An Introduction to Physical Science

Seventh Edition

SHIPMAN WILSON TODD

An Introduction to Physical Science

Seventh Edition

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Lexington, Massachusetts *Toronto*

To

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Preface

In today's world, a knowledge of science and an understanding of modern technology grow increasingly important. Our purpose in revising *An Introduction to Physical Science* for this Seventh Edition is to stimulate student interest in the physical sciences and to present the skills needed to cope in this technological society.

This textbook, written for the first-year college nonscience major, presents basic concepts in the five major areas of physical science: physics, chemistry, astronomy, meteorology, and geology. Unlike many other texts, we present a balanced coverage of the five subject areas.

We have made these concepts easily accessible to students by developing them in a logical rather than a chronological fashion and by discussing them in the context of everyday experience. Chapter 1 begins with the fundamental concepts of measurement. From these fundamentals, we move on progressively to the concepts of motion, force, energy, wave motion, heat, electricity, magnetism, and modern physics. These concepts are then used to develop the principles of chemistry, astronomy, meteorology, and geology. The text is readily adaptable to either a one- or two-semester course, as its past success has demonstrated.

We have treated each discipline both descriptively and quantitatively. Even though we have provided mathematical assistance for those students who may need it the most, the relative emphasis, whether descriptive or quantitative, is left to the discretion of the instructor. To those who wish to emphasize the descriptive approach in teaching physical science, we recommend using only the Questions at the end of each chapter and omitting the Exercises.

Changes in the Seventh Edition

The most significant change to *An Introduction to Physical Science* is the addition of a new author, Aaron W. Todd, to our team. Dr. Todd has rewritten the chemistry section completely, updating material and providing real-world examples to explain concepts in chemistry.

We have updated all other areas of the text as well and have added many new photos, including the first close-up view of an asteroid and the first photo by the Hubble Space Telescope of the solar system.

Another outstanding feature of *An Introduction to Physical Science,* Seventh Edition is the pedagogy in every chapter (see A Note From the Authors on p. xv). First, we have added a chapter outline to the beginning of each chapter. Next, wherever appropriate, we have provided a step-by-step solution to model problems and in-text exercises in the chapter. We have added paired exercises to the end-of-chapter material—one exercise has the answer provided, the other is left for the student to work out. A third paired exercise with a complete solution is in the students' *Study Guide.* Finally, we have added Thought Questions at the end of each chapter to stimulate cumulative learning and further application of concepts covered in the text.

We have expanded the coverage of environmental issues and real-world examples throughout the text to emphasize the importance of physical science in understanding the world we live in. We continue to emphasize historic and special-interest topics in Highlight boxes, and there is now at least one Highlight box per chapter.

SUPPLEMENTS

Many of the supplements have been revised and updated in response to user recommendations.

• The *Study Guide,* by James T. Shipman, Jerry D. Wilson, Aaron W. Todd, and Clyde D. Baker. Each chapter includes study goals, a revised discussion that summarizes the text chapter; review questions, each with an essay answer; solved problems, including a third paired exercise with solution; multiple-choice questions, some with explanations; and two quizzes, one multiple-choice and one short-answer. The Math Review at the end of the *Study Guide* provides additional practice for students.

• The *Instructor's Guide* by James T. Shipman, Jerry D. Wilson, and Aaron W. Todd, has been updated to accommodate text changes, particularly in chemistry. The *Guide* includes Teaching Aids and audiovisual resources for each of the five sciences. Each chapter includes a brief discussion, suggested demonstrations, answers to text questions and solutions for exercises, and answers to the *Study Guide* quizzes.

• The *Laboratory Guide,* by James T. Shipman and Clyde D. Baker, contains 6 new experiments for a total of 53. Each experiment includes an introduction, learning objectives, a list of required apparatus, a detailed procedure for collecting data (requiring students to generate tables and graphs and to perform calculations), and questions about the experiment.

• The *Instructor's Resource Manual for the Laboratory Guide,* by James T. Shipman and Clyde D. Baker, includes an integrated equipment list to assist instructors in planning experiments. Additional data and calculations are provided for most experiments, as well as answers to the *Lab Guide* questions, a discussion of each experiment, and additional questions.

• The *Instructor's Test Bank,* available to adopters, offers a printed version of more than 2000 questions in completion, multiple-choice, and short-answer formats. Most of the questions in the chemistry section are completely new.

• The *Test Bank* questions are also available in a computerized testing program. Instructors can produce chapter tests, midterms, and final exams—with graphics—easily. Instructors may edit existing questions or add new ones as desired and preview questions on screen. The computerized testing program is available for IBM, Macintosh, and Apple computers.

• The Transparencies—more than 80 one-, two-, and four-color—illustrate important concepts from the text and are available to adopters of the Seventh Edition. Most of the transparencies from the chemistry chapters are completely new.

Acknowledgments

We wish to thank our colleagues and students for the many contributions made to this Seventh Edition of *An Introduction to Physical Science.* We would also like to thank the following reviewers for their suggestions and comments:

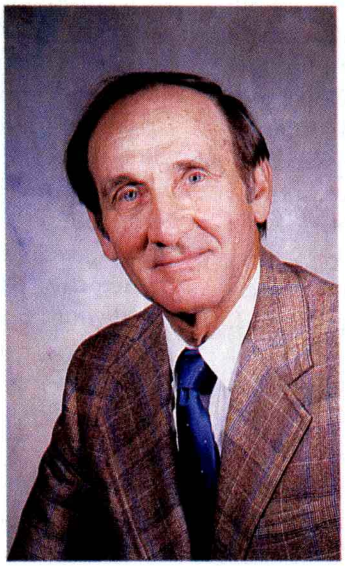
Stephen R. Addison, University of Central Arkansas; Barry Barnhart, Harrisburg Area Community College; J. Edward Bennett, Arkansas State University; William J. Brown, Montgomery Community College; Anthony W. Gray, Community College of Allegheny County; Eric Harms, Brevard Community College; Gary D. Henson, East Tennessee State University; Jo Ann Heslip, University of Arkansas at Pine Bluff; J. Ronald Mowery, Harrisburg Area Community College; David Munch, Seattle Central Community College; Bruce E. Perry, Miami University; D. K. Philbin, Allan Hancock College; Ross J. Sears, Lake City Community College; Randy G. Shadburn, Northeast Missouri Community College; Kathy Cox Stokes, Jefferson Davis College; Barbara Z. Thomas, Brevard Community College; Susan Todd, Brookhaven College; Charles A. Weatherford, Florida A & M University; Cheryl Williams, Gainesville College; Linda Arney Wilson, Middle Tennessee State University.

We are grateful to those individuals and organizations who contributed photographs, illustrations, and other information used in this text. We are also indebted to the D. C. Heath staff for their dedicated and conscientious efforts in producing this Seventh Edition. In particular, we thank Kent Porter Hamann, acquisitions editor; Barbara Withington Meglis, developmental editor; Kathleen Deselle, production editor; Alwyn Velásquez, book designer; Sue McDermott, photo researcher; and Joanne Williams, assistant developmental editor in charge of supplements. Finally, we acknowledge the contributions of Genny Shipman, Clyde Baker, and Howard H. Hively, Jr., to the various aspects of the writing and production of this book and its supplements.

We welcome comments from students and instructors of physical science, and invite you to forward your impressions and suggestions.

J.T.S.
J.D.W.
A.W.T.

About the Authors



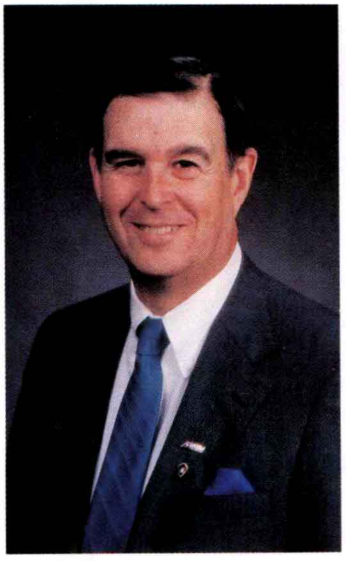
After serving in the U.S. Navy during World War II, **James T. Shipman** attended Ohio University. He received his B.S. and M.S. degrees from Ohio and an honorary Ph.D. from Chubu University in Japan. For 25 years, he taught physics and physical science at Ohio, where he was also Department Chair for five years (1968-73). He has also taught physics and/or physical science at Clark College, Fairmont State College, and Salem-Teikyo University.

Professor Shipman has received and has served as director of several National Science Foundation education grants. His research activities have included radio tracking. He is a member of the American Association of Physics Teachers, and he has served as president of the Appalachian Section. He has written a number of other books, including *Fundamentals of Physical Science, Concepts of Modern Physics and Chemistry*, the *Physical Science Laboratory Guide*, and the six earlier editions of *An Introduction to Physical Science.* A translation of the physics section of *An Introduction to Physical Science* is currently used in Japan.

Dr. Shipman is now Professor Emeritus of Physics at Ohio University, where he remains active in writing and continues an active role. He serves on the National Campaign Council. He is now semiretired and living in West Virginia, his native state.

Jerry D. Wilson, a native of Ohio, is now Professor Emeritus of Physics and former Chair of the Division of Biological and Physical Sciences at Lander University in Greenwood, South Carolina. He received his B.S. from Ohio University, an M.S. from Union College, and in 1970 a Ph.D. from Ohio University. As a doctoral graduate student, he taught physical science and held the faculty rank of Instructor. He wrote his portion of the first edition of *An Introduction to Physical Science* at that time. The text, now in its seventh edition, was originally published locally in three sections before being published nationally *in toto* in 1971 by D. C. Heath and Company.

Recently retired from full-time science teaching, Dr. Wilson continues writing and currently has three other texts and a laboratory manual in publication in various editions–*Physics: A Practical and Conceptual Approach, Technical College Physics,* and *College Physics.* His popular laboratory manual, *Physics Laboratory Experiments,* published by D. C. Heath, is now in its third edition. He has also written articles for professional journals and presented a number of papers at various scientific-organization meetings. He writes a weekly column, The Science Corner, for local newspapers.



Aaron W. Todd is Professor of Chemistry and coordinator of the general education physical science course at Middle Tennessee State University in Murfreesburo. Although a native Tennessean, he received his B.S. and Ph.D. in chemistry at Georgia Tech, where he earned the Woodruff Award for outstanding chemistry major.

Professor Todd's teaching interest lies in the area of general education science, and he has won the university's outstanding teacher award. He has served on the national board of the Association for General and Liberal Studies. For twelve years he was the national director for The Gamma Beta Phi Society, a college honor-service organization, leading an expansion of the Society from 20 chapters to 80. Dr. Todd has authored two physical science lab manuals and served as reviewer for numerous textbooks. He spends much of his free time on the golf course and maintains a 4 handicap. He also enjoys collecting minerals and fossils.

A Note From the Authors

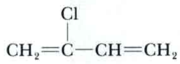
In this Seventh Edition of *An Introduction to Physical Science,* we have paid particular attention not only to helping students solve problems but also to providing current, relevant examples of physical science. In the following pages, we point out some of the features in this edition that will help students think logically when approaching a word problem, guide them through the solution process, and apply the principles they learn in each chapter to their own world.

Unlike many other texts in the field, ours has balanced coverage of the five areas of physical science: physics, chemistry, astronomy, meteorology, and geology.

Brief Table of Contents

A Note From the Authors

Our brand-new chemistry section, Chapters 11–15, written by new coauthor, Aaron W. Todd, has many real-world examples to generate interest in chemistry and a thorough explanation of concepts to help students understand chemistry.



Neoprene (the monomer)

Condensation polymers are constructed from molecules that have two or more reactive groups. One molecule attaches to another by an ester or amide linkage. Water is the other product, hence the name condensation polymer. Of course, if a simple monoacid reacts with a monoalcohol or monoamine, the reaction stops with the condensation of the two molecules and there is no chance to form a long-chain polymer. However, if a diacid reacts with a dialcohol or a diamine, the reaction can go on and on. Examples are the formation of polyesters such as Dacron and polyamides such as nylon, which are widely used as synthetic fibers (Fig. 15.11). Velcro is made of two nylon strips, one strip having thick loops that are slit open to form "hooks" and the other having thin, closed loops that entangle the slit fibers when the sides are pressed together (Fig. 15.12). The inventor of Velcro took his idea from noticing how cockleburrs clung to his clothing when he walked through a field.

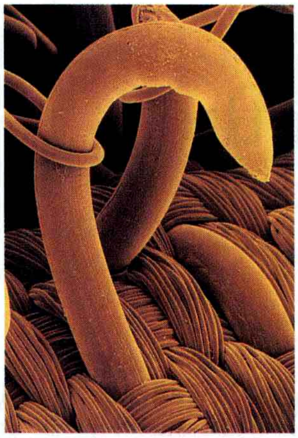


Figure 15.12 A scanning electron micrograph of Velcro.

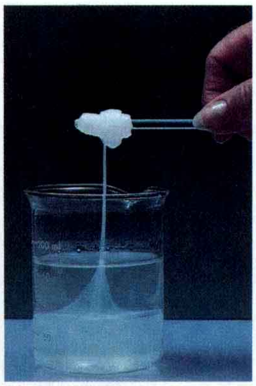


Figure 15.11 Nylon, a polyamide, synthesized 1935 by Dr. Wallace Carothers at Du Pont. Here a strand of nylon is being drawn from t interface of the two reactants, where reactio occurring.

Every reaction is to some extent reversible. That is, there will always be some of every kind of atom or molecule present that can possibly occur in a reaction. For example, consider the reaction

$$2\,HI \longrightarrow H_2 + I_2$$

This equation says that hydrogen iodide decomposes into hydrogen and iodine. However, any sample containing both hydrogen and iodine will contain some hydrogen iodide, even though it may be a very small amount. To show explicitly that this is the case, we write the reaction with a smaller arrow going from right to left:

$$2\,HI \rightleftharpoons H_2 + I_2$$

Writing the reaction this way emphasizes its reversibility, however slight. In the discussions that follow we will omit the smaller arrow from right to left. It will be understood that at equilibrium some molecules of all the various reactants and products are always present in the reaction.

13.3 Balancing Equations

A chemical reaction is simply a rearrangement of atoms in which some of the original chemical bonds are broken and new bonds are formed to give different chemical structures (Fig. 13.3). Only an atom's valence electrons are directly involved in a chemical reaction. The nucleus, and hence the atom's identity as a particular element, is unchanged.

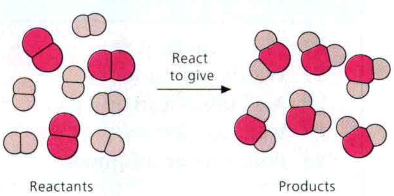


Figure 13.3 A chemical reaction, such as hydrogen and oxygen reacting to give water, is a rearrangement of atoms.
Bonds are broken in the reactants and new bonds are formed to give the products. No atoms can be lost, gained, or changed in identity.

A chemical equation can be written for each chemical reaction. The correct chemical formulas for the reactants and products must be used. For example, the decomposition of hydrogen iodide is written, $HI \longrightarrow H_2 + I_2$. However, until the equation is *balanced,* it does not express the actual *ratio* in which the substances react and form. Most chemical reactions can be balanced by trial and error using three simple principles.

1. The same number of atoms of each element must be represented on each side of the reaction arrow, because no atoms can be gained, lost, or changed in identity during a chemical reaction.

The equation $HI \rightarrow H_2 + I_2$ is unbalanced because two atoms of H and I are represented on the right side, but only one of each is known on the left side.

2. When balancing an equation, you may manipulate only the *coefficients*—the numbers in front of the formulas, which designate the relative amounts of the substance—and not the subscripts, which denote the correct formulas of the substances.

Thus, you cannot balance the equation above by changing the formula of HI to H_2I_2. However, you can place a coefficient of 2 before the formula of HI. The 2 HI represents two molecules of hydrogen iodide, each made up of one hydrogen atom and one iodine atom. This gives $2\,HI \rightarrow H_2 + I_2$ and balances the equation. (Just as with subscripts, a coefficient of 1 is not written, just understood.)

3. The final set of coefficients must be whole numbers (not fractions) and should be the smallest whole numbers that will do the job.

For example, $2\,HI \rightarrow H_2 + I_2$ is correct, but not $HI \rightarrow \frac{1}{2}H_2 + \frac{1}{2}I_2$ or $4\,HI \rightarrow 2\,H_2 + 2\,I_2$

The following tips will help you to apply the three principles.

1. You must be able to count atoms, and this requires understanding subscripts and coefficients. Consider $4\,Al_2(SO_4)_3$. The subscript 2 multiplies the Al; the subscript 3 multiplies everything in parentheses; the coefficient 4 multiplies the whole formula. Therefore, a total of 8 Al atoms, 12 S atoms, and 48 O atoms are on

HIGHLIGHT

Frost Formation and Bacteria

Research has shown that frost is a result of bacteria-seeded ice formation. Without two common types of bacteria on leaf surfaces, water will not freeze at 0°C but can be supercooled to −6° to −8°C. These bacteria exist on shrubs, fruit trees, and so on, throughout the United States and serve as nuclei for frost formation.

With frost damage to crops and fruits exceeding $1 billion a year, scientists are exploring techniques to prevent the formation of bacteria-seeded frost. One method involves the development of genetically engineered bacteria altered so that they no longer trigger ice formation. Researchers believe that a protein on the surface of the bacterium acts as the seed for the formation of frost. By genetically removing the gene that serves as the blueprint for that protein, they hope to make "frost-free" bacteria.

Field trials for genetically altered bacteria were blocked for some time by legal actions. Some concerned citizens believe that the regular ice-seeding bacteria blown into the atmosphere may be important in precipitating rain and snow. Should the genetically engineered bacteria get into the atmosphere, people fear that the bacteria might alter the climate.

Antifrost bacteria were sprayed on test fields of strawberry and potato plants (Fig. 1). They did reduce the frost damage, and there was no evidence that the microbes had spread outside the test plots.

Figure 1 Antifrost bacteria.
Genetically altered, frost-fighting bacteria being sprayed on a newly planted potato field. Such initial tests were successful in reducing frost formation.

t. The presence of a catalyst is indicated by g its formula over the reaction arrow.

$$2\,KClO_3 + \text{heat} \xrightarrow{MnO_2} 2\,KCl + 3\,O_2$$

common example of catalysis is the use of ic converters in cars. Beads of a platinum or ium catalyst are packed into a chamber gh which the exhaust gases must pass before ave the tailpipe. During the passage through nverter, CO and NO are changed to CO_2 and hich are normal components of the atmo-. This results in a great decrease in air ion.

atalysts are used extensively in manufacturing, ey also play an important part in biochemical sses. The human body has many thousands of sts called **enzymes** that act to control various logical reactions. The names of enzyme cat-usually end in *-ase*. During digestion, lactose sugar) is broken down in a reaction catalyzed enzyme lactase. Many infants and adults, par-ly those of African and Oriental descent, have iency of lactase and thus are unable to digest Glowworms and fireflies use enzymes to cat-*hemiluminescence* reactions in which light (but or no heat) is emitted from the excited molecular products of a reaction (Fig. 13.13). The bombardier beetle also uses enzymes (Fig. 13.14).

place rapidly at 250°C. The manganese dioxide is not consumed in the reaction but acts only as a

Expanded coverage of current environmental issues and new environmental examples both in Highlight boxes and in the text emphasize the connection between physical science and the environment in our world today.

Figure 13.13 Chemiluminescence.
Fireflies employ a light-emitting reaction between the compounds luciferin and adenosine triphosphate (ATP). The enzymatic catalyst is named luciferase.

Figure 13.14 Bombardier beetle.
An enzyme catalyzes the highly exothermic reaction that gives the hot spray of chemicals with which the beetle protects itself.

Powers-of-10 notation is very useful in expressing the results of mathematical operations with the proper number of significant figures, as discussed in the last section. For example, consider the calculator operation:

$$325 \times 45 = 14{,}625$$

To express the result with two significant figures by our general rule in Section 1.5, we write:

$$325 \times 45 = 1.5 \times 10^4$$

EXAMPLE 1.5 *Using Powers-of-10 Notation to Express Calculation Results*

Perform the following mathematical operation on a calculator and express the result properly using significant figures and scientific notation:

$$\frac{0.0024}{8.05} = ?$$

Solution

Doing this operation on a calculator gives

$$\frac{0.0024}{8.05} = 0.000298136$$

(*Note:* The number of digits in the result may vary with different calculators.)

The number 0.0024 has two significant figures, since the zeros to the left simply locate the measurement digits; and 8.05 has three significant figures. In the latter number the zero is significant because it is within the measured value.* Then we should write:

$$\frac{0.0024}{8.05} = 3.0 \times 10^{-4}$$

1.7 Approach to Problem Solving

One of the major difficulties many students have in science is solving problems, particularly word problems. There is no set way to work a problem. In fact, it may be possible to use more than one approach to obtain a correct solution. Even so, a general procedure is helpful in most cases. The following procedure will guide you in solving a problem by giving you steps to follow as you analyze it.

Step 1
Read the problem and identify the chapter principle(s) that applies to it. Write down the given quantities using symbol representation. (Be sure to include units.)

Step 2
Determine what is wanted and write it down. (This is very important. You have to know what is wanted before you can find it.) Then check to see that the units of the given quantities are appropriate. If they are not, use appropriate conversion factors. In general, all quantities should be expressed in the same system of units. Your answer will then be in units of that system.

Step 3
Survey the chapter equations and determine the one that relates what is given to what is wanted. (In some instances, two equations may be necessary.) Perform the mathematical operation(s) and express your answer with the appropriate units and number of significant figures.

Let's apply these steps to an example. In general, an *expanded* procedure, as follows, will be done in the text when a new concept is introduced in order to help you understand its application.

EXAMPLE 1.6 *Applying Problem-Solving Procedures to Find the Distance Earth Travels Around the Sun*

Earth goes around the Sun in a nearly circular orbit with a radius of 93 million miles. How many miles does Earth travel in making one revolution about the Sun?

Solution

Step 1
Here, the given quantity is the radius of Earth's (approximately) circular orbit, and we have

GIVEN: $r = 93$ million miles $= 9.3 \times 10^7$ mi

* See Appendix V for rules in determining the number of significant figures.

Step-by-step problem-solving strategies and procedures are highlighted for easy student reference.

gain note how the units cancel. In effect, this cancellation tells you what form of the conversion factor u should use.

You can perform a similar exercise to convert ass to weight or vice versa on Earth's surface. rictly speaking, mass and weight refer to two fferent quantities. They are not equal, but a given ass does have an equivalent weight on Earth. The propriate conversion factor on Earth's surface is

$$1 \text{ kg (mass)} = 2.2 \text{ lb (weight)}$$

ere is an example done in stepwise form. The steps ay be summarized as follows:

Steps for Converting One Unit to Another

Step 1 **Use a conversion factor, that is, a ratio that may be obtained from an equivalence statement. [Often these factors or statements must be looked up in a table (see the inside back cover of this text).]**

Step 2 **Choose the appropriate form of conversion factor (or factors) so that the unwanted units cancel.**

Step 3 **Check to see that the units cancel and that you have the desired unit. Then perform the multiplication or division of the numerical quantities.**

EXAMPLE 1.1 *Conversion Factors: One-Step Conversion*

A student weighs 132 lb. What is the student's mass in kilograms?

Solution

One might represent this problem by an equivalence statement:

$$132 \text{ lb} = ? \text{ kg}$$

That is, 132 lb is equivalent to how many kilograms?

We carry out the conversion using an appropriate conversion factor:

Step 1
Using the equivalence statement

$$1 \text{ kg} = 2.2 \text{ lb}$$

the cm unit on both sides of the equation.

QUESTION What is this height (165 cm) in meters?

Answer 1.65 m. Can you do this conversion in your head? Write it out with a conversion factor so you can see the procedure.

Alternative Approach: Another approach to unit conversion starts with an identity equation, for example,

$$65.0 \text{ in.} = 65.0 \text{ in.}$$

Then, the right side of the equation is operated on with the appropriate conversion factor(s):

$$65.0 \text{ in.} = 65.0 \not{\text{in.}} \times \frac{2.54 \text{ cm}}{1 \not{\text{in.}}} = 165 \text{ cm}$$

In this manner, the original identity equation is transformed into a statement of equivalence.

One can easily convert the other way (cm to in.) by using the other form of the conversion factor:

$$165 \not{\text{cm}} \times \frac{1 \text{ in.}}{2.54 \not{\text{cm}}} = 65.0 \text{ in.}$$

is that it contains not only ^{12}C but also a little ^{13}C and ^{14}C.

Example 11.1 *Calculating an Element's Atomic Mass*

Oxygen occurs naturally on Earth as a mixture of 99.759% oxygen-16 (atomic mass of isotope 15.9949 u), 0.037% as oxygen-17 (atomic mass of isotope 16.9991 u), and 0.204% as oxygen-18 (atomic mass of isotope 17.9992 u). Find the atomic mass of oxygen.

Solution

Step 1

Given: the percentage abundances and atomic masses of the three naturally occurring isotopes of oxygen

Step 2

Wanted: the atomic mass of the element oxygen

Step 3

Calculate the contribution each isotope ma
to the atomic mass by multiplying the *fracti*
abundance of each (the percentage abundance
vided by 100) by its atomic mass, then add
three answers to get the atomic mass of the
ment.

$0.99759 \times 15.9949\ u = 15.956\ u$ (^{16}O
$0.00037 \times 16.9991\ u = 0.0063\ u$ (^{17}O
$0.00204 \times 17.9992\ u = 0.0367\ u$ (^{18}O
for a total of 15.999 u

so, the atomic mass of oxygen is 15.999 u.

11.4 The Periodic Table

By 1869 a total of 65 elements had been discov
Dedicated researchers identified the atomic ma
careful measurement of the mass relationshi
chemical reactions) and other properties of
of them. However, except for a few sketchy atte
a system of classifying the elements had not
established. As discussed in the chapter High
it remained for the Russian chemist Dmitri
deleev (men-duh-LAY-eff) to formulate a sat
tory classification scheme—the periodic table.

The *periodic table* puts the elements, in order of increasing atomic number, into seven horizontal rows called **periods.** As a result, the elements' properties show regular trends, and similar properties occur *periodically;* that is, at definite intervals. In particular, elements having similar chemical properties fall into the same column. Later in this chapter we will see some examples of these regular trends. The modern statement of the **periodic law** is:

The properties of elements are periodic functions of the atomic number.

The vertical columns in the periodic table are called **groups.** At present there is some disagreement on the designation of the groups. In 1986 the IUPAC decreed that the groups be labeled 1 through 18 from left to right, as shown in the periodic table inside the front cover. However, for many years in the United States and elsewhere, the groups have been divided into A and B subgroups, also shown in your periodic table. Not many textbooks in the United States are changing to the new notation (it

All in-text examples are labeled to identify what text material is covered by the example.

Clear step-by-step solutions are provided to model in-text examples throughout the text.

Here's another labeled example, this one from astronomy, showing the step-by-step problem-solving approach.

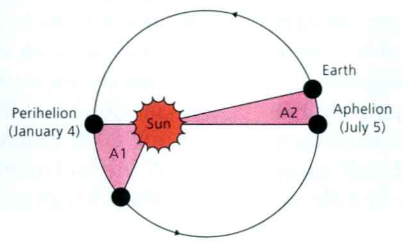


Figure 16.7 Kepler's law of equal areas.
An imaginary line joining a planet to the Sun sweeps out equal areas in equal periods of time. Area A1 equals area A2. Earth has a greater orbital speed in January than in July.

The square of the sidereal period of a planet is proportional to the cube of its semimajor axis (its mean distance to the Sun).

This can be written as

$$(\text{period})^2 \propto (\text{semimajor axis})^3$$

or

$$T^2 = kR^3 \tag{16.1}$$

where T = the sidereal period (time of one revolution in respect to a star),
R = the length of the semimajor axis,
k = the constant of proportionality (the same value for all planets).

If the sidereal period of the planet is measured in years and the semimajor axis in astronomical units, k is equal to $1\ y^2/1\ AU^3$.

Example 16.1 *Calculating the Period of a Planet*

Calculate the period of a planet whose orbit has a semimajor axis of 1.52 AU.

Solution

Step 1

Use Eq. 16.1 and substitute in the values for k and R.

$$T^2 = \frac{1\ y^2}{(1\ AU)^3} \times \frac{1.52^3\ AU^3}{1}$$

Step 2

Cube 1.52 AU and cancel the AU³s.

$$T^2 = 3.51\ y^2$$

Step 3

Take the square root of both sides.

$$T = 1.87\ y$$

Galileo Galilei (1564–1642), Italian astronomer, mathematician, and physicist who is usually called just Galileo, was one of the greatest scientists of all time (Fig. 16.8). The most important of his many contributions to science were in the field of mechanics. He originated the basic ideas for the formulation of Newton's first two laws of motion, and he founded the modern experimental approach to scientific knowledge. The motion of bodies, especially the planets, was of prime interest to Galileo. His concepts of motion and the forces that produce

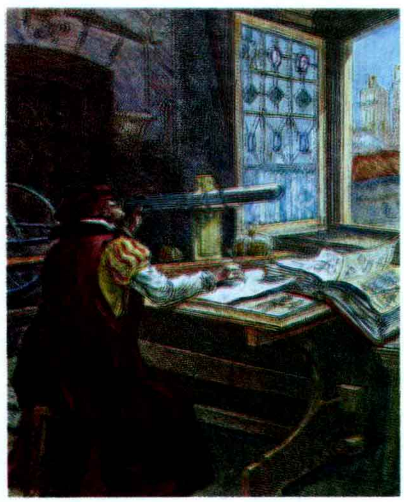


Figure 16.8 Galileo Galilei.
The great Italian scholar was the first to use the newly invented telescope to observe the planets and stars.

We have added several challenging Thought Questions to the end-of-chapter material to allow students to integrate material learned in the chapter with their own knowledge of the world. Here are Thought Questions from two separate chapters.

THOUGHT QUESTIONS (from Chapter 3)

1. Is it possible to have motion without a force? Explain.
2. When observing an object, how can you tell if an unbalanced force is acting on it? Can you always "see" what is applying the force?
3. Consider the following statements: Newton's first law may be derived from his second law. Newton's second law may be derived from his first law. Is either correct, and if so, why?
4. Suppose a hole could be drilled through the center of Earth to the other side. If an object were dropped down the hole, what would happen?
5. Someone suggested that a new, super space shuttle should include a basketball court so the astronauts could exercise. Describe how a basketball game might look if it were played in a space shuttle orbiting Earth.
6. When a rocket blasts off, is it the fiery exhaust gases "pushing against" the launch pad that causes it to lift off? Explain.

THOUGHT QUESTIONS (from Chapter 5)

1. We commonly say that machines do work for us. Do machines *save* us work? Explain?
2. Some factory workers are paid by the hour. Others may be on piecework (paid according to the number of pieces or items they process or produce). Is a power consideration involved in either of these methods of payment? Explain.
3. Can we detect energy with our senses? For example, can we smell energy?
4. The efficiency of a machine may be defined as the ratio or work output/work (energy) input and is usually expressed as a percentage. A perpetual-motion machine would have to have an efficiency of 100%. Explain why. What would it mean if a machine had an efficiency greater than 100%?
5. What happens when chemical energy is released?

We have also added paired exercises to the end-of-chapter material. One exercise has the answer provided, and the other is left for students to work out.

EXERCISES (from Chapter 14)

19. If the inside pressure of an automobile tire is 1.90 atm at 27°C and the car is then driven until the temperature inside the tire is 37°C, what is the new pressure in atm? Assume no expansion of the tire.

    Answer: 1.96 atm
20. A cylinder of compressed gas has a pressure of 95 atm at 25°C. If a fire breaks out and raises the temperature to 455°C, what will be the pressure in atm in the cylinder?

Introduction

"Bear in mind that the wonderful things that you learn in your schools are the work of many generations, produced by enthusiastic effort and infinite labor in every country of the world. All this is put into your hands as your inheritance in order that you may receive it, honor it, add to it, and one day faithfully hand it on to your children. Thus do we mortals achieve immortality in the permanent things that we create in common."
—Albert Einstein

This book will introduce you to the various disciplines of physical science, the basic laws that govern each of them, and some of the history of their development. This exploration will enrich your perspective of how scientific knowledge has grown throughout the course of human history, how science influences the world we live in today, and how it could be employed in the future.

The English word *science* is derived from the Latin *scientia,* meaning knowledge. Physical science is the organized knowledge of our physical environment and the methods used to obtain it. Physical science is classified into five major divisions: physics, the science of matter and energy; chemistry, the science of matter and its changes; astronomy, the science of the universe beyond our planet; meteorology, the science of climate and weather; and geology, the science of Earth and its history. Physical science studies the nonliving matter in the universe, whereas biological science studies the living matter.

Because we live in a highly technological age, we tend to view science myopically as an exclusive product of the twentieth century. An appreciation of the physical sciences, however, dates back to the beginning of the human race. Although the earliest humans did not have sophisticated tools with which to view the universe, they did have a curiosity about the world around them and a compelling need to survive in a harsh environment. The movement of the stars, the passing of the seasons, and the need to make tools, create fire, and predict the weather using the clues of the wind and the clouds grew out of such a curiosity or need and was addressed through observation of Earth and sky. Every aspect of physical science you study in this book has its roots in mankind's first observations.

Indeed, observation forms the basis of all scientific knowledge, even in the modern world. Scientific knowledge is cumulative, and if the earliest humans had not asked questions and made observations, our own knowledge of the physical sciences could not exist. Over the entire history of the human race, people have gathered information about physical science in very much the same way the first humans did.

But although observation has remained the first step in unveiling scientific discovery throughout history, the wealth of scientific knowledge has developed and advanced, and each new discovery yields the possibility for many more.

The activities of scientists are complex, and although they may not follow a given set of rules, scientists do approach problems in a systematic way. There is no single well-defined method or procedure for uncovering the secrets of nature; however, scientists find that some loose guidelines are helpful for isolating a phenomenon, determining the best way to observe it, and drawing conclusions from their observations. The scientific method is the main way that scientists define a problem and seek its solution. In general terms, the scientific method includes the following:

1. **Observation of phenomena and recording of facts.** *Phenomena* are defined as whatever happens in the environment, and *facts* are accurate descriptions of what is observed.
2. **Formulation of a theory** from the generalization of the phenomena. A *theory* is a description of a certain behavior of nature that extends beyond what has been observed—usually stated in general terms.
3. **Prediction of new data** and new phenomena based on the theory. A theory comprises a general scheme of thought that explains the nature or behavior of the phenomena and correlates the known facts in such a manner that new thoughts and relationships initiate the prediction of new phenomena. Einstein's theory of relativity and the kinetic theory of gases are examples.
4. **Experimentation** to confirm the new data or phenomena predicted by the theory.
5. **Confirmation, modification, or disposal of the theory**. Further predictions are made. Steps 4 and 5 are then repeated.

The scientific method is no magic formula, but rather a formulation of the thought processes that carry one from questions (observations of phenomena) to solutions (explanations of phenomena). Researchers in all disciplines of physical science employ its steps to increase scientific knowledge, not only on the edge of modern technology but also in very mundane ways. We hear daily about advances in technology, some of which will be discussed in this book. But it is more important that you use the concepts in this book to increase your understanding of how the scientific method affects your day-to-day life. The digital watch on your wrist, the compact disc player in your room, the optical scanner in your supermarket, and the calculator as small as a credit card all resulted from scientists employing the scientific method to discover new technology and apply it usefully.

We hope you will not only become knowledgeable about how the scientific method applies to your life but also about why scientific discovery appears to take such a haphazard course. An understanding of how scientists learn should give you a better grasp of how technological change occurs and why our knowledge seems to be increasing rapidly in one area yet slowly in another. As you read about the many scientific discoveries discussed in the text, you should realize that major discoveries often come to light by accident, and years of intense research may yield few results. While we may discuss the scientific method as discrete and organized steps in the pursuit of knowledge, the reality of scientific discovery rarely follows a predictable course.

The world in which we live changes constantly, and people are constantly seeking to discover and understand these changes. Scientific research results in advances in technology and affects all aspects of our daily life. To cope with a rapidly evolving society, each individual needs to know and understand the physical concepts that make technological advancement possible. Complex issues such as industrialization, pollution control and cleanup, space exploration, and the search for new energy sources will therefore demand a basic understanding of basic physical concepts and their modern applications.

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