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Physical Science

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WCB Wm. C. Brown Publishers

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Library of Congress Catalog Card Number: 90–80174

ISBN 0–697–03156–X

Printed in the United States of America by Wm. C. Brown Publishers, 2460 Kerper Boulevard, Dubuque, IA 52001

10 9 8 7 6 5 4 3 2 1

Physical Science

*"To Patricia, Tonya,
Lisa, and Elizabeth"*

Preface

P*hysical 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.

The book is divided into four sections: physics, chemistry, astronomy, and the earth sciences. With laboratory studies, *Physical Science* contains enough material for a two-semester course. The chapters and sections are flexible: the instructor can determine topic sequence and depth of coverage. *Physical Science* can also serve as a text in a one-semester course; the materials are complete enough to be used in a one-semester physics and chemistry course, a one-semester astronomy and earth science course, or in other combinations.

To make room for a wide spectrum of physical science focused on student needs, interests, and abilities, the technical details and terminology that are of interest to the science major are not included. In addition, special interest areas such as environmental concerns are not isolated in an arbitrary section or chapter; they are discussed where they occur naturally. After all, environmental concerns are a part of everyday life, not some isolated part to be considered at times and ignored other times.

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 integrate concepts and understand the use of relationships called equations. They also serve as a problem solving model; 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 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.

Physical Science also contains a number of innovative learning aids. Each chapter begins with an *introductory overview* and a brief *outline* that help students to organize their thoughts for the coming chapter materials. Each chapter ends with a brief *summary* that organizes the main concepts presented, a *summary of equations* (where appropriate) written both with words and with symbols, a list of page-referenced *key terms,* a set of *multiple-choice questions* with nearby answers for immediate correction or reinforcement of major understandings, a set of *thought questions* for discussion or essay answers, and, *two sets of problem exercises* with complete solutions for one set provided in the appendix. The two sets are nearly parallel in early chapters, but they become progressively less so in successive chapters. The set with the solutions provided is intended to be a model to help students through assigned problems in the other set. In trial classroom testing, this approach proved to be a tremendous improvement over the traditional "odd problem answers." The "odd answer only" approach provided students little help in learning problem solving skills, unless it was how to work a problem backward.

Finally, each chapter of *Physical Science* also includes a boxed feature that discusses topics of special human or environmental concern (the use of seat belts, acid rain, and air pollution, for example), topics concerning interesting technological applications (passive solar homes, solar cells, and catalytic converters, for example), or topics on the cutting edge of scientific research (quarks, superstrings, and deep-ocean exploration, for example). All boxed features are informative materials that are supplementary in nature.

Physical Science is accompanied by an instructor's manual, a laboratory manual, a student study guide, WCB TestPak—a computer bank of multiple-choice test items, WCB QuizPak—a computer quizzing program, and a set of overhead transparencies. The laboratory manual, written and classroom tested by the author, presents a selection of traditional laboratory exercises specifically written for the interest and abilities of nonscience majors. 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 manual, also written by the text author, provides a chapter outline, an introduction/summary of each chapter, suggestions for discussion and demonstrations, additional multiple choice questions (with answers), and answers and solutions to all end-of-chapter questions and exercises not provided in the text.

The student study guide, cowritten with John Grant, was designed after extensive tutoring experiences with beginning physical science students. The guide provides a solid foundation for nonscience students by stressing conceptual understanding as well as techniques for successful problem solving. All the examples and illustrations are new and different from the examples and illustrations of the text, which tends to maintain interest as it adds a new dimension to student understanding of course concepts and skills.

The author 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? Write to:

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Acknowledgments

Many constructive suggestions, new ideas, and invaluable advice were provided by reviewers through several stages of manuscript development. Special thanks and appreciation to those who reviewed all or part of the manuscript, often under tight time deadlines. Thanks is extended to Lawrence H. Adams, *Polk Community College;* Charles L. Bissell, *Northwestern State University of Louisiana;* W. H. Breazeale, Jr., *Francis Marion College;* William Brown, *Montgomery College;* Stan Celestian, *Glendale Community College;* Carl G. Davis, *Danville Area Community College;* Dennis Englin, *The Master's College;* Floretta Haggard, *Rogers State College;* Robert G. Hamerly, *University of Northern Colorado;* Eric Harms, *Brevard Community College;* L. D. Hendrick, *Francis Marion College;* Abe Korn, *New York City Tech College;* Robert Larson, *St. Louis Community College;* William Luebke, *Modesto Junior College;* Douglas L. Magnus, *St. Cloud State University;* L. Whit Marks, *Central State University;* Jesse C. Moore, *Kansas Newman College;* Michael D. Murphy, *Northwest Alabama Community College;* David L. Vosburg, *Arkansas State University.* Special thanks and appreciation is also extended to my wife, Patricia Northrop Tillery, who assisted directly with typing and photograph acquisition as well as indirectly with her ongoing support. Finally, thanks is extended to Jeffrey L. Hahn and Lynne Meyers of Wm. C. Brown for their understanding of student and instructor needs, commitment to quality, and assistance in the publication of this edition.

Contents

Chapter 1

The World Around You

Figure 1.1
Your physical surroundings include naturally occurring as well as human-made objects such as sidewalks, trash receptacles, and buildings.

HAVE you ever thought about your thinking and what you know? On a very simplified level, you could say that everything you know came to you through your senses. You see, hear, and touch things of your choosing and you can also smell and taste things in your surroundings. Information is gathered and sent to your brain by your sense organs. Somehow, your brain processes all this information in an attempt to find order and make sense of it all. Finding order helps you understand the world and what may be happening at a particular place and time. Finding order also helps you predict what may happen next, which can be very important in a lot of situations.

This is a book on thinking about and understanding your physical surroundings. These surroundings range from the obvious, such as the landscape and the day-to-day weather, to the not so obvious, such as how atoms are put together. Your physical surroundings include natural things as well as things that people have made and used (figure 1.1). You will learn how to think about your surroundings, whatever your previous experience with thought-demanding situations. This first chapter is about "tools and rules" that you will use in the thinking process.

Objects and Properties

Physical science is concerned with making sense out of the physical environment. The early stages of this "search for sense" usually involve **objects** in the environment, things that can be seen or touched. These could be objects you see every day, such as a glass of water, a moving automobile, or a blowing flag. They could be quite large, such as the sun, the moon, or even the Solar System, or invisible to the unaided human eye. Objects can be any size, but people are usually concerned with objects that are larger than a pinhead and smaller than a house. Outside these limits, the actual size of an object is difficult for most people to comprehend.

As you were growing up, you learned to form a generalized mental image of objects called a **concept.** Your concept of an object is an idea of what it is, in general, or what it should be according to your idea (figure 1.2). You usually have a word stored away in your mind that represents a concept. The word "chair," for example, probably evokes an idea of "something to sit on." Your generalized mental image for the concept that goes with the word "chair" probably includes a four-legged object with a backrest. Upon close inspection, most of your (and everyone else's) concepts are found to be somewhat vague. For example, if the word "chair" brings forth a mental image of something with four legs and a backrest (the concept), what is the difference between a "high chair" and a "bar stool"? When is a chair a chair and not a stool? Thinking about this question is troublesome for most people.

Not all of your concepts are about material objects. You also have concepts about intangibles such as time, motion, and relationships between events. As was the case with concepts of material objects, words represent the existence of intangible concepts. For example, the words "second," "hour," "day," and "month" represent concepts of time. A concept of the pushes and pulls that come with changes of motion during an airplane flight might be represented with such words as "accelerate" and "falling." Intangible concepts might seem to be more abstract since they do not represent material objects.

Figure 1.2
What is your concept of a chair? Are all of these pieces of furniture chairs? Most people have concepts, or ideas of what things in general should be, that are loosely defined. The concept of a chair is one example of a loosely defined concept.

By the time you reach adulthood you have literally thousands of words to represent thousands of concepts. But most, you would find on inspection, are somewhat ambiguous and not at all clear-cut. That is why you find it necessary to talk about certain concepts for a minute or two to see if the other person has the same "concept" for words as you do. That is why when one person says, "Boy, was it hot!" the other person may respond, "How hot was it?" The meaning of "hot" can be quite different for two people, especially if one is from Arizona and the other from Alaska!

The problem with words, concepts, and mental images can be illustrated by imagining a situation involving you and another person. Suppose that you have found a rock that you believe would make a great bookend. Suppose further that you are talking to the other person on the telephone and you wish to discuss the suitability of the rock as a bookend. But you do not know the name of the rock. If you knew the name, you would simply state that you found a "_____ ." Then you would probably discuss the rock for a minute or so to see if the other person really understood what you were talking about. But not knowing the name of the rock, and wishing to communicate about the suitability of the object to serve as a bookend, what would you do? You would probably describe the characteristics, or **properties,** of the rock. Properties are the qualities or attributes that, taken together, are usually peculiar to an object. Since you commonly determine properties with your senses (smell, sight,

Figure 1.3

Could you describe this rock to another person over the telephone so that person knows *exactly* what you see? This is not probable with everyday language, which is full of implied comparisons, assumptions, and imprecise descriptions.

hearing, touch, and taste), you could say that the properties of an object are the effect the object has on your senses. For example, you might say that the rock is a "big, yellow, smooth rock with shiny gold cubes." But consider the mental image that is formed in the mind of the other person on the telephone when these properties are described. It is entirely possible that the other person is thinking of something very different from what you are describing (figure 1.3)!

As you can see, the example of describing a proposed bookend by listing its properties in everyday language leaves much to be desired. The description does not really help the other person form an accurate mental image of the rock. One problem with the attempted communication is that the description of any property implies some kind of **referent.** Referent means that you *refer to,* or think of, a given property in terms of another, more familiar object. Colors, for example, are sometimes stated with a referent. Examples are "sky blue," "grass green," or "lemon yellow." The referents for the colors blue, green, and yellow are, respectively, the sky, living grass, and a ripe lemon.

Referents for properties are not always explicit as with colors, but a comparison is always implied. Since the comparison is implied, it often goes unspoken and leads to assumptions in comunications. For example, when you stated that the rock was "big," you assumed that the other person knew that you did not mean as big as a house or even as big as a bicycle. You assumed that the other person knew that you meant that the rock was about as large as a book, perhaps a bit larger.

Another problem with the listed properties of the rock is the use of the word "smooth." The other person would not know if you meant that the rock *looked* smooth or *felt* smooth. After all, some objects can look smooth and feel rough. Other objects can look rough and feel smooth. Thus, here is another assumption, and probably all of the properties lead to implied comparisons, assumptions, and a not very accurate communication. This is the nature of your everyday language and the nature of most attempts at communication.

ACTIVITIES

1. Find out how people communicate about the properties of objects. Ask several friends to describe a paper clip while their hands are behind their backs. Perhaps they can do better describing a goatee-type beard? Try to make a sketch that represents each description.
2. Ask two classmates to sit back to back. Give one of them a sketch or photograph that shows an object in some detail, perhaps a guitar or airplane. This person is to describe the properties of the object *without naming it.* The other person is to make a scaled sketch from the description. Compare the sketch to the description, then see how the use of measurement would improve the communication.

Quantifying Properties

Typical day-to-day communications are often vague and leave much to be assumed. A communication between two people, for example, could involve one person describing some person, object, or event to a second person. The description is made by using referents and comparisons that the second person may or may not have in mind. Thus such attributes as "long" fingernails or "short" hair may have entirely different meanings to different people involved in a conversation. Assumptions and vagueness can be avoided by using **measurement** in a description. Measurement is a process of comparing a property to a well-defined and agreed-upon referent. The well-defined and agreed-upon referent is used as a standard called a **unit.** The measurement process involves three steps: (1) *comparing* the referent unit to the property being described, (2) following a *procedure,* or operation, which specifies how the comparison is made, and (3) *counting* how many standard units describe the property being considered.

As an example of how the measurement process works, consider the property of *length.* Most people are familiar with the concept of the length of something ("long" or "short"), the use of length to describe distances ("close" or "far"), and the use of length to describe heights ("tall" or "short"). The referent units used for measuring length are the familiar inch, foot, and mile from the English system and the centimeter, meter, and kilometer of the metric system. These systems and specific units will be discussed later. For now, imagine that these units do not exist but that you need to measure the length and width of this book. This imaginary exercise will illustrate how the measurement process eliminates vagueness and assumption in communication.

The first requirement in the measurement process is to choose some referent unit of length. You could arbitrarily choose something that is handy, such as the length of a standard paper

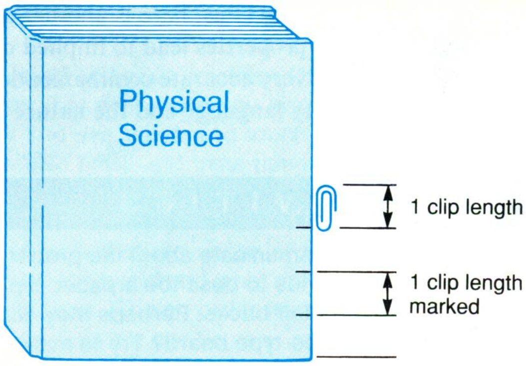

Figure 1.4

As an example of the measurement process a standard paper clip length is selected as a referent unit. The unit is compared to the property that is being described. In this example, the property of the book length is measured by counting how many clip lengths describe the length.

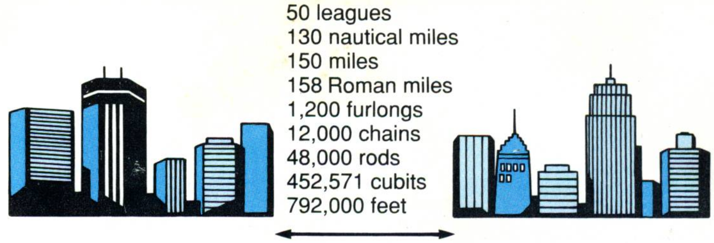

Figure 1.5

All of these units and values have been used at some time or another to describe the same distance between two towns. Any unit could be used for this purpose, but when one particular unit is officially adopted, the unit becomes known as the standard unit.

clip, and you could call this length a "clip." Now you must decide on the procedure, which specifies how you will use the clip unit. You could define some specific procedures. For example:

1. Place a clip parallel to and on the long edge, or length, of the book so the end of the referent clip is lined up with the bottom edge of the book. Make a small pencil mark at the other end of the clip as shown in figure 1.4.
2. Move the outside end of the clip to the mark and make a second mark at the other end. Continue doing this until you reach the top edge of the book.
3. Compare how may clip replications are in the book length by counting.
4. Record the length measurements by writing (a) how many clip replications were made and (b) the name of the clip length.

If the book length did not measure to a whole number of clips, you might need to divide the clip length into smaller subunits to be more precise. You could develop a *scale* of the basic clip unit and subunits. In fact, you could use multiples of the basic clip unit for an extended scale, using the scale for measurement rather than moving an individual clip unit. You could call the scale a "clipstick" (as in yardstick or meterstick).

The measurement process thus uses a defined referent unit, which is compared to a property being measured. The *value* of the property is determined by counting the number of referent units. The name of the unit implies the procedure that results in the number. A measurement statement always contains a *number* and *name* for the referent unit. The number answers the question of "how much?" and the name answers the question "of what?" Thus a measurement always tells you "how much of what." You will find that using measurements will sharpen your communications. You will also find that using measurements is one of the first steps in understanding your physical environment.

Measurement Systems

Measurement is a process that brings precision to a description by specifying the "how much" and "of what" of a property in a particular situation. A number expresses the value of the property and the name of a unit tells you what the referent is as well as implying the procedure for obtaining the number. Referent units must be defined and established, however, if others are to understand and reproduce a measurement. It would be meaningless, for example, for you to talk about a length in "clips" if other people did not know what you meant by a "clip" unit. When standards are established the referent unit is called a **standard unit** (figure 1.5). The use of standard units makes it possible to communicate and duplicate measurements. Standard units are usually defined and established by governments and their agencies that are created for that purpose. In the United States, the agency concerned with measurement standards is appropriately named the National Bureau of Standards.

There are two major *systems* of standard units in use today, the English system and the metric system. The metric system is used throughout the world except in the United States, where both systems are in use. The continued use of the English system in the United States presents problems in international trade, so there is pressure for a complete conversion to the metric system. More and more metric units are being used in everyday measurements, but a complete conversion will involve an enormous cost. Both the metric system and the English system will be used in this text. You can therefore use units that are more familiar to you as you learn to use the metric system. Appendix A contains a simple method to convert from one system to the other easily. Consult this section if you need to convert from one metric unit to another metric unit or to convert from English to metric units or vice versa.

People have used referents to communicate about properties of things throughout human history. The ancient Greek civilization, for example, used units of *stadia* to communicate about distances and elevations. The "stadium" was a referent unit based on the length of the race track at the local stadium ("stadia" is the plural of stadium). Later civilizations, such as the ancient Romans, adopted the stadia and other referent units from the ancient Greeks. Some of these very same referent units were later adopted by the early English civilization, which eventually led to the **English system** of measurement. Some adopted units of the English system were originally based on parts of the human body, presumably because you always had these referents with you (figure 1.6). The inch, for example, used the end joint of the thumb for a referent. A foot, naturally, was the length

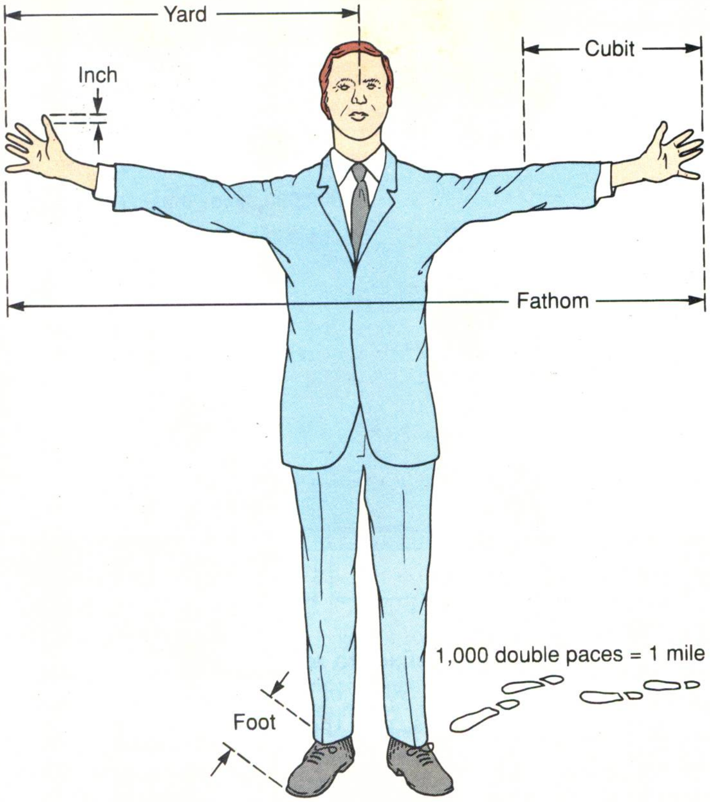

Figure 1.6

Many early units for measurement were originally based on the human body. Some of the units were later standardized by governments to become the basis of the English system of measurement.

of a foot, and a yard was the distance from the tip of the nose to the end of the fingers on an arm held straight out. A cubit was the distance from the end of an elbow to the fingertip, and a fathom was the distance between the fingertips of two arms held straight out. As you can imagine there were problems with these early units because everyone was not the same size. Beginning in the 1300s the size of the units were gradually standardized by various English kings (table 1.1). In 1879, the United States, along with sixteen other countries, signed the *Treaty of the Meter,* defining the English units in terms of the metric system. The United States thus became officially metric but not entirely metric in everyday practice.

The **metric system** was established by the French Academy of Sciences in 1791. The academy created a measurement system that was based on invariable referents in nature, not human body parts. These referents have been redefined over time to make the standard units more reproducible. In 1960, six standard metric units were established by international agreement. The *International System of Units,* abbreviated *SI,* is a modernized version of the metric system. Today, the SI system has seven units that define standards for the properties of length, mass, time, electric current, temperature, amount of substance, and light intensity. The standard units for the properties of

Table 1.1

Early conversion table for English units of volume

2 mouthfuls	= 1 jigger	2 quarts	= 1 pottle
2 jiggers	= 1 jack	2 pottles	= 1 gallon
2 jacks	= 1 jill	2 gallons	= 1 pail
2 jills	= 1 cup	2 pails	= 1 peck
2 cups	= 1 pint	2 pecks	= 1 bushel
2 pints	= 1 quart		

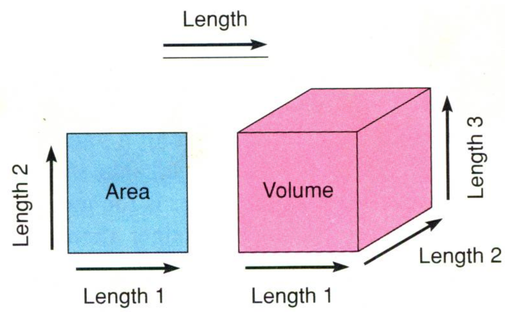

Figure 1.7

Area, or the extent of a surface, can be described by two length measurements. Volume, or the space that an object occupies, can be described by three length measurements. Length, however, can be described only in terms of how it is measured, so it is called a fundamental property.

length, mass, and time are introduced in this chapter. The remaining units will be introduced in later chapters as the properties the units measure are discussed.

Standard Units for the Metric System

If you consider all the properties of all the objects and events in your surroundings, the number seems overwhelming. Yet, close inspection of how properties are measured reveals that some properties are combinations of other properties (figure 1.7). Volume, for example, is described by the three length measurements of length, width, and height. Area, on the other hand, is described by just the two length measurements of length and width. Length, however, cannot be defined in simpler terms of any other property. There are four properties that cannot be described in simpler terms, and all other properties are combinations of these four. For this reason they are called the **fundamental properties.** A fundamental property cannot be defined in simpler terms other than to describe how it is measured. These four fundamental properties are (1) *length,* (2) *mass,* (3) *time,* and (4) *charge.* Used individually or in combinations, these four properties will describe or measure what you observe in nature. Metric units for measuring the fundamental properties of length, mass, and time will be described next. The fourth fundamental property, charge, is associated with electricity, and a unit for this property will be discussed in a future chapter.