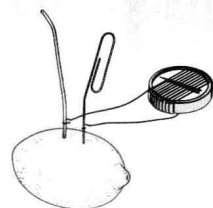
Each chapter also includes one or more *Concepts Applied* boxes. These activities are simple investigative exercises that students can perform at home or in the classroom to demonstrate important concepts and reinforce understanding of them. This feature also describes the application of those concepts to everyday life.

certain modifications and applications, the galvanometer can be used to measure current (ammeter), potential difference (voltmeter), and resistance (ohmmeter).

Concepts Applied

Lemon Battery

1. You can make a simple compass galvanometer that will detect a small electric current (Box Figure 6.2). All you need is a magnetic compass and some thin insulated wire (the thinner the better).
2. Wrap the thin insulated wire in parallel windings around the compass. Make as many parallel windings as you can, but leave enough room to see both ends of the compass needle. Leave the wire ends free for connections.
3. To use the galvanometer, first turn the compass so the needle is parallel to the wire windings. When a current passes through the coil of wire the magnetic field produced will cause the needle to move from its north-south position, showing the presence of a current. The needle will deflect one way or the other depending on the direction of the current.
4. Test your galvanometer with a "lemon battery." Roll a soft lemon on a table while pressing on it with the palm of your hand. Cut two slits in the lemon about 1 cm apart. Insert a 8-cm (approximate) copper wire in one slit and a same-sized length of a straightened paperclip in the other slit, making



BOX FIGURE 6.2
You can use the materials shown here to create and detect an electric current.

sure the metals do not touch inside the lemon. Connect the galvanometer to the two metals. Try the two metals in other fruits, vegetables, and liquids. Can you find a pattern?

Electromagnetic Switches

A relay is an electromagnetic switch device that makes possible the use of a low-voltage control current to switch a larger, high-voltage circuit on and off (Figure 6.29). A thermostat, for example, utilizes two thin, low-voltage wires in a glass tube of mercury. The glass tube of mercury is attached to a metal coil that expands and contracts with changes in temperature, tipping the attached glass tube. When the temperature changes enough to tip the glass tube, the mercury flows to the bottom end, which makes or breaks contact with the two wires, closing or opening the circuit. When contact is made, a weak current activates an electromagnetic switch, which closes the circuit on the large-current furnace or heat pump motor.

A solenoid is a coil of wire with a current. Some solenoids have a spring-loaded movable piece of iron inside. When a current flows in such a coil the iron is pulled into the coil by the magnetic field, and the spring returns the iron when the current is turned off. This device could be utilized to open a water valve, turning the hot or cold water on in a washing machine or dishwasher, for example. Solenoids are also used as mechanical switches on VCRs, automobile starters, and signaling devices such as bells and buzzers. The dot matrix computer printer works with a group of small solenoids that are activated by

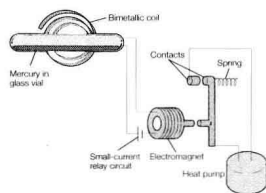


FIGURE 6.29
A schematic of a relay circuit. The mercury vial turns as changes in temperature expand or contract the coil, moving the mercury and making or breaking contact with the relay circuit. When the mercury moves to close the relay circuit, a small current activates the electromagnet, which closes the contacts on the large-current circuit.

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A Closer Look

Ultrasonics

Ultrasonic waves are mechanical waves that have frequencies above the normal limit of hearing of the human ear. The arbitrary upper limit is about 20,000 Hz, so an ultrasonic wave has a frequency of 20,000 Hz or greater. Intense ultrasonic waves are used in many ways in industry and medicine.

Industrial and commercial applications of ultrasound utilize lower-frequency ultrasonic waves in the 20,000 to 40,000 Hz range. Commercial devices that send ultrasound through the air include burglar alarms and rodent repellents. An ultrasonic burglar alarm sends ultrasonic spherical waves through the air of a room. The device is adjusted to ignore echoes from the contents of the room. The presence of a person provides a new source of echoes, which activates the alarm. Rodents emit ultrasonic frequencies up to 150,000 Hz that are used in rodent communication when they are disturbed or during aggressive behavior. The ultrasonic rodent repeller generates ultrasonic waves of similar frequency. Other commercial applications of ultrasound include sonar and depth measurements, cleaning and drilling, welding plastics and metals, and material flow detection. Ultrasonic cleaning baths are used to remove dirt and foreign matter from solid surfaces, usually

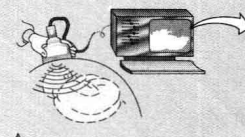
within a liquid solvent. The ultrasonic waves create vapor bubbles in the liquid, which vibrate and emit audible and ultrasonic sound waves. The audible frequencies are often heard as a hissing or frying sound.

Medical applications of ultrasound use frequencies in the 1,000,000 to 20,000,000 Hz range. Ultrasound in this frequency range cannot move through the air because the required displacement amplitudes of the gas molecules in the air are less than the average distance between the molecules. Thus, a gas molecule that is set into motion in this frequency range cannot collide with other gas molecules to transmit the energy of the wave. Intense ultrasound is used for cleaning teeth and disrupting kidney stones. Less intense ultrasound is used for therapy (heating and reduction of pain). The least intense ultrasounds are used for diagnostic imaging. The largest source of exposure of humans to ultrasound is for the purpose of ultrasonic diagnostic imaging, particularly in fertility and pregnancy cases (Box Figure 5.1).

Originally developed in the late 1950s, ultrasonic medical machines have been improved and today make images of outstanding detail and clarity. One type of ultrasonic medical machine uses a transducer probe, which emits an ultrasonic pulse that passes

into the body. Echoes from the internal tissues and organs are reflected back to the transducer, which sends the signals to a computer. Another pulse of ultrasound is then sent out after the echoes from the first pulse have returned. The strength of and number of pulses per second vary with the application, ranging from hundreds to thousands of pulses per second. The computer constructs a picture from the returning echoes, showing an internal view without the use of more dangerous X rays.

Ultrasonic scanners have been refined to the point that the surface of the ovaries can now be viewed, showing the number and placement of developing eggs. The ovary scan is typically used in conjunction with fertility-stimulating drugs, where multiple births are possible, and to identify the exact time of ovulation. As early as four weeks after conception, the ultrasonic scanner is used to identify and monitor the fetus. By the thirteenth week, an ultrasonic scan can show the fetal heart movement, bone and skull size, and internal organs. The ultrasonic scanner is often used to show the position of the fetus and placenta for the purpose of amniocentesis, which involves withdrawing a sample of amniotic fluid from the uterus for testing.



BOX FIGURE 5.1
(A) Physicians can "see" a baby inside its mother's body by using the handheld external probe of an ultrasonic imaging system. (B) An ultrasonic image of 10-week old human twins inside the mother's body.

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People Behind the Science

Many chapters also have one or two fascinating biographies that spotlight well-known scientists, past or present. From these *People Behind the Science* biographies, students learn about the human side of the science: physical science is indeed relevant, and real people do the research and make the discoveries. These readings present physical science in real-life terms that students can identify with and understand.

People Behind the Science

Shirley Ann Jackson (1946–)

Shirley Ann Jackson was born in Washington, D.C., in 1946. She received her B.S. from Massachusetts Institute of Technology in 1968 and her Ph.D. (Physics) in 1973. Shirley Jackson became the first African American female to receive a doctorate in Theoretical Solid State physics from MIT. Dr. Jackson became a Research Associate in Theoretical Physics at the Fermi National Accelerator Laboratory from 1973–1974 and served as a Visiting Science Associate at the European Organization for Nuclear Research (1974–1975). In 1975–1976 she returned to Fermi National Accelerator Laboratory as a Research Associate in Theoretical Physics. She spent 1976–1977 at the Stanford Linear Accelerator Center and Aspen Center for Physics. Dr. Jackson then served on the Technical Staff of Bell Telephone Laboratories in the

oretical physics from 1976 until 1978. In 1978 she began working with the Technical Staff of the Scattering and Low Energy Physics Research Laboratory of Bell Telephone Laboratories. From 1979 to 1991 Dr. Jackson was appointed as Professor of Physics at Rutgers University in Piscataway, N.J. From 1991 to 1995 she served, concurrently with her professorship at Rutgers, as a consultant in semiconductor theory to AT&T Bell Laboratories in Murray Hill, N.J. Dr. Jackson was appointed as Commissioner of the Nuclear Regulatory Commission and assumed the Chairmanship on May 2, 1995.

Her research has focused on Landau theories of charge density waves in one- and two-dimensions. Dr. Jackson's research also touched on two-dimensional Yang-Mills gauge theories and neutrino reactions.

"I am interested in the electronic, optical, magnetic, and transport properties of novel semiconductor systems. Of special interest is the behavior of magnetic polarons in semimagnetic and dilute magnetic semiconductors, and the optical response properties of semiconductor quantum wells and superlattices. My interests also include quantum dots, mesoscopic systems, and the role of nanoscale fluctuations in correlated 2D electron systems."

—Professor Shirley Jackson

The Honorable Dr. Shirley Ann Jackson, chairman of the U.S. Nuclear Regulatory Commission, was also named the 18th president of Rensselaer Polytechnic Institute on July 1, 1999.

Source: Mitchell C. Brown, *The Faces of Science: African Americans in the Sciences*.

"The People Behind the Science features help relate the history of science and the contributions of the various individuals."

—Richard M. Woolheater, Southeastern Oklahoma State University

End-of-Chapter Features

At the end of each chapter, students will find the following materials:

- **Summary:** highlights the key elements of the chapter.
- **Summary of Equations** (chapters 1–13): reinforces retention of the equations presented.
- **Key Terms:** gives page references for finding the terms defined within the context of the chapter reading.
- **Applying the Concepts:** tests comprehension of the material covered with a multiple-choice quiz.
- **Questions for Thought:** challenges students to demonstrate their understanding of the topics.
- **Parallel Exercises** (chapters 1–13): reinforces problem-solving skills. There are two groups of parallel exercises, Group A and Group B. The Group A parallel exercises have complete solutions worked out, along with useful comments, in appendix D. The Group B parallel exercises are similar to those in Group A but do not contain answers in the text. By working through the Group A parallel exercises and checking the solutions in appendix D, students will gain confidence in tackling the parallel exercises in Group B, and thus reinforce their problem-solving skills.

“I like this [Summary of Equations] feature. It collects the equations together for easy reference. . . . I also like this [Key Terms] feature. It is well organized, thorough and gives the student a tool for review. The instructor can also use it for a checklist of topics. . . . The end-of-chapter features of Summary of Equations and Key Terms make the chapters very user-friendly.”

—Richard M. Woolheater, Southeastern Oklahoma State University

“The Parallel Exercises and the explanation in the appendix, the readability of the material, and the depth of coverage are the strongest features of this text.”

—Martha K. Newchurch, Nicholls State University

“The provision of solutions to a set of problems as a guide for solving identical problems on an adjacent set is an ingenious learning tool.”

—Ignatius Okafor, Jarvis Christian College

End-of-Text Materials

Appendices providing math review, additional background detail, solubility and humidity charts, and solutions for the Group A Parallel Exercises can be found at the back of the text. There is also a glossary of all key terms, an index, and special tables printed on the inside covers for reference use.

Summary

Electromagnetic radiation is emitted from all matter with a temperature above absolute zero, and as the temperature increases, more radiation and shorter wavelengths are emitted. Visible light is emitted from matter hotter than about 700°C, and this matter is said to be incandescent. The sun, a fire, and the ordinary lightbulb are incandescent sources of light.

The behavior of light is shown by a light ray model that uses straight lines to show the straight-line path of light. Light that interacts with matter is reflected with parallel rays, moves in random directions by *diffuse reflection* from points, or is *absorbed*, resulting in a temperature increase. Matter is *opaque*, reflecting light, or *transparent*, transmitting light.

In reflection, the incoming light, or *incident ray*, has the same angle as the *reflected ray* when measured from a perpendicular from the point of reflection, called the *normal*. That the two angles are equal is called the *law of reflection*. The law of reflection explains how a flat mirror forms a *virtual image*, one from which light rays do not originate. Light rays do originate from the other kind of image, a *real image*.

Light rays are bent, or *refracted*, at the boundary when passing from one transparent medium to another. The amount of refraction depends on the *incident angle* and the *index of refraction*, a ratio of the speed of light in a vacuum to the speed of light in the medium. When the refracted angle is 90°, *total internal reflection* takes place. This limit to the angle of incidence is called the *critical angle*, and all light rays with an incident angle at or beyond this angle are reflected internally.

Each color of light has a range of wavelengths that forms the spectrum from red to violet. A glass prism has the property of *dispersion*, separating a beam of white light into a spectrum. Dispersion occurs because the index of refraction is different for each range of colors, with short wavelengths refracted more than larger ones.

A wave model of light can be used to explain interference and polarization. *Interference* occurs when light passes through two small slits or holes and produces an *interference pattern* of bright lines and dark zones. *Polarized light* vibrates in one direction only, in a plane. Light can be polarized by certain materials, by reflection, or by scattering. Polarization can only be explained by a transverse wave model.

A wave model fails to explain observations of light behaviors in the photoelectric effect and blackbody radiation. Max Planck found that he could modify the wave theory to explain blackbody radiation by assuming that vibrating molecules could only have discrete amounts, or quanta, of energy and found that the quantized energy is related to the frequency and a constant known today as *Planck's constant*. Albert Einstein applied Planck's quantum concept to the photoelectric effect and described a light wave in terms of quanta of energy called photons. Each photon has an energy that is related to the frequency and Planck's constant.

Today, the properties of light are explained by a model that incorporates both the wave and the particle nature of light. Light is considered to have both wave and particle properties and is not describable in terms of anything known in the everyday-sized world.

Summary of Equations

7.1

angle of incidence = angle of reflection

$$\theta_i = \theta_r$$

7.2

$$\text{index of refraction} = \frac{\text{speed of light in vacuum}}{\text{speed of light in material}}$$
$$n = \frac{c}{v}$$

7.3

$$\text{speed of light in vacuum} = (\text{wavelength})(\text{frequency})$$

7.4

$$\text{energy of photon} = \left(\text{Planck's constant} \right) (\text{frequency})$$
$$E = hf$$

KEY TERMS

blackbody radiation (p. 180)	polarized (p. 194)
incandescent (p. 180)	quanta (p. 186)
index of refraction (p. 187)	real image (p. 201)
interference (p. 191)	refraction (p. 201)
light ray model (p. 182)	total internal reflection (p. 186)
luminous (p. 180)	unpolarized light (p. 194)
photoelectric effect (p. 195)	virtual image (p. 185)
photons (p. 196)	

APPLYING THE CONCEPTS

1. A luminous object is an object that
a. reflects a dim blue-green light in the dark.
b. produces light of its own by any method.
c. shines by reflected light only, such as the moon.
d. an object that glows only in the absence of light.
2. An object is hot enough to emit a dull red glow. When this object is heated even more, it will
a. emit shorter wavelength, higher-frequency radiation.
b. emit longer wavelength, lower-frequency radiation.
c. emit the same wavelengths as before, but with more energy.
d. emit more of the same wavelengths with more energy.
3. The difference in the light emitted from a candle, an incandescent lightbulb, and the sun is basically from differences in
a. energy sources.
b. materials.
c. temperatures.
d. phases of matter.

7.25

Chapter Review Light 201

Appendix A Mathematical Review

Working with Equations

Many of the problems of science involve an equation, a shorthand way of describing patterns and relationships that are observed in nature. Equations are also used to identify properties and to define certain concepts, but all uses have well-established meanings, symbols that are used by convention, and allowed mathematical operations. This appendix will assist you in better understanding equations and the reasoning that goes with the manipulation of equations in problem-solving activities.

Background

In addition to a knowledge of rules for carrying out mathematical operations, an understanding of certain quantitative ideas and concepts can be very helpful when working with equations. Among these helpful concepts are (1) the meaning of inverse and reciprocal, (2) the concept of a ratio, and (3) fractions.

The term *inverse* means the opposite, or reverse, of something. For example, addition is the opposite, or inverse, of subtraction, and division is the inverse of multiplication. A *reciprocal* is defined as an inverse multiplication relationship between two numbers. For example, if the symbol n represents any number (except zero), then the reciprocal of n is $1/n$. The reciprocal of a number $(1/n)$ multiplied by that number (n) always gives a product of 1. Thus, the number multiplied by 5 to give 1 is $1/5$: $5 \times 1/5 = 5/5 = 1$. So $1/5$ is the reciprocal of 5, and 5 is the reciprocal of $1/5$. Each number is the *inverse* of the other.

The fraction $1/5$ means 1 divided by 5, and if you carry out the division it gives the decimal 0.2. Calculators that have a $1/x$ key will do the operation automatically. If you enter 5, then press the $1/x$ key, the answer of 0.2 is given. If you press the $1/x$ key again, the answer of 5 is given. Each of these numbers is a reciprocal of the other.

A *ratio* is a comparison between two numbers. If the symbols m and n are used to represent any two numbers, then the ratio of the number m to the number n is the fraction m/n . This expression means to divide m by n . For example, if m is 10 and n is 5, the ratio of 10 to 5 is $10/5$, or 2:1.

Working with *fractions* is sometimes necessary in problem-solving exercises, and an understanding of these operations is needed to carry out unit calculations. It is helpful in many of

these operations to remember that a number (or a unit) divided by itself is equal to 1, for example,

$$\frac{5}{5} = 1 \quad \frac{\text{inch}}{\text{inch}} = 1 \quad \frac{5 \text{ inches}}{5 \text{ inches}} = 1$$

When one fraction is divided by another fraction, the operation commonly applied is to “invert the denominator and multiply.” For example, $2/5$ divided by $1/2$ is

$$\frac{2}{5} \div \frac{1}{2} = \frac{2}{5} \times \frac{2}{1} = \frac{4}{5}$$

What you are really doing when you invert the denominator of the larger fraction and multiply is making the denominator (1/2) equal to 1. Both the numerator (2/5) and the denominator (1/2) are multiplied by 2/1, which does not change the value of the overall expression. The complete operation is

$$\frac{2}{5} \div \frac{1}{2} = \frac{2}{5} \times \frac{2}{1} = \frac{4}{5}$$

Symbols and Operations

The use of symbols seems to cause confusion for some students because it seems different from their ordinary experiences with arithmetic. The rules are the same for symbols as they are for numbers, but you cannot do the operations with the symbols until you know what values they represent. The operation signs, such as $+$, $-$, \times , and \div are used with symbols to indicate the operation that you would do if you knew the values. Some of the mathematical operations are indicated several ways. For example, $a \times b$, $a \cdot b$, and ab all indicate the same thing, that a is to be multiplied by b . Likewise, $a \div b$, a/b , and $a \cdot 1/b$ all indicate that a is to be divided by b . Since it is not possible to carry out the operations on symbols alone, they are called *indicated operations*.

Operations in Equations

An equation is a shorthand way of expressing a simple sentence with symbols. The equation has three parts: (1) a left side, (2) an equal sign ($=$), which indicates the equivalence of

A-1

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Supplements

Physical Science is accompanied by a variety of multimedia supplementary materials, including an interactive website; an Instructor's Testing and Resource CD-ROM, with testing software containing multiple-choice test items for the text and other teacher resources; and a Digital Content Manager CD-ROM, with digital images from the text. The supplement package also contains more traditional supplements: a laboratory manual and overhead transparencies.

Multimedia Supplementary Materials

Online Learning Center

A text-specific website, our *Physical Science* Online Learning Center, offering unlimited resources for both the student and instructor, can be found at: www.mhhe.com/tillery/. By way of this website, students and instructors will be better able to quickly incorporate the Internet into their classrooms. This interactive resource is packaged free with any new textbook.

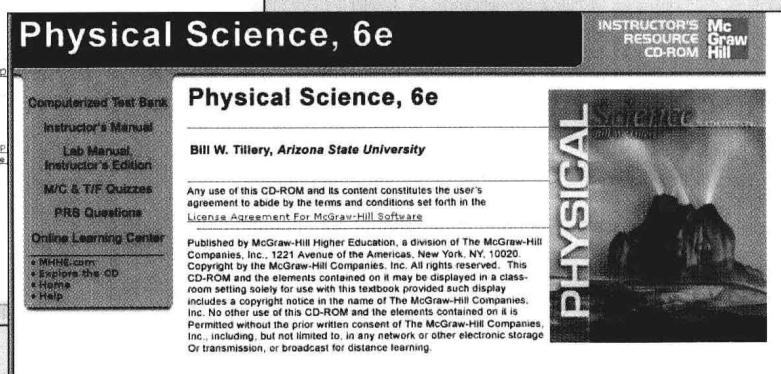
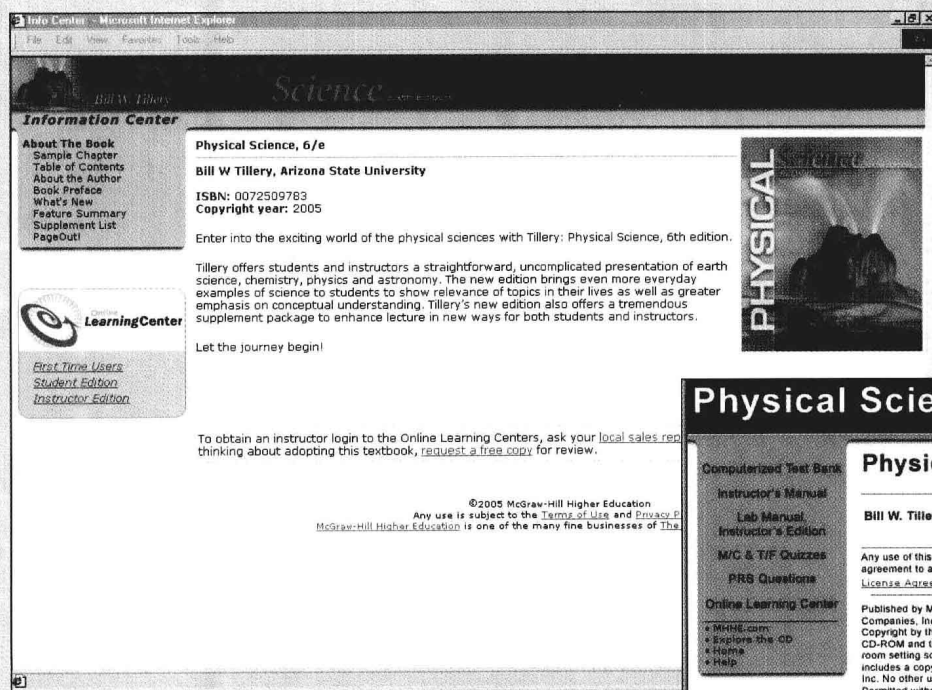
Student Edition of the Online Learning Center. The *Physical Science, Sixth Edition* Online Learning Center has book-specific study aids organized by chapter. Each chapter includes animations modeling key concepts discussed in the book; interactive questions and problems, such as self-test quizzes and crossword puzzles, flashcards, and matching exercises using key terms and glossary definitions; chapter resources; and web-linked resources. Also included are Exploring Physical Science articles, which expose students to a different viewpoint on a topic or a new research project, as well as links to McGraw-Hill's Access Science and PowerWeb sites, which provide additional research resources.

Instructor's Edition of the Online Learning Center. For instructors, there is an image bank containing the images from the text, PowerPoint lectures, a bank of personal response system questions, the *instructor's manual*, the *instructor's edition of the laboratory manual*, clip art, a database of equations, and much more. From the student edition, instructors can access questions and problems from the text and additional Closer Look questions with e-mail boxes for gradable responses from students.

The *instructor's manual*, also written by the text author, is housed on the Online Learning Center and provides a chapter outline, an introduction/summary of each chapter, suggestions for discussion and demonstrations, multiple-choice questions (with answers) that can be used as resources for cooperative teaching, and answers and solutions to all end-of-chapter questions and exercises not provided in the text.

Instructor's Testing and Resource CD-ROM

The **Instructor's Testing and Resource CD-ROM** contains the *Physical Science* test bank (test questions in a combination of true/false and multiple-choice formats) within the Brownstone DIPLOMA® test generator. The Brownstone software includes a test generator, an online testing program, Internet testing, and a grade management system. This user-friendly software's testing capability is consistently ranked number one in evaluations over other products. Also located on the Instructor's Testing and Resources CD-ROM are Word and PDF files of the test bank, the instructor's manual, instructor's edition of the laboratory manual, the bank of personal response system questions, and the quizzes from the Online Learning Center. Any of these Word files can be used in combination with the Brownstone software or independently.

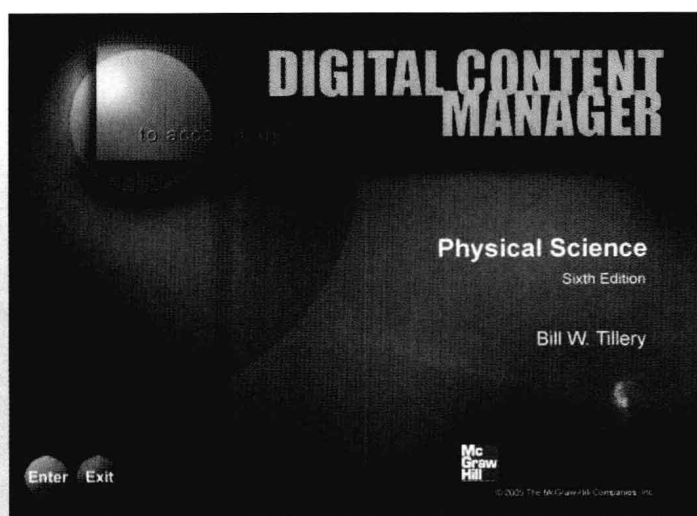


Digital Content Manager CD-ROM

The **Digital Content Manager** contains JPEG files of the four-color illustrations, photos, and tables from the text as well as a collection of animations and video clips. The CD also contains a PowerPoint presentation of the text images and another lecture PowerPoint presentation. These digital assets are contained on a cross-platform CD-ROM and are grouped by chapter within a user-friendly interface. With the help of these valuable resources, instructors can create customized classroom presentations, visually based tests and quizzes, dynamic course website content, and attractive printed support materials.

"I find Physical Science to be superior to either of the texts that I have used to date. . . . The animations and illustrations are better than those of other textbooks that I have seen, more realistic and less trivial."

—T. G. Heil, University of Georgia



Printed Supplementary Material

Laboratory Manual

The *laboratory manual*, written and classroom tested by the author, presents a selection of laboratory exercises specifically written for the interests and abilities of nonscience majors. There are laboratory exercises that require measurement, data analysis, and thinking in a more structured learning environment. Alternative exercises that are open-ended "Invitations to Inquiry" are provided for instructors who would like a less structured approach. When the laboratory manual is used with *Physical Science*, students will have an opportunity to master basic scientific principles and concepts, learn new problem-solving and thinking skills, and understand the nature of scientific inquiry from the perspective of hands-on experiences. The *instructor's edition of the laboratory manual* can be found on the *Physical Science Online Learning Center*.

Overhead Transparencies

A set of over 100 full-color transparencies features images from the text. The images have been modified to ensure maximum readability in both small and large classroom settings.

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William Brown Montgomery College
Steven Carey Mobile College
Darry S. Carlston University of Central Oklahoma
Stan Celestian Glendale Community College
Randel Cox Arkansas State University
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Keith B. Daniels University of Wisconsin–Eau Claire
Valentina David Bethune-Cookman College
Carl G. Davis Danville Area Community College
Joe D. DeLay Freed-Hardeman University
Renee D. Diehl Pennsylvania State University
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Steven S. Funck Harrisburg Area Community College
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Meet the Author

Bill W. Tillery

Bill W. Tillery is a professor in the Department of Physics and Astronomy at Arizona State University, where he has been a member of the faculty since 1973. He earned a bachelor's degree at Northeastern State University (1960), and master's and doctorate degrees from the University of Northern Colorado (1967). Before moving to Arizona State University, he served as director of the Science and Mathematics Teaching Center at the University of Wyoming (1969–73) and as an assistant professor at Florida State University (1967–69). Bill has served on numerous councils, boards, and committees and was honored as the “Outstanding University Educator” at the University of Wyoming in 1972. He was elected the “Outstanding Teacher” in the Department of Physics and Astronomy at Arizona State University in 1995.

During his time at Arizona State, Bill has taught a variety of courses, including general education courses in science and society, physical science, and introduction to physics. He has received more than 40 grants from the National Science Foundation, the U.S. Office of Education, from private industry (Arizona Public Service), and private foundations (The Flinn Foundation) for science curriculum development and science teacher inservice training. In addition to teaching and grant work, Bill has authored or coauthored more than 60 textbooks and many monographs, and has served as editor of three separate newsletters and journals between 1977 and 1996.

Bill also maintains a website dedicated to providing resources for science teachers. This site is named The Science Education Resource Page (SERP) and is funded by a grant from the Flinn Foundation. The URL is <http://serp.la.asu.edu>.

Bill has attempted to present an interesting, helpful program that will be useful to both students and instructors. Comments and suggestions about how to do a better job of reaching this goal are welcome. Any comments about the text or other parts of the program should be addressed to:

Bill W. Tillery
 Department of Physics and Astronomy
 Arizona State University
 PO Box 871504
 Tempe, AZ 85287-1504 USA
 Or (preferred) e-mail: bill.tillery@asu.edu

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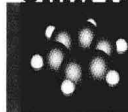
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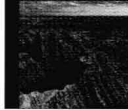
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