

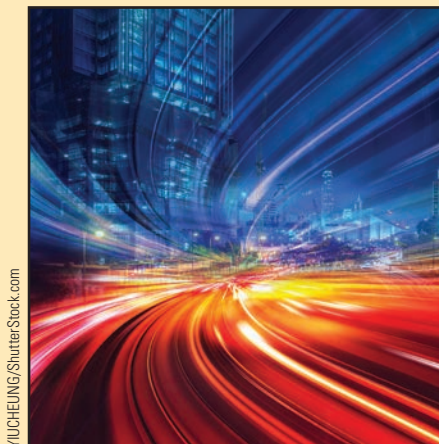
Fifteenth Edition

AN INTRODUCTION TO

Physical Science

SHIPMAN • WILSON • HIGGINS • LOU

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AN INTRODUCTION TO

Physical Science

Fifteenth Edition

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Fifteenth Edition

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Preface

Science and technology are the driving forces of change in our world today. They revolutionize all aspects of our lives, including communication, transportation, medical care, the environment, politics, and education. To understand and fully participate in this transformation, it is important that today's students advance their knowledge of science. In addition to increasing their understanding of the principles of science, it is imperative that students know how science is truly conducted, and when, where, and to what science is applied. Equipped with this knowledge, they can better adapt to their environment and make informed decisions that ultimately affect their lives and the lives of others.

Approach

An Introduction to Physical Science (IPS) had its beginnings in the late 1960s for a course at Ohio University. Science was a popular offering at the time with the excitement of the first mission to the Moon. James T. Shipman wrote a physics section, which was quickly followed by sections of the other physical sciences. Published locally at first, the textbook was picked up and published nationally in 1971. It flourished and went on for subsequent editions. In 2009, IPS won the McGuffey Longevity Award from Textbook & Academic Authors Association. The award recognizes a textbook whose excellence has been demonstrated over time, must have been in print at least 15 years, and still be selling. That was for the Eleventh Edition, and now we present a Fifteenth Edition.

What makes IPS such a long running textbook? Over the years there have been many changes and developments in science, and IPS has addressed these by keeping current and up-to-date. Our motivation to present advancements in science is driven by the interests of the students taking this course. Student interest is often overshadowed by the belief that the study of science should focus exclusively on technical skills and understanding. To counter this, IPS uses a predominately conceptual approach with descriptions and examples that students will understand and find relevant to their life and education.

In keeping with this approach, we added a new feature to the Fifteenth Edition, *Physical Science Today*. These articles showcase current technologies and applications, some of which have important biological and medical uses. Take a look at these in the list given on the next page. Also below is our approach to mathematics so that students always have a reference for the math they'll be solving. Only basic high school math is needed for this course. Worked out Exercises are given. Also new to the Fifteenth Edition is a *Thinking It Through* section that has been added to each exercise prior to the answer to show the student the thought process for solution. Our hope is these new features, along with the hallmarks of fourteen previous editions, will make your course a learning and rewarding experience.

One of the outstanding features of this textbook continues to be its emphasis on fundamental concepts. We build on these concepts as we progress through the chapters. For example, Chapter 1, which introduces the concepts of measurement, is followed by chapters on the basic topics of physics: motion, force, energy, heat, wave motion, electricity and magnetism, atomic physics, and nuclear physics. This foundation in physics is useful in developing the principles of chemistry, astronomy, meteorology, and geology in the chapters that follow. We hope that this will lead to more students choosing careers in the sciences, engineering, and mathematics.

Evolving from previous editions of *An Introduction to Physical Science*, the goal of the new Fifteenth Edition is to present the physical sciences in a way that promotes an active learning approach. IPS aims to inspire curiosity, involve students in every step of the learning process and improve their overall science literacy. The text's real-world emphasis along with scaffolded pedagogy are further enhanced in this Fifteenth Edition by a new active learning digital workbook in WebAssign®, Cengage's online learning

platform. The Digital Workbook lessons will expose students to in-depth, comprehensive activities with rich targeted feedback that will help them build a conceptual and practical mastery of key ideas in physical science. It provides a new source of contextual support for students and teachers, and provides an auxiliary study guide for when assessment time comes around.

To address the need for critical reasoning and problem-solving skills in an ever-changing technological world, we emphasize fundamental concepts in the five divisions of physical sciences: physics, chemistry, astronomy, meteorology, and geology. Topics are treated both descriptively and quantitatively, in a fashion ideal for nonscience majors, providing instructors with greater flexibility in teaching. Concepts are thoroughly introduced and are followed with quantitative examples. Features like *Highlights* and *Physical Science Today* provide extended information on applied sciences. Consistent with prior editions, the end-of-chapter section has dozens of questions for review in various forms. We hope that instructors find the textbook up-to-date, with clear, concise, and classical treatment of the physical sciences. As instructors, you have great flexibility in emphasizing certain topics for a one-semester course or using the full set of topics for a two-semester course.

Organizational Updates and Key Features in the Fifteenth Edition

Physical Science Today (PST)—These descriptions link important concepts in physical science to current technologies and applications of current interest. Some are important biological and medical applications. These include:

- Chapter 1: What's Your Body Density? Try BMI
- Chapter 2: Rotating Tablet Screens
- Chapter 4: Light Bulbs That Last 50,000 Hours?
- Chapter 5: Boyle's Law: Breathing and the Heimlich Maneuver
- Chapter 6: Deaf and Can Still Hear? Bone Conduction
- Chapter 7: Visual Acuity and 20/20 Vision
- Chapter 8: Sensitive to the Touch: Touch Screens
- Chapter 10: Zapped with Gamma Rays: Irradiated Food
- Chapter 10: Smoking and Tobacco Radiation: Bad for Your Health
- Chapter 12: Lithium-Ion Rechargeable Batteries
- Chapter 13: Auto Air Bag Chemistry and Millions of Recalls
- Chapter 14: DNA Gene Therapy
- Chapter 17: Total Solar Eclipses
- Chapter 18: Gravity Waves
- Chapter 20: Don't Go Under That Tree! Lightning Formation and Tree Strikes
- Chapter 20: Ruminating Up Some CH₄

New Topic Highlights for this edition:

- Chapter 13: Acids and Bases in Your Stomach
 - Chapter 14: Breathalyzers
 - Chapter 15: Time Traveler
 - Chapter 16: Juno Reveals Jupiter
 - Chapter 21: Tectonic Activity on Mars
 - Chapter 22: Kilauea: The Most Active Volcano in the World
- Updated photographs and information of the latest astronomical discoveries like exoplanets, Pluto's surface, gravity waves, supermassive black holes, and the age of the universe.
 - *Thinking It Through (TIT)*—Following *Example* questions and before given *Solutions*, *TIT* sections help students engage critical thinking, analysis, and problem-solving strategies while working through the example.

Physical Science Today 7.1 Visual Acuity and 20/20 Vision

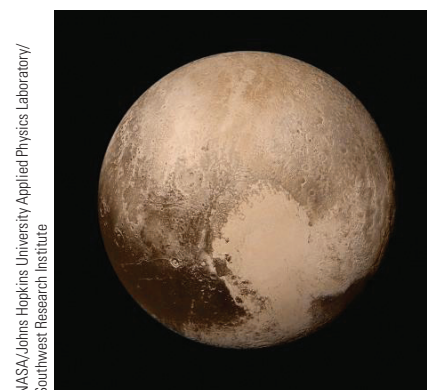
Do you have 20/20 vision? If so, you have good visual acuity, which is clarity or sharpness of vision. What the 20/20 means is that you can see clearly at 20 ft, which should normally be seen at that distance (20 ft). If you had 20/100 vision, then you would have to be as close as 20 ft to see clearly what a person with normal vision can see at 100 ft. And 20/200 means a normal person sees at 200 ft what another would have to be at 20 ft. That is, the distance one could normally see compared to someone with a vision problem sees at 20 ft. The problem with visual acuity arises from visual defects such as nearsightedness and farsightedness, as just discussed; the shape of the eyeball or cornea; and so on.

The reference value for visual acuity is taken to be 20 ft, with the 20/20 value as a normal standard for good acuity. In metric countries this would be 6.16 (6 m for 20 ft). Having 20/20 vision does not mean you have perfect vision. Other factors such as side vision, depth perception, eye coordination, and color vision contribute to overall vision ability.

On a visit to the optometrist, you probably had your acuity measured. This is done by identifying letters on a distance chart. A typical chart is shown in Fig. 1. The visual acuity test is done for each eye. A person reads lines downward until coming to the last line that the letters are clearly seen. For example, if this is the P E C F D line, the visual acuity is 20/40. That is, a person with this visual acuity would have to get within 20 ft to identify a letter that could be seen clearly at 40 feet with a normal eye. The standard 20/20 is the fourth line from the bottom. The three lines below this correspond to 20/15, 20/10, and 20/5. Many people have a visual acuity of 20/15, which is better than normal. Not many folks have a 20/10 or better visual acuity, but some animals do, especially birds of prey, which have been estimated to have acuity of 20/5 or better.

E	1	20/200
F P	2	20/100
T O Z	3	20/70
L P E D	4	20/50
P E C F D	5	20/40
E D F C Z P	6	20/30
P E L O P Z D	7	20/25
D E F F O T E C	8	20/20
L E F O P P O T	9	
P E C F D E C	10	
.....	11	

Figure 1



- *Did You Know*—Each chapter begins with key questions and their accompanying sections to help quickly orient students and introduce them to the central ideas of the chapter.
- *Facts*—Each chapter begins with a list of *Facts*, a brief description of pertinent, interesting, and user-friendly items regarding concepts and topics to be covered in the chapter.
- *Key Questions*—A short set of preview questions ask about important topics that will be covered in the following section.
- *Did You Learn?*—A short set of answers to the *Key Questions* reviews what the student should know after reading a section.
- *Conceptual Question and Answer*—These test student comprehension with a *Conceptual Question*, often related to an everyday application, and give the answer, which reinforces the topic of the text.

Math Coverage and Support

Each discipline in science is treated both descriptively and quantitatively. To make the Fifteenth Edition user-friendly for students who are not mathematically inclined, we continue to introduce concepts to be treated mathematically as follows. First, the concept is defined, as briefly as possible, using words. The definition is then presented, where applicable, as an equation in word form. And, finally, the concept is expressed in symbolic notation.

This is an example of the language-first introduction to a mathematical concept for Newton's Second Law. It first describes the empirical features of the law in a narrative form, then writes out the relationship as a 'word equation' and then finally using symbols as a numbered equation.

The level of mathematics in the textbook continues to be no greater than that of general high school math. Appendixes A, B, C, D, E, F, and G provide a review of the math skills needed to deal with the mathematical exercises in this textbook. It may be helpful for students to begin their study by

working through these seven appendixes. This will help identify and remediate common challenges students face in mathematics and thereby build their confidence and ability to solve quantitative exercises in the textbook. Additional *Practice Exercises* for mathematical concepts and skills are available in WebAssign.

Assistance is also offered to students by means of in-text worked *Examples* and follow-up *Confidence Exercises* (with answers). However, the emphasis on these exercises, whether descriptive or quantitative, is left to the discretion of the instructor. For instance, the end-of-chapter material may be selected according to the instructor's preferences. For those who want to maintain a more descriptive approach, they can choose to omit the Exercises and use the other end-of-chapter sections for assignments.

Complete Ancillary Support

An Introduction to Physical Science, Fifteenth Edition, is supported by a complete set of ancillaries. Each piece has been designed to enhance student understanding and to facilitate creative instruction.

Instructor Resources

Instructor Solutions Manual (ISM): Includes worked-out solutions to all exercises in the text. The ISM is available through the Instructor Companion Site and WebAssign.

1. The acceleration produced by an unbalanced force acting on an object (or mass) is directly proportional to the magnitude of the force ($a \propto F$) and in the direction of the force (the \propto symbol is a proportionality sign). In other words, the greater the unbalanced force, the greater the acceleration.

2. The acceleration of an object being acted on by an unbalanced force is inversely proportional to the mass of the object ($a \propto 1/m$). That is, for a given unbalanced force, the greater the mass of an object, the smaller the acceleration.

Combining these effects of force and mass on acceleration gives

$$\text{acceleration} = \frac{\text{unbalanced force}}{\text{mass}}$$

When appropriate units are used, the effects of force and mass on acceleration can be written in equation form as $a = F/m$. Or, as commonly written in terms of force in magnitude form, we have **Newton's second law of motion**:

$$\begin{aligned} \text{force} &= \text{mass} \times \text{acceleration} \\ F &= ma \end{aligned}$$

3.1

Instructor's Guide to Accompany Laboratory Guide: Contains useful information and sample data for many of the experiments in this manual, and has worked-out calculations and even typical answers for the exercises and questions. This material has been prepared to help both experienced and inexperienced laboratory instructors, and will be especially useful to laboratory assistants assigned to do the grading for these experiments when they are used in a formal laboratory setting, but anyone needing to prepare lecture or demonstration material for physical science classes at any level can benefit from this information. The Instructor's Guide to Accompany Laboratory Guide is available through the Instructor Companion Site and WebAssign.

PowerPoint Lecture Tools: PowerPoint slides are available for every chapter of the text. Each presentation contains important concepts, images, and questions from each chapter and section to help guide lectures and activities. In addition to lecture slides, other available presentations contain only the images from each chapter, for use on assignments, tests, and projects and clicker content is also available. All PowerPoint lecture tools are available through the Instructor Companion Site and WebAssign.

Cengage Testing, Powered by Cognero®: Cognero is a flexible online system that allows you to author, edit, and manage test bank content online. You can create multiple versions of your test in an instant and deliver tests from your LMS or exportable PDF or Word docs you print for in-class assessment.

Test Banks: Microsoft Word-compatible versions of the text's test banks are included and can be imported into your Learning Management System (LMS). Word-compatible test banks are available through the Instructor Companion Site.

Student Ancillaries

Laboratory Guide: The Laboratory Guide contains 55 experiments in the five major divisions of physical science: physics, chemistry, astronomy, geology, and meteorology. Each experiment includes an introduction, learning objectives, a list of apparatus, procedures for taking data, and questions. The Laboratory Guide is available as a print-on-demand item.

Active Learning Online with WebAssign

WebAssign for Shipman, Wilson, Higgins, Lou's *An Introduction to Physical Science, Fifteenth Edition*: Exclusively from Cengage Learning, WebAssign combines the exceptional mathematics, physics, and astronomy content that you know and love with the most powerful online homework solution. Designed with engaging activities, immediate feedback, an interactive eBook, and a digital workbook, this platform helps students develop a deeper conceptual understanding of their subject matter. Online assignments can be constructed by selecting from hundreds of text-specific problems or supplemented with problems from any Cengage Learning textbook. WebAssign also includes the Cengage MindTap Reader: an engaging and customizable eBook that lets you tailor the textbook to fit your course and connect with your students. It includes highlighting and other tools for students and is also available to download in the Cengage Mobile App.

WebAssign for *An Introduction to Physical Science*, Fifteenth Edition

New Opportunities for Active Learning

Digital Workbook The new Digital Workbook is a series of online lessons that interweave narrative, assessment elements, and a variety of interactive media to form a singular learning activity.

Written in a conversational and engaging tone, these lessons constitute a primer of relevant topics essential to developing a functional awareness of the topic at hand. The goal then is to address each topic as a dialogue with the reader explaining the idea to them in the most straightforward and direct way possible. It is not a formalized approach as those nuances can be sought out by the learner as needed.

Educational research on introductory science courses tells us that no one “gets” science on their first instruction. Rather than trying to cover the topic exhaustively, the workbook acts as the very first exposure to each idea in order to set up a solid basis of understanding that can be built upon via subsequent reading, discussions, and exercises.


The pacing of the workbook is such that there are frequent checkpoints and opportunities for brief reflection throughout the lesson using a variety of different question types following narrative, short animations, or html interactive simulations. Definitions are available by moving the cursor over the highlighted key terms providing context-specific reminders to those students who need them without disrupting the narrative flow for those that do not. Each question contains rich targeted feedback that explains not only what went wrong but also in what context their answer would have been correct. The feedback also serves to reinforce the lesson by offering a rejoinder following a correct response. Because the rejoinder text persists after the lesson has been completed, the student is able to return to the lesson in order to review the extended narrative that they “created” by going through the workbook activities.

Virtual Astronomy Labs A strong understanding of astronomy, cosmology, and the foundations of the universe are essential components of *An Introduction to Physical Science*. WebAssign now offers students a chance to dive deeper into Astronomy through Virtual Astronomy Labs that are integrated into the IPS WebAssign course. This is a set of interactive, active learning experiences that combine analysis of real astronomical data with robust simulations to

provide a true online laboratory experience for your course. Each lab is presented in a modular format containing individual auto-graded segments, giving you the control to assign it as a standalone activity or as part of a larger learning experience.

Concise tutorials summarize the relevant content in sections that can be opened and closed for quick access during follow-up activity or assessment. Targeted feedback guides students in revising any incorrect answers. Many items provide scaffolding to build skills and confidence in the use of simple algebra, geometry, and proportional reasoning to solve astronomy problems.

Changing Motion



Source: Shutterstock.com


A runner speeds up. A ball curves. A bag slips from your hands and falls. A car stops. Motion changes. But how does motion change? What causes this change? To better understand motion, we need to introduce some additional concepts. Only then can we advance from describing to predicting—and sometimes controlling—motion.

Part 1 of 5 - Introducing Acceleration

In this first lesson we introduce the concept of **acceleration**, the rate of change of velocity per unit time. Part, velocity, tells us the distance an object moves per unit time and the direction in which it moves. Put another way, velocity describes the rate at which an object's position changes.

Part 2 of 5 - Acceleration in Action

This short video shows us the ways in which acceleration can affect a car's motion.



Which of the following scenarios shows evidence of acceleration?

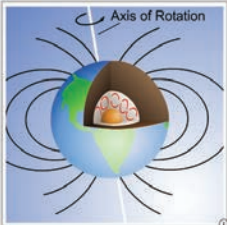
- a dropped stone speeding up as it falls
- a car slowing down as its brakes are applied
- a satellite following a circular orbit at constant speed

Earth's magnetic field is evidence that convection occurs within Earth's iron-rich outer core.

The illustration below depicts convection currents in the outer (liquid) core. Like boiling molasses on a stove top, this layer of hot, dense material has rising currents that transport thermal energy outward.

This circulation of the liquid iron-nickel alloys constitutes an electric current. Because of this, the outer-core convection is thought to be responsible for Earth's magnetic field. When coupled with Earth's rapid spin, this process gives rise to an electromagnetic phenomenon known as the **dynamo effect**.

The process by which a rotating and convecting mass of electrically conductive matter can generate a magnetic field.



You may wonder how it can be that Earth's hotter inner core is solid, while the relatively cooler outer core is liquid. Remember that the particular phase of matter (solid, liquid, or gas) depends on both temperature and pressure. The material in the inner core is under much higher pressures than that of the outer core and, thus, has a much higher melting point.

MindTap Reading eBook Content You and your students have access to a MindTap Reader (MTR) in WebAssign. The MTR is an interactive eBook with multimedia enabled, plus extra features that turn your student's textbook into a one of a kind learning tool.

The MindTap Reader provides:

- A modern, interactive study experience with embedded multimedia
- Answers to practice problems embedded right in the text
- Learning flexibility with Readspeaker Text-to-Speech capabilities
- Easy highlighting, note taking and bookmarking
- Improved accessibility with an HTML5-based experience
- Anytime, anywhere access through the Cengage Mobile App

Access your ebook in the Cengage Mobile App:



Acknowledgments

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As in previous editions, we continue to welcome comments from students and instructors of physical science and invite you to send us your impressions and suggestions.

About the Authors

With the Fifteenth Edition of *An Introduction to Physical Science*, first published nationally in 1971, the textbook has had a long run of 50 years. This accomplishment reflects the contributions over the years of several authors who are now deceased. We pay tribute to them: *James T. Shipman*, originator of the text and contributing to Editions 1–9 (as the book is known as the “Shipman” book, his name is retained on the authors’ list); *Jerry L. Adams*, Editions 1–5; and *Aaron W. Todd*, Editions 7–11. Their contributions remain an integral part of *An Introduction to Physical Science*.

That being said, we have for the current edition:

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Measurement

CHAPTER

1



AP Images/Kevin Terrell

It is a capital mistake to theorize before one has data. Insensibly one begins to twist the facts to suit the theories, instead of the theories to suit the facts.

•
Sherlock Holmes
(Arthur Conan Doyle,
1859–1930)

< Bring in the chain for a measurement. No first and 10!

Did You Know?	Section
There are five major divisions in physical science.	1.1
Mass and weight are related, but mass is the fundamental quantity.	1.4
Density describes the compactness of matter or mass per unit volume of a substance.	1.6

Science is concerned with the description and understanding of our environment. A first step is to measure and describe the physical world. Over the centuries, humans have developed increasingly sophisticated methods of measurement, and scientists make use of the most advanced of these.

We are continually making measurements in our daily lives. Watches and clocks are used to measure the time it takes for events to take place. A census is taken every 10 years in the United States to determine (measure) the population. Money, calories, and the days and years of our lives are counted.

It was once thought that all things could be measured with exact certainty. But as smaller and smaller objects were measured, it became evident that the act of measuring distorted the measurement. This uncertainty in making measurements of the very small is discussed in more detail in Chapter 9.5. (Note that “Chapter 9.5” means “Chapter 9, Section 5.” This format will be used throughout this book to call your attention to further information in another part of the book.)

Measurement is crucial to understanding our physical environment, but first let’s discuss the physical sciences and the methods of scientific investigation.

Chapter Outline

- 1.1 The Physical Sciences 2
- 1.2 Scientific Investigation 3
- 1.3 The Senses 4
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- 1.4 Standard Units and Systems of Units 6
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 - Highlight 1.2 Is Unit Conversion Important? It Sure Is 20
- 1.7 Significant Figures 21

PHYSICS FACTS

- Tradition holds that in the twelfth century, King Henry I of England decreed that 1 yard should be the distance from his royal nose to the thumb of his outstretched arm. (Had King Henry's arm been 3.37 inches longer, the yard and the meter would have been equal in length.)
- Is the old saying "A pint's a pound the world around" true? It depends on what you are talking about. The saying is a good approximation for water and similar liquids. Water weighs 8.3 pounds per gallon, so one-eighth of that, or 1 pint, weighs 1.04 lb.
- The United States officially adopted the metric system in 1893.

1.1 The Physical Sciences

Key Questions*

- What are the two major divisions of natural science?
- What are the five major divisions of physical science?

Think about the following:

- **Hung up.** A basketball player leaping up to make a shot seems to "hang" in the air before he slam-dunks a basketball.
- **Spot you one.** Driving in the summer, you may see what looks like water or a "wet spot" on the road ahead, but you never get to it.
- **All stuck up.** The professor rubs a balloon on his sweater and touches it to the ceiling, and the balloon stays there.
- **Mighty small.** There are pictures of individual atoms.
- **It doesn't add up.** Exactly 100 cc of ethanol alcohol is mixed with exactly 100 cc of water, and the resulting mixture is less than 200 cc.
- **Get in line.** There won't be a total solar eclipse visible from the United States until 2024, but there will be more visible elsewhere before then.
- **Dark Moon.** The dark side of the Moon isn't dark all the time.
- **A bolt from the blue.** You don't have to be in a thunderstorm for lightning to strike.
- **No blow.** One continent has no hurricanes, and a particular latitude has none either.
- **All shook up.** An earthquake with a magnitude of 8.0 on the Richter scale is not twice as energetic as one with a magnitude of 4.0 (but about a million times more).
- **Keep an eye on the sky.** There is evidence that a meteorite caused dinosaurs to become extinct.

Would you like to know how or why such things occur, or how they are known? All these statements are explained in this book. Most people are curious about such topics, and explanations of these and many other phenomena are obtained through scientific observations. The above statements pertain to physical science, but there are several other branches of science as well.

Science (from the Latin *scientia*, meaning "knowledge") may be defined as an organized body of knowledge about the natural universe and the processes by which that knowledge is acquired and tested. In general, there are *social sciences*, which deal with human society and individual relationships, and *natural sciences*, which investigate the natural universe. In turn, the *natural sciences* are divided into the *biological sciences* (sometimes called *life sciences*), which are concerned with the study of living matter, and the *physical sciences*, which involve the study of nonliving matter.

This book introduces the various disciplines of physical science, the theories and laws fundamental of each, some of the history of their development, and the effect each has on our lives. Physical science is classified into five major divisions (● Fig. 1.1):

Physics, the most fundamental of the divisions, is concerned with the basic principles and concepts of matter and energy.

Chemistry deals with the composition, structure, and reactions of matter.

Astronomy is the study of the universe, which is the totality of all matter, energy, space, and time.

Meteorology is the study of the atmosphere, from the surface of the Earth to where it ends in outer space.

*Key Questions are listed at the beginning of each section. The answers to these questions are found in the section and in the related Did You Learn? at the end of the section.

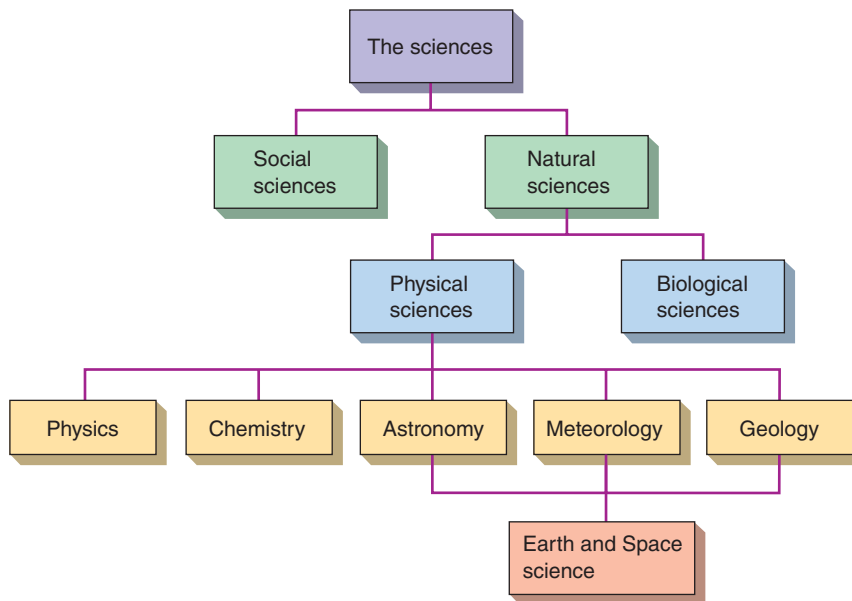


Figure 1.1 The Major Physical Sciences A diagram showing the five major physical sciences and how they fit into the various divisions of the sciences. (See text for discussion.)

Geology is the science of the planet Earth: its composition, structure, processes, and history. (The last three physical sciences are sometimes combined as *Earth and Space Science*.)

Physics is considered the most fundamental of these divisions because each of the other disciplines applies the principles and concepts of matter and energy to its own particular focus. Therefore, our study of physical science starts with physics (Chapters 1–10); then moves on to chemistry (Chapters 11–14), astronomy (Chapters 15–18), meteorology (Chapters 19 and 20); and ends with geology (Chapters 21–24).

This exploration will enrich your knowledge of the physical sciences and give you perspective on how science has grown throughout the course of human history; how science influences the world we live in today; and how it is employed through *technology* (the application of scientific knowledge for practical purposes).

Did You Learn?*

- Biological (life) and physical sciences make up the natural sciences.
- The major divisions of physical science are physics, chemistry, astronomy, meteorology, and geology.

1.2 Scientific Investigation

Key Questions

- What does the scientific method say about the description of nature?
- Do scientific laws and legal laws have anything in common?

Theory guides. Experiment decides. Johannes Kepler (1571–1630)

Today's scientists do not jump to conclusions as some of our ancestors did, which often led to superstitious results. Today, measurements are the basis of scientific investigation. Phenomena are observed, and questions arise about how or why these phenomena occur. These questions are investigated by the **scientific method**.

*Did You Learn? notes are listed at the end of each section and relate to the Key Questions at the beginning of each section.

The scientific method can be broken down into the following elements:

1. *Observations and measurements* (quantitative data).
2. *Hypothesis*. A possible explanation for the observations; in other words, a tentative answer or an educated guess.
3. *Experiments*. The testing of a hypothesis under controlled conditions to see whether the test results confirm the hypothetical assumptions, can be duplicated, and are consistent. If not, more observations and measurements may be needed.
4. *Theory*. If a hypothesis passes enough experimental tests and generates new predictions that also prove correct, then it takes on the status of a theory, a well-tested explanation of observed natural phenomena. (Even theories may be debated by scientists until experimental evidence decides the debate. If a theory does not withstand continued experimentation, then it must be modified, rejected, or replaced by a new theory.)
5. *Law*. If a theory withstands the test of many well-designed, valid experiments and there is great regularity in the results, then that theory may be accepted by scientists as a *law*. A law is a concise statement in words or mathematical equations that describes a fundamental relationship of nature. Scientific laws are somewhat analogous to legal laws, which may be repealed or modified if inconsistencies are later discovered. Unlike legal laws, scientific laws are meant to describe, not regulate.

The bottom line on the scientific method is that *no hypothesis, theory, or law of nature is valid unless its predictions are in agreement with experimental (quantitative measurement) results*. See ● Fig. 1.2 for a flowchart representing the scientific method.

The **Highlight 1.1: The “Face” on Mars**, which follows, illustrates the need for the scientific method.

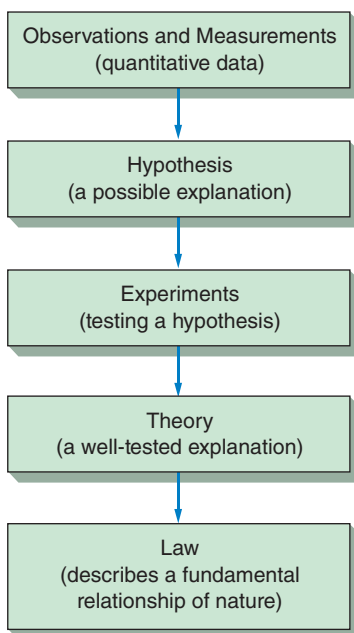


Figure 1.2 The Scientific Method
A flowchart showing the elements of the scientific method. If experiments show that a hypothesis is not consistent with the facts, more observations and measurements may be needed.

Did You Learn?

- No hypothesis, theory, or law of nature is valid unless its predictions are in agreement with experimental results.
- Scientific laws describe nature, and legal laws regulate society.

1.3 The Senses

Key Questions

- Which two senses give us the most information about our environment?
- How may our senses be enhanced?

Our environment stimulates our senses, either directly or indirectly. The five senses (sight, hearing, touch, taste, and smell) make it possible for us to know about our environment. Therefore, the senses are vitally important in studying and understanding the physical world.

Most information about our environment comes through sight. Hearing ranks second in supplying the brain with information about the external world. Touch, taste, and smell, although important, rank well below sight and hearing in providing environmental information.

All the senses have limitations. For example, the unaided eye cannot see the vast majority of stars and galaxies. We cannot immediately distinguish the visible stars of our galaxy from the planets of our solar system, which all appear as points of light (although with time the planets move). The limitations of the senses can be reduced by using measuring instruments such as microscopes and telescopes. Other examples of limitations are our temperature sense of touch being limited to a range of hotness

Highlight 1.1 The “Face” on Mars

In 1976, NASA's Viking 1 spacecraft was orbiting Mars. When snapping photos, the spacecraft captured the shadowy likeness of an enormous head, 2 miles from end to end and located in a region of Mars called Cydonia (Fig. 1a).

The surprise among the mission controllers at NASA was quickly tempered as planetary scientists decided that the “face” was just another Martian mesa, a geologic landform common in the Cydonia region. When NASA released the photo to the public a few days later, the caption noted a “huge rock formation . . . which resembles a human head . . . formed by shadows giving the illusion of eyes, nose, and mouth.” NASA scientists thought that the photo would attract the public's attention to its Mars mission, and indeed it did!

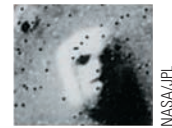
The “face” on Mars became a sensation, appearing in newspapers (particularly tabloids), in books, and on TV talk shows. Some people thought that it was evidence of life on Mars, either at present or in the past, or perhaps that it was the result of a visit to the planet by aliens. As for NASA's contention that the “face” could be entirely explained as a combination of a natural landform and unusual lighting conditions, howls arose from some of the public about “cover-up” and “conspiracy.” Other people, with a more developed scientific attitude, gave provisional acceptance to NASA's conclusion, realizing that extraordinary claims (aliens) need extraordinary proof.

Twenty-two years later, in 1998, the Mars Global Surveyor (MGS) mission reached Mars, and its camera snapped a picture of the “face” 10 times sharper than the 1976 Viking photo. Thousands waited for the image to appear on NASA's website. The photo revealed a natural landform, not an alien monument. However, the image was taken through wispy clouds, and some people were still not convinced that the object was just a plain old mesa.

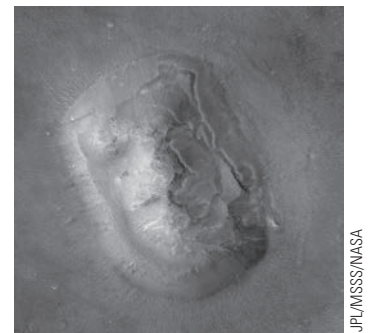
Not until 2001 did the MGS camera again pass over the object. This time there were no clouds, and the high-resolution picture was clearly that of a mesa similar to those common in the Cydonia region and the American West (Fig. 1b).

Why would so many articles and books be written extolling the alien origin of the “face”? Perhaps many authors were trading on the gullibility and ignorance of part of our population to line their own pockets or to gain attention. If so, the best ways to deal with similar situations in the future would be to improve the standard of education among the general public and to emphasize the importance of a well-developed scientific method.

Source: Most of the information for this Highlight came from Tony Phillips, “Unmasking the Face on Mars,” NASA, May 24, 2001.



(a)



(b)

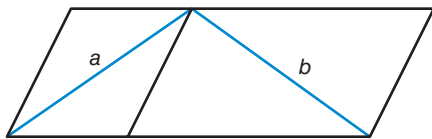
Figure 1 The Face on Mars
(a) In 1976, at the low resolution of the Viking 1 camera, the appearance of a sculpted face can be seen. (b) In 2001, at the high resolution of the Mars Global Surveyor camera, the object is seen to be a common mesa.

and coldness before injury and our hearing being limited to a certain frequency range (Chapter 6.4).

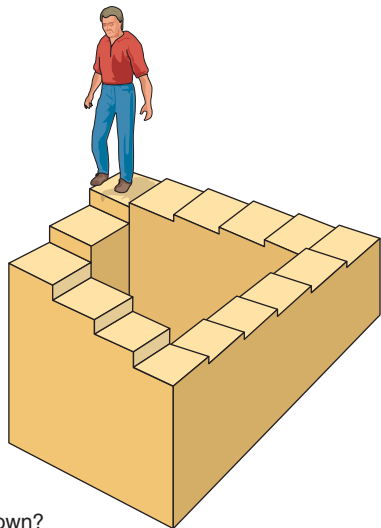
Not only do the senses have limitations, but they also can be deceived, thus providing false information about our environment. For example, perceived sight information may not always be a true representation of the facts because the brain can be fooled. There are many well-known optical illusions, such as those shown in ● Fig. 1.3. Some people may be quite convinced that what they see in such drawings actually exists as they perceive it. However, we can generally eliminate deception by using instruments. For example, rulers can be used to answer the questions in Fig. 1.3a and b.

Did You Learn?

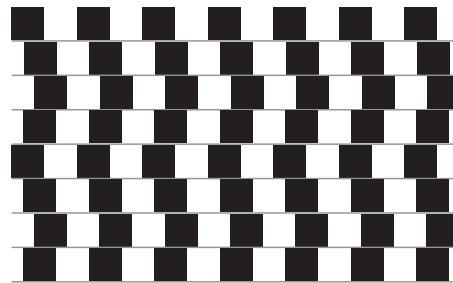
- Sight and hearing give us the greatest amount of information about our environment.
- The limitations of the senses can be reduced by using instruments, such as microscopes and telescope for sight.



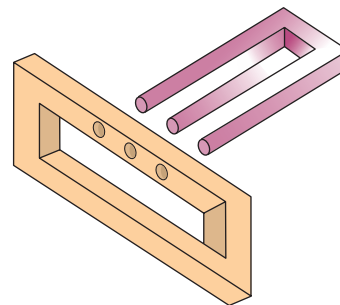
(a) Is the diagonal line b longer than the diagonal line a ?



(c) Going down?



(b) Are the horizontal lines parallel or do they slope?



(d) Is something dimensionally wrong here?

Figure 1.3 Some Optical Illusions We can be deceived by what we see. Answer the questions under the drawings.

1.4 Standard Units and Systems of Units

Key Questions

- What is a standard unit?
- What are the standard units of length, mass, and time in the SI?

To describe nature, we make measurements and express these measurements in terms of the magnitudes of units. Units enable us to describe things in a concrete way, that is, numerically. Suppose that you are given the following directions to find the way to campus when you first arrive in town: “Keep going on this street for a few blocks, turn left at a traffic light, go a little ways, and you’re there.” Certainly some units or numbers would be helpful.

Many objects and phenomena can be described in terms of the *fundamental* physical quantities of length, mass, and time (*fundamental* because they are the most basic quantities or properties we can imagine). In fact, the topics of *mechanics*—the study of motion and force—covered in the first few chapters of this book require *only* these physical quantities. Another fundamental quantity, electric charge, will be discussed in Chapter 8. For now, let’s focus on the units of length, mass, and time.

To measure these fundamental quantities, we compare them with a reference, or standard, that is taken to be a standard unit. That is, a **standard unit is a fixed and reproducible value for the purpose of taking accurate measurements**. Traditionally, a government or international body establishes a standard unit.

A group of standard units and their combinations is called a system of units. Two major systems of units in use today are the **metric system** and the **British system**. The latter is used primarily in the United States, whereas the metric system is used throughout most of the world. The United States is the only major country that has not gone completely metric (● Fig. 1.4).

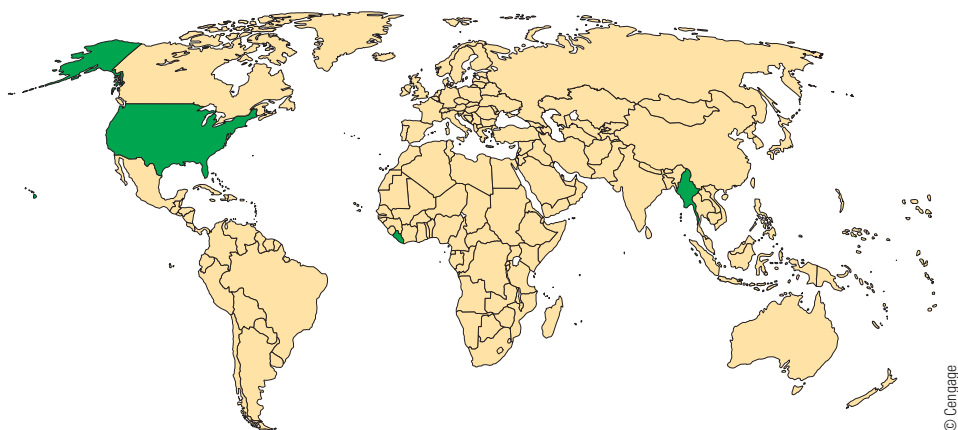


Figure 1.4 A Mostly Metric World Map of world showing metric and nonmetric nations (in green). The metric system is used throughout most of the world. The United States is the only major country that has not gone completely metric. Other countries include Liberia in Africa and Myanmar in Asia.

Length

The description of space might refer to a location or to the size of an object (amount of space occupied). To measure these properties, we use the fundamental quantity of **length**, *the measurement of space in any direction*.

Space has three dimensions, each of which can be measured in terms of length. The three dimensions are easily seen by considering a rectangular object such as a bathtub (● Fig. 1.5). It has length, width, and height, but each dimension is actually a length. The dimensions of space are commonly represented by a three-dimensional Cartesian coordinate system (named in honor of French mathematician René Descartes, 1596–1650, who developed the system).

The standard unit of length in the metric system is the meter (m), from the Greek *metron*, “to measure.” It was defined originally as one ten-millionth of the distance from the geographic North Pole to the Earth’s equator (● Fig. 1.6a). A portion of the meridian between Dunkirk, France, and Barcelona, Spain, was measured to determine the meter length, and that unit was first adopted in France in the 1790s. One meter is slightly longer than 1 yard, as illustrated in Fig. 1.6b.

From 1889 to 1960, the standard meter was defined as the length of a platinum–iridium bar kept at the International Bureau of Weights and Measures in Paris, France. However, the stability of the bar was questioned (for example, length variations occur with temperature changes), so new standards were adopted in 1960 and again in 1983. The current definition links the meter to the speed of light in a vacuum, as illustrated in Fig. 1.6c. Light travels at a speed of 299,792,458 meters/second (usually listed as 3.00×10^8 m/s). So, by definition, 1 meter is the distance light travels in $1/299,792,458$ of a second.

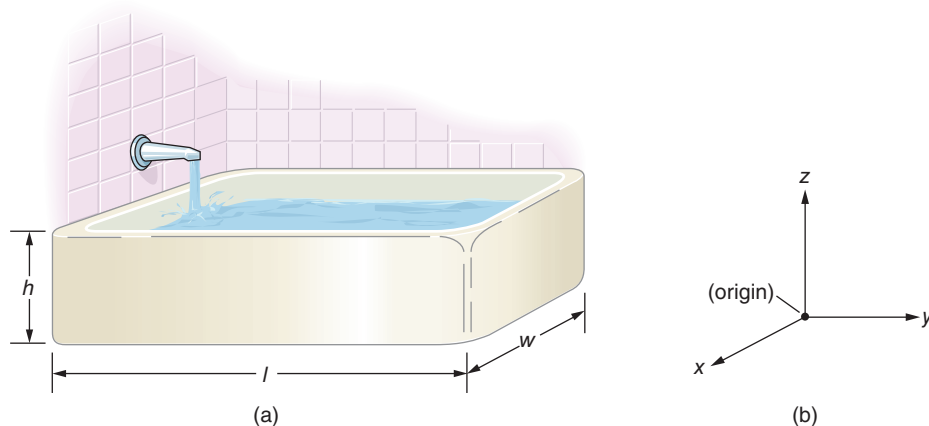


Figure 1.5 Space Has Three Dimensions (a) The bathtub has dimensions of length (l), width (w), and height (h), but all are actually measurements of length. (b) The dimensions of space are commonly represented by a three-dimensional Cartesian coordinate system (x, y, z) with the origin as the reference point.

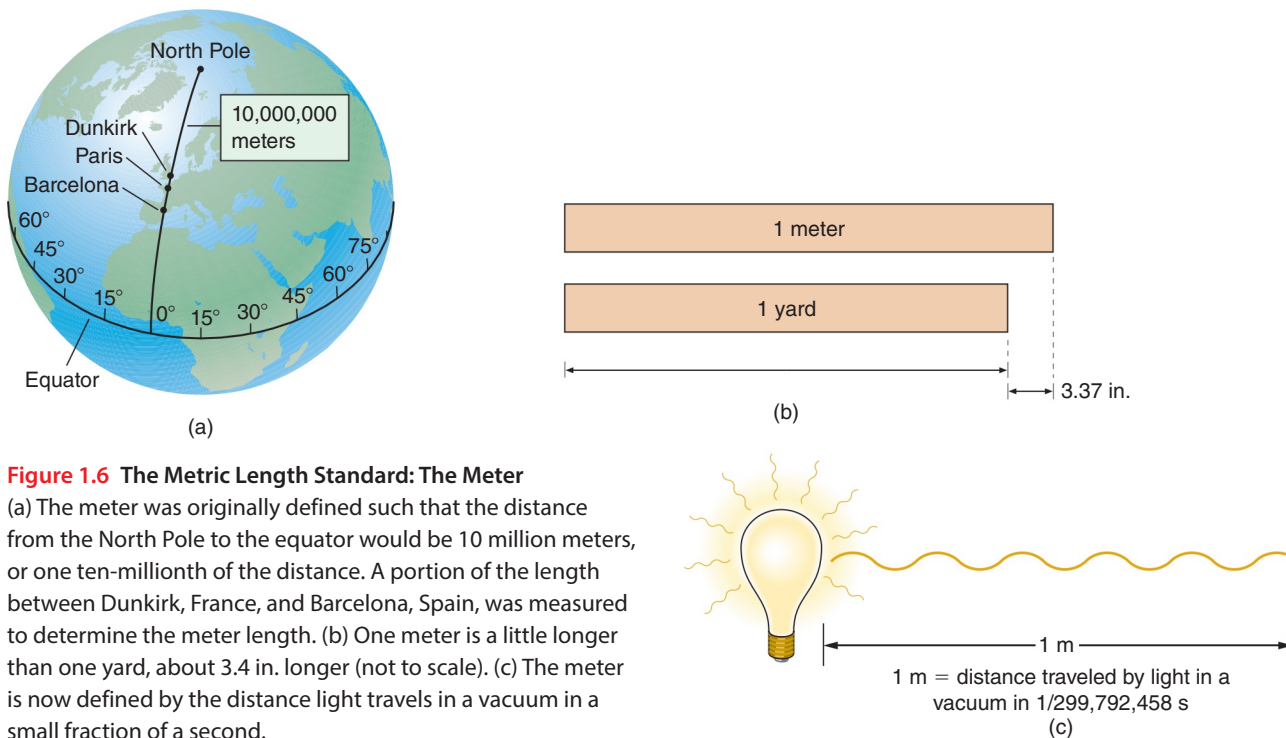


Figure 1.6 The Metric Length Standard: The Meter

(a) The meter was originally defined such that the distance from the North Pole to the equator would be 10 million meters, or one ten-millionth of the distance. A portion of the length between Dunkirk, France, and Barcelona, Spain, was measured to determine the meter length. (b) One meter is a little longer than one yard, about 3.4 in. longer (not to scale). (c) The meter is now defined by the distance light travels in a vacuum in a small fraction of a second.

The standard unit of length in the British system is the *foot*, which historically was referenced to the human foot. As noted in the Physics Facts at the beginning of this chapter, King Henry I used his arm to define the yard. Other early units commonly were referenced to parts of the body. For example, the *hand* is a unit that even today is used in measuring the heights of horses (1 hand is 4 in.).

Mass

Mass is the amount of matter an object contains. The more massive an object, the more matter it contains. (More precise definitions of mass in terms of force and acceleration, and in terms of gravity, will be discussed in Chapter 3.)

The standard metric unit of mass is the **kilogram** (kg). Originally, this amount of matter was related to length and was defined as the amount of water in a cubic container 0.10 m, or 10 cm, on a side (● Fig. 1.7a). However, for convenience, the mass standard was referenced to a material standard (an artifact or a human-made object). The kilogram was defined to be the mass of a cylinder of platinum–iridium kept at the International Bureau of Weights and Measures in Paris. The U.S. prototype (copy) is kept at the National Institute of Standards and Technology (NIST) in Washington, D.C. (Fig. 1.7b).

This standard is based on an artifact rather than on a natural phenomenon. Even though the cylinder is kept under controlled conditions, its mass is subject to slight changes because of contamination and loss from surface cleaning. A property of nature, by definition, is always the same and in theory can be measured anywhere. While in the final production stages of this book (2019), the International Committee for Weights and Measures has adopted a new definition of the kilogram based on a fundamental quantity, Planck's constant. Planck's constant is discussed in Chapter 9.2.

The unit of mass in the British system is the *slug*, a rarely used unit. We will not use this unit in our study because a quantity of matter in the British system is expressed in terms of weight on the surface of the Earth and in units of *pounds*. (The British system is sometimes said to be a gravitational system.) Unfortunately, weight is not a *fundamental*

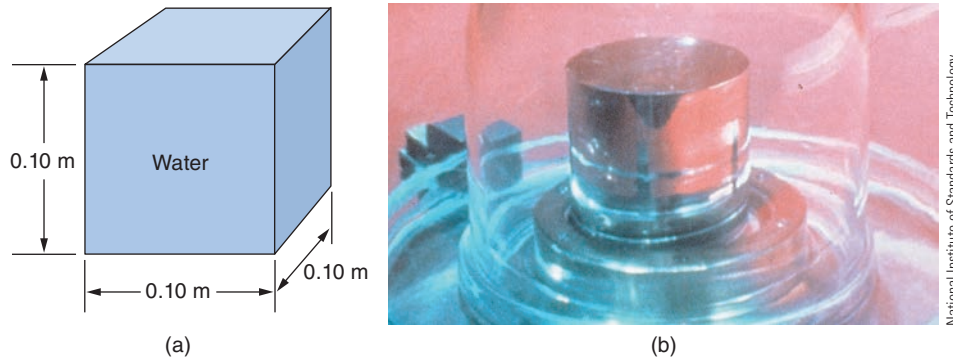


Figure 1.7 The Metric Mass Standard: The Kilogram (a) The kilogram was originally defined in terms of a specific volume of water, that of a cube 0.10 m on a side (at 4°C, the temperature at which water has its maximum density). As such, the mass standard was associated with the length standard. (b) Prototype kilogram number 20 is the U.S. standard unit of mass. The prototype is a platinum–iridium cylinder 39 mm in diameter and 39 mm high.

quantity, and its use often gives rise to confusion. Of course, a fundamental quantity should be the same and not change. However, weight is the gravitational attraction on an object by a celestial body, and this attraction is different for different celestial bodies. The gravitational attraction of a body depends on its mass.

For example, on the less massive Moon, the gravitational attraction is $\frac{1}{6}$ of that on the Earth, so an object on the Moon weighs $\frac{1}{6}$ of its weight on the Earth. This means a suited astronaut who weighs 300 pounds on the Earth will weigh $\frac{1}{6}$ that amount, or 50 pounds, on the Moon, but the astronaut's mass will be the same (● Fig. 1.8).

A fundamental quantity does not change at different locations. The astronaut has the same mass, or quantity of matter, wherever he or she is. As will be learned in Chapter 3.3, mass and weight are related, but they are not the same. For now, keep in mind that *mass, not weight, is the fundamental quantity.*

Time

Each of us has an idea of what time is, but when asked to define it, you may have to ponder a bit.

Some terms often used when referring to time are *duration*, *period*, and *interval*. A common descriptive definition is that **time** is the *continuous, forward flow of events*. Without

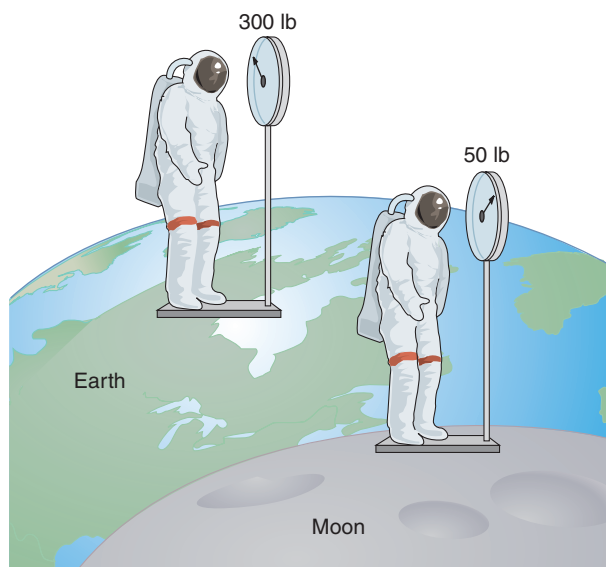


Figure 1.8 Mass Is the Fundamental Quantity The weight of an astronaut on the Moon is $\frac{1}{6}$ the astronaut's weight on the Earth, but the astronaut's mass is the same at any location.