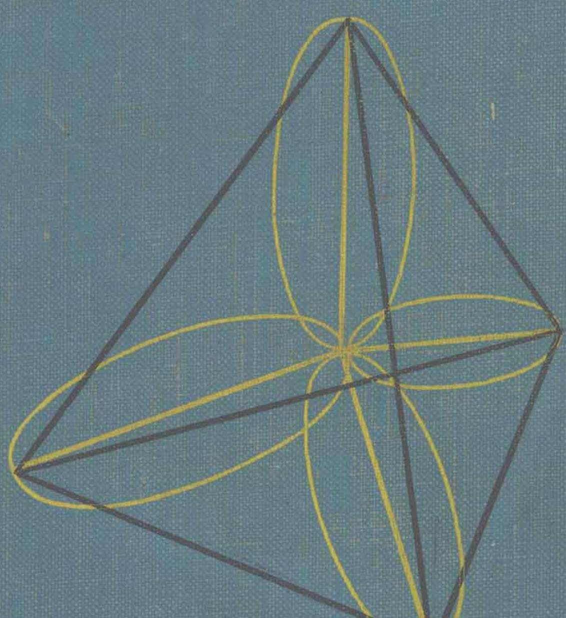
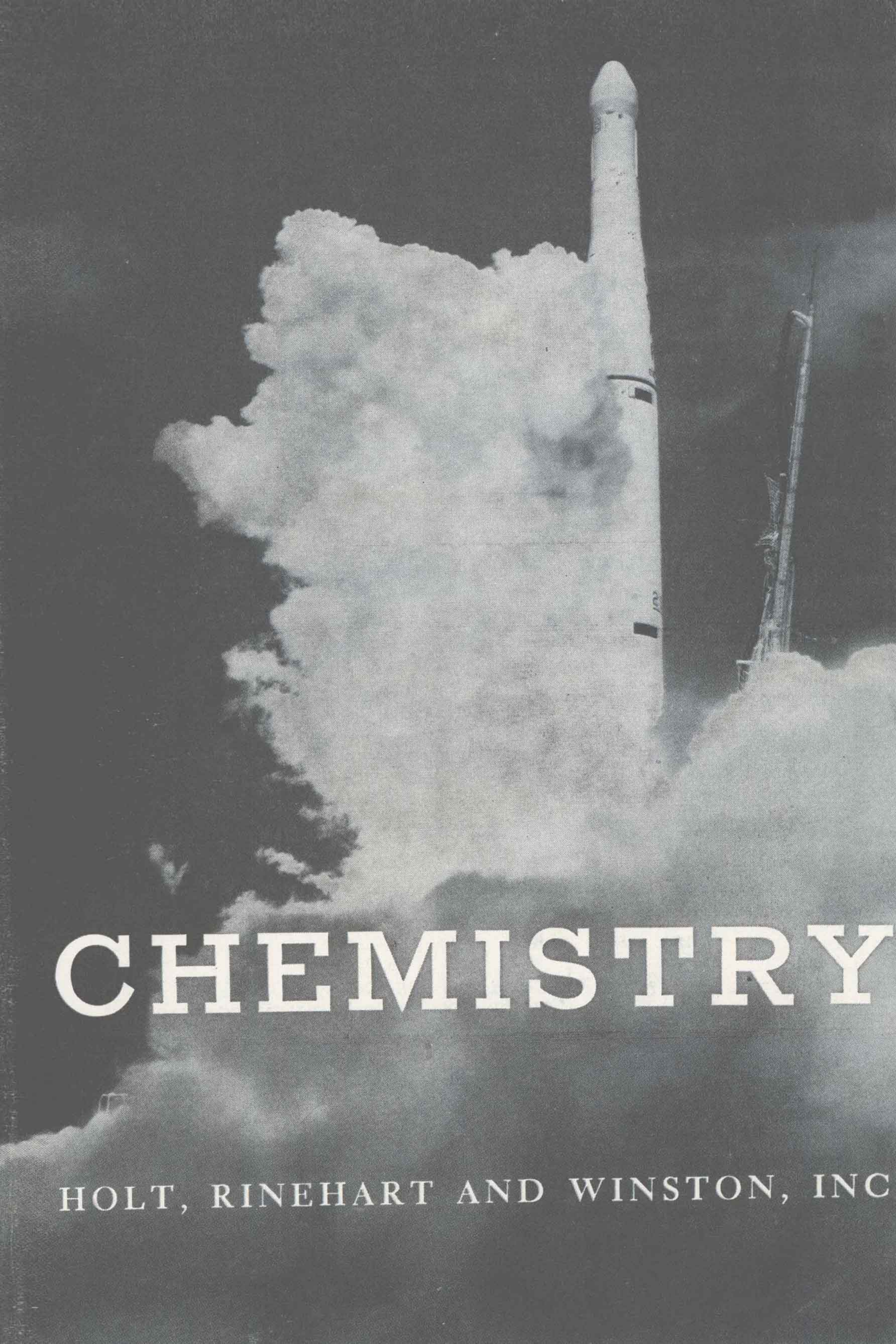
MODERN
CHEMISTRY




CHEMISTRY
HOLT, RINEHART AND WINSTON, INC

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Unit Opening Photographs. **1.** Pyrex glass laboratory equipment, *Corning Glass Works;* **2.** Field ion microscope picture of a tungsten crystal, *E. W. Müller;* **3.** Oxy-acetylene torches on a large-capacity cutting machine, *Union Carbide;* **4.** Ozone testing chamber, *Standard Oil (N.J.);* **5.** Giant tree ferns, *W. H. Hodge;* **6.** Chemist using a pH meter, *Beckman Instruments;* **7.** Mining of rock salt, *International Salt;* **8.** Spraying liquid sulfur, *Freeport Sulphur;* **9.** Book matches on an assembly line, *Diamond National;* **10.** Forest on the way to Yosemite Valley, California, *Philip Gendreau;* **11.** Thermite welding, *Thermit;* **12.** Steel rails being cut by hot saws, *United States Steel;* **13.** Nuclear core of Shippingport, Pennsylvania, nuclear reactor, *Westinghouse Electric;* **14.** Copper wheel engraving of glass bowl, *Steuben Glass;* **15.** Hortonspheres for butadiene storage and naphtha fractionating unit, *Humble Oil Refining.*

Title Page Photograph. Launching of a communications satellite, *U. S. Air Force.*

Library of Congress Catalog Card Number 62–7165

11950–1612 64P4

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Charles E. Dull
H. Clark Metcalfe
John E. Williams

MODERN

NEW YORK

PREFACE

MODERN CHEMISTRY is an all-purpose textbook designed to meet the varying needs of the standard high school course in chemistry. Classroom-developed from its first edition, this revision carries forward the sound idea of classroom testing.

To present the study of chemistry in the light of modern theory and to keep the subject matter abreast of the latest developments in the field, this edition has been carefully revised. After an introduction to some fundamental terms and concepts of physical science which includes a detailed explanation of significant figures and scientific notation, the authors develop the topics of atomic structure, the Periodic Table, and chemical bonding. The concept of sublevels and sublevel notation is introduced in the discussion of atomic structure. The periodicity of atomic radii and of ionization potentials is explained in the discussion of the Periodic Table. Electronegativity and its importance in compound formation are described in connection with chemical bonding. The Stock system of nomenclature is introduced and used in this edition of MODERN CHEMISTRY. The remainder of the theoretical and descriptive material of the course is then based on the relationship between the structure of substances and the properties they exhibit.

In this revision of the text, the authors describe and explain the concept of equilibrium more extensively than in previous editions. Various types are included, such as physical, solubility, and ionic equilibria. Oxidation and reduction are treated entirely in terms of electron transfer. Acids and bases are defined in the modern sense and the hydronium ion is used exclusively instead of the hydrogen ion in explaining certain aspects of acid behavior. Many other significant changes have been made in the text at the suggestion of teachers and students who have used the previous edition, and from the authors' own secondary teaching experience. The areas of secondary-school chemistry which the authors consider to be fundamental are treated in detail. However, no attempt has been made to produce a text which is encyclopedic in nature or which includes a multiplicity of topics.

Teachers will find ample material in MODERN CHEMISTRY for an outstanding college-preparatory course. For those students who do not plan to go to college, there is sufficient elementary theory and interest-arousing descriptive material for a complete and thorough course. It has been the authors' purpose to include more material than can ever be covered in one school year, thus permitting a wide choice of topics and allowing for selectivity according to student, school, and community differences. Teachers should feel free to choose those topics which best meet their local needs. As a guide in the selection of material, some paragraphs, and certain questions and problems, have been marked with a star (★). These starred sections are intended only for the better students. The needs of the average student are amply provided for in the unstarred material which constitutes the major portion of the text.

Careful attention has been given to teaching and learning aids. The inductive approach, so helpful to teachers and students alike, has been used wherever possible. The language of chemistry has been made clear and meaningful. Chemical words and terms are defined and pronounced in a short glossary at the beginning of each chapter and again, when the word or term appears in the text, it is printed in ***boldface italics*** and defined. These words and terms are also listed at the end of each chapter in the material entitled *Test Yourself on These Terms.* In addition, an extensive *Glossary* appears at the back of the book and includes definitions of all words and terms presented in the text. The complete *Appendix,* also in the back of the book, contains tables of useful data.

The material for each chapter concludes with *Questions* which are based on the text itself, graded according to difficulty in *Groups A* and *B.* There are more *Problems* than in previous editions of this book, and these are also graded into *Group A* and *Group B.* All problems have been revised and edited so that the rules for significant figure computation may be meaningfully applied. The average student should master all the *Group A* questions and problems; the better students will be able to do both. Special activities appear under the title *Some Things for You to Do.*

At the end of each unit there appear two sets of more difficult exercises: *Check Your Progress in Chemistry* and *Challenging Your Knowledge.* The former contains an abundance of drill material in chemical equations and in all types of problems as a cumulative review, while the latter consists of questions and problems which will really challenge even the best students.

Because of their great learning value, line drawings are used extensively. The text is also illustrated with many fine photographs, chosen with great care for their teaching value.

The following teachers have been kind enough to read the entire manuscript or special parts of it, and have offered invaluable assistance by their helpful criticisms: Edward A. Kassig, head of the science department, Broad Ripple High School, Indianapolis, Indiana; Earl V. Good, head of the science department, Stamford High School, Stamford, Connecticut; Richard B. Williams, chairman of the science department, San Jose High School, San Jose, California; Mrs. Helen Crawley, Natick High School, Natick, Massachusetts; and Miss Marcile Hollingsworth, head of science department, Lamar Senior High School, Houston, Texas.

The authors also acknowledge with thanks the work of: Felix Cooper, who prepared the text illustrations; and Gabrielle Wunderlick, who obtained the photographs.

In this printing of the 1962 edition of MODERN CHEMISTRY all data in the body of the text and in supplementary tables has been changed where necessary to conform with the revision of the physical atomic mass scale and chemical atomic weight scale to the basis of a carbon atom, mass number 12, defined as exactly 12. The revised atomic weights appear in the Periodic Table, in the Complete Table of Elements inside the back cover, and in appropriate places throughout the text.

Practical Pointers in Reading MODERN CHEMISTRY

Read this page before you read your textbook.

1. Keep your eyes and your mind continually open. In science we base each conclusion on known facts and nothing can be taken for granted. Your eyes must be trained to observe carefully and your mind must be equally trained to reason from observations, both printed and otherwise, so as to draw logical conclusions from the observed data. With open eyes and inquiring mind you will go far in your work.
2. Get your bearings by examining the Table of Contents on pages vii and viii. What is the scope of this book? Are certain words in the chapter titles unfamiliar? Possibly they are now but by the time your work is completed at the end of the course, you will be familiar with all of them. This over-all glance at the contents will give you a perspective necessary to understand what you will be reading.
3. After your teacher has made the assignment for which you will be responsible at the next class meeting, it's up to you to know what to do about preparing it. But first, be sure you understand exactly what is expected of you—what pages to read, what words to know, what questions, problems, projects or other activities to do, and whether the assignment is to be written or oral or both. If you are not sure, don't hesitate to ask. Write down all parts of the assignment in your notebook.
4. Skim over the assigned text material hastily to get a general idea what it is about, paying special attention to the paragraph headings in **boldface type.** These are key items in your textbook and form the basis for its organization.
5. Having obtained a general idea as to the subject matter of your assignment, go over the material carefully and give it your thorough concentration. Ask yourself repeatedly, Do I understand this? and if you cannot honestly answer yes, then read it again. As you read, study the drawings, tables, and photographs and read the captions which explain them. In the drawings, examine each label and learn the part of the drawing to which the label relates. Trace with a blunt object (not a pencil) the drawing of any process (such as flow of liquids and gases or movement of electrons) and understand what takes place, in which direction, and why.
6. In your reading, pay special attention to the scientific words and terms printed in ***boldface italic type.*** These are key words and are important to a clear understanding of the text. Many of them will be unfamiliar but you must know them and be able to define each one. Science is not a difficult subject if you learn its language, but you will never succeed unless you master this essential aspect of it. Each new word or term is printed in ***boldface italics*** the first time is appears, but it may and probably will be used again later. If you find that you do not understand the pronunciation and meaning of a new word, look it up immediately in the *Glossary.* Similarly, if you have forgotten such a word or term and can't remember on what page you originally met it, turn to the *Glossary* at the back of the book and look up its definition.
7. Having read the material assigned and learned the new scientific words and terms, turn to the questions at the end of the chapter which cover the text material you have completed. Answer each one fully and, if you are unable to do so, return to that part of the text which is still unclear. Reread it with the question in mind until you have the answer. Use the same procedure with the problems.

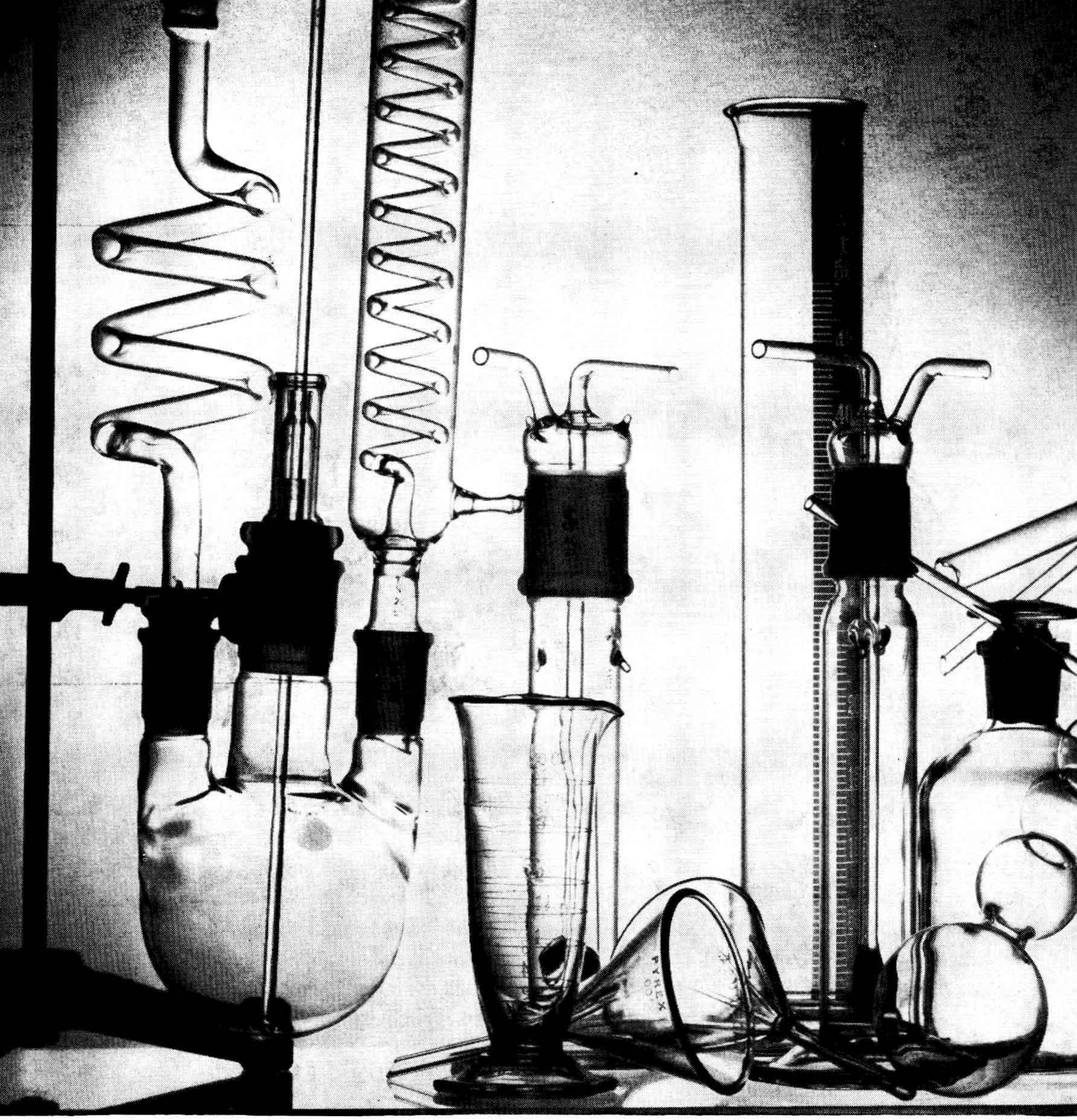
COMMON ELEMENTS

Name	Symbol	Approx. At. Wt.	Common Ox. Nos.	Name	Symbol	Approx. At. Wt.	Common Ox. Nos.
Aluminum	Al	27	+3	Magnesium	Mg	24	+2
Antimony	Sb	122	+3, +5	Manganese	Mn	55	+2, +4, +7
Arsenic	As	75	+3, +5	Mercury	Hg	201	+1, +2
Barium	Ba	137	+2	Nickel	Ni	59	+2
Bismuth	Bi	209	+3	Nitrogen	N	14	−3, +3, +5
Bromine	Br	80.	−1, +5	Oxygen	O	16	−2
Calcium	Ca	40.	+2	Phosphorus	P	31	+3, +5
Carbon	C	12	+2, +4	Platinum	Pt	195	+2, +4
Chlorine	Cl	35.5	−1, +5, +7	Potassium	K	39	+1
Chromium	Cr	52	+2, +3, +6	Silicon	Si	28	+4
Cobalt	Co	59	+2, +3	Silver	Ag	108	+1
Copper	Cu	63.5	+1, +2	Sodium	Na	23	+1
Fluorine	F	19	−1	Strontium	Sr	88	+2
Gold	Au	197	0, +3	Sulfur	S	32	−2, +4, +6
Hydrogen	H	1.0	−1, +1	Tin	Sn	119	+2, +4
Iodine	I	127	−1, +5	Titanium	Ti	48	+3, +4
Iron	Fe	56	+2, +3	Tungsten	W	184	+6
Lead	Pb	207	+2, +4	Zinc	Zn	65	+2

VALENCE OF COMMON IONS

Name	Symbol	Valence	Name	Symbol	Valence
Aluminum	Al^{+++}	+3	Lead(II)	Pb^{++}	+2
Ammonium	NH_4^+	+1	Magnesium	Mg^{++}	+2
Barium	Ba^{++}	+2	Mercury(I)	Hg_2^{++}	+1
Calcium	Ca^{++}	+2	Mercury(II)	Hg^{++}	+2
Chromium(III)	Cr^{+++}	+3	Nickel(II)	Ni^{++}	+2
Cobalt(II)	Co^{++}	+2	Potassium	K^+	+1
Copper(I)	Cu^+	+1	Silver	Ag^+	+1
Copper(II)	Cu^{++}	+2	Sodium	Na^+	+1
Hydronium	H_3O^+	+1	Tin(II)	Sn^{++}	+2
Iron(II)	Fe^{++}	+2	Tin(IV)	Sn^{++++}	+4
Iron(III)	Fe^{+++}	+3	Zinc	Zn^{++}	+2
Acetate	$C_2H_3O_2^-$	−1	Hydroxide	OH^-	−1
Bicarbonate	HCO_3^-	−1	Hypochlorite	ClO^-	−1
Bisulfate	HSO_4^-	−1	Iodide	I^-	−1
Bromide	Br^-	−1	Nitrate	NO_3^-	−1
Carbonate	$CO_3^=$	−2	Nitrite	NO_2^-	−1
Chlorate	ClO_3^-	−1	Oxide	$O^=$	−2
Chloride	Cl^-	−1	Permanganate	MnO_4^-	−1
Chromate	$CrO_4^=$	−2	Peroxide	$O_2^=$	−2
Fluoride	F^-	−1	Phosphate	$PO_4^{\equiv}$	−3
Hexacyanoferrate(II)	$Fe(CN)_6^{\equiv}$	−4	Sulfate	$SO_4^=$	−2
Hexacyanoferrate(III)	$Fe(CN)_6^{\equiv}$	−3	Sulfide	$S^=$	−2
Hydride	H^-	−1	Sulfite	$SO_3^=$	−2

CONTENTS



Unit 1 · CHEMISTRY IN A MODERN WORLD

Chemistry: A Science of Matter and Energy
The Composition of Matter
Matter and Its Changes

Chapter 1 · CHEMISTRY: A SCIENCE OF MATTER AND ENERGY

1. AN INTRODUCTION TO CHEMISTRY

1. Chemistry is a physical science. Through the ages, man has learned many things about himself and his environment. However, it was not until he started to record his discoveries and observations that modern science, as such, began. Early scientists soon started to organize and classify their discoveries and observations. This organized knowledge has developed into the fundamental sciences with which we are familiar today. Each important discovery suggests new avenues of investigation, the result being the expansion of scientific knowledge at an ever-increasing rate.

All the sciences may be grouped into two large divisions: the ***biological sciences,*** which are concerned with living things, their structure, life processes, and environment; and the ***physical sciences,*** which deal with the natural relationships about us. An understanding of basic concepts in the sciences helps us to recognize and appreciate the orderliness in nature.

Chemistry *is the science dealing with the structure and composition of materials and the changes in composition which these materials undergo.*

Physics is concerned primarily with changes in materials which do *not* involve a change in composition. It deals with the laws and principles of the physical universe.

Mathematics is the science of our number system. It gives us a means of expressing the relationships we observe in nature and of performing useful and necessary computations. Mathematics is often called the *language of the sciences.*

During the present century it has become increasingly evident that chemistry holds the key to the life sciences. As a result, there is an increasing merger of chemical research with the other sciences. Substantial knowledge of more and more complex chemical structures has enabled chemists to make major contributions toward the ultimate understanding of the mysterious life processes. This is the realm of ***biochemistry,*** a blend of biology and chemistry.

2. Keystones of modern chemistry. The initial concept of modern chemistry, *that elements are the basic stuff of which all things are made,* was under development in France at about the time of the American revolution. In 1778 **Antoine Lavoisier** (la-*vwah*-see-ay) demonstrated that oxygen was the active fraction of the air involved in ordinary combustion processes. This set the stage for a great search for chemical elements and finally, through the efforts of a long line of investigators, some ninety elements were recognized. By 1920 most of these had been isolated and their properties studied.

Lavoisier was followed closely by **John Dalton** of England who, in 1808, conceived elements as consisting of chemically indivisible particles he called *atoms.* In 1811 the Italian physicist, **Amadeo Avogadro,** formulated some general laws describing the behavior of combined atoms, or *molecules.* Then in 1852, Great Britain's **Sir Edward Frankland** proposed the first useful explanation of the manner in which these atoms combined to form molecules, a combining quality later to be called *valence.* Chemistry was soon to be recognized as the architecture of molecules.

The first great chemical architect was **Friedrich Kekulé** of Germany, who in 1858 determined the bases on which the carbon skeletons of long-chain and ring molecules of organic compounds are formed. From this beginning chemists went on to construct a great variety of useful molecules in the forms of drugs, dyes, explosives, fibers, plastics, and solvents.

The first Nobel Prize in chemistry was given to **Jacobus H. van't Hoff** of Holland in 1901 for his pioneering work in developing the laws of reactions and solutions. Germany's **Emil Fischer** received the second Nobel Prize in chemistry in 1902 for his work on the structure of sugars and proteins. Sweden's **Svante Arrhenius,** about whom you will learn more in Unit 6, was awarded the third Nobel Prize in 1903 for his theory explaining the behavior of electrolytes in solution.

Later, in 1909, the Nobel Prize went to the German chemist **Wilhelm Ostwald** for his work in catalysis, a technique of tremendous importance in industrial chemistry. Ostwald is sometimes referred to as the father of physical chemistry. The Swiss chemist, **Alfred Werner,** received the Prize in 1913 for

VOCABULARY

Active material. One which reacts vigorously with other materials.
Density. The mass of a material per unit volume.
Energy. The capacity for doing work.
Inactive material. One which reacts passively with other materials.
Inert material. One which does not react with other materials under the ordinary conditions of chemical reactions.
Inertia. Resistance of matter to change of position or motion.
Law. A statement of scientific fact concerning natural phenomena.
Mass. The measure of inertia of a body.
Matter. Anything which occupies space and has mass.
Phenomenon. An event or situation of scientific interest susceptible of scientific description and explanation.

his studies of the structure of complex compounds. Again in 1920 a German, **Walther Nernst,** was awarded the Nobel Prize for his discoveries in thermodynamics.

Marie Curie, whose discovery of the radioactive elements, radium and polonium, was probably the most important contribution to modern chemistry since Lavoisier introduced the modern concept of elements, was awarded the Nobel Prize in 1911. No longer was the atom to be considered impregnable; here were atoms of elements which burst apart giving off tiny particles and high-energy radiations. Thus a chemist opened up a whole new realm for exploration by physicists, the structure within the atom.

The list of Nobel Prizes, while not infallible, gives a rough indication of the creative effort in chemistry being put forth by scientists of the various nations of the world. Up to 1920 only one American chemist had been awarded this prize. Eight German, three French, and two British chemists had been selected. Since 1920, however, eight American chemists have become Nobel Prize winners. Meanwhile German scientists have won eleven, British scientists eight, and French and Russian scientists one each.

3. The methods of science. In some instances, important scientific discoveries have come about quite by accident. However, most of our scientific knowledge is the result of carefully planned investigations carried on by trained scientists. Their techniques, known as ***scientific methods,*** are simply *logical approaches to the solution of problems which lend themselves to investigation.* Scientific methods require strict honesty, the ability to withhold a decision until all the evidence is in, and the desire for truth.

Scientists believe implicitly in the or-

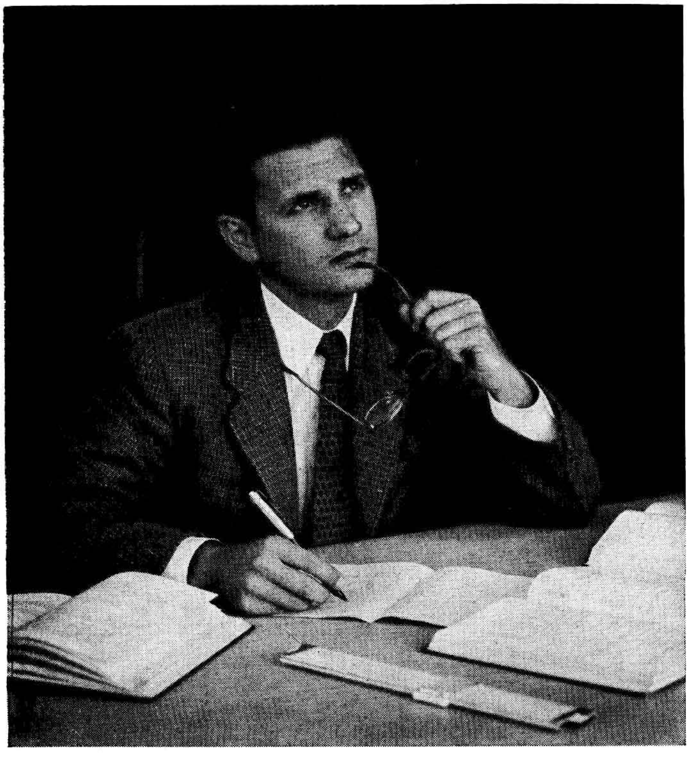


Fig. 1-1. Curiosity is the beginning of discovery. (Hedrich-Blessing)

derliness in nature—that everything in the universe behaves in an ordered way, and that man can discover and understand natural rules of behavior. Chemists, like other scientists, strive to explain a large number of related observations in terms of *broad principles* or *generalizations*. All basic scientific research is devoted to the discovery of these principles. *The generalizations which describe behavior in nature are called* ***laws.*** Natural laws tell us what relations *do* occur in nature; they *do not* tell us what relations *must* occur. The laws of science may be expressed by concise statements or by means of mathematical formulas.

One of the distinguishing qualities of man is his curiosity. This causes him to ask two important questions: "*what?*" and "*why?*" When an event or situation in nature, called a *phenomenon,* is observed by one trained in the methods of science, the answers to these questions are sought by carrying out systematic, disciplined, and persistent investigations.

We may recognize four distinct phases in the application of scientific methods: *observing, generalizing, theorizing,* and *testing.*

1. *Observing.* The scientist accumulates as much reliable data as possible about an observed phenomenon, his initial interest being in *what* actually occurs. These data may come from direct observations, from a search of scientific literature for information previously reported, and from well planned and skillfully executed experiments.

2. *Generalizing.* The scientist organizes the accumulated data and looks for relations between them. Relations he discovers may enable him to formulate a broad generalization describing what does occur. When well established by

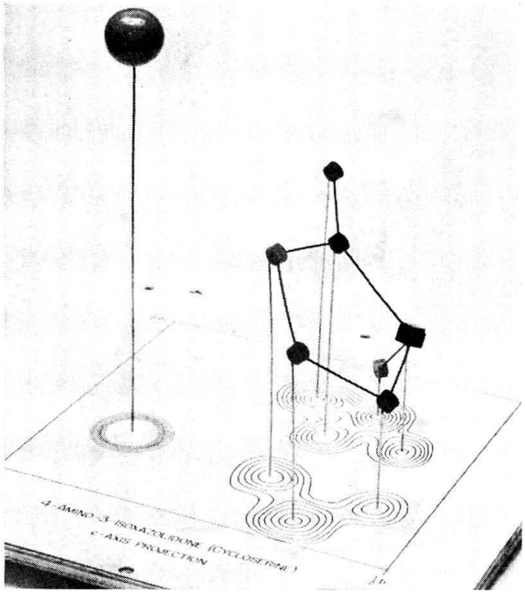


Fig. 1-2. **A physical model is often used by chemists to help them understand the behavior of matter.** (Ray Pepinsky, Crystal Research Laboratory)

abundant supporting data, this generalization may be recognized as a new law or principle which states what the behavior is.

3. *Theorizing.* When the scientist understands *what* occurs he is ready to move on to the more stimulating task of determining *why* the phenomenon occurs. A creative imagination may enable him to develop a plausible explanation and to construct a simple physical or mental model which will relate the observed behavior to familiar and well-understood phenomena. *A plausible explanation of an observed natural phenomenon in terms of a simple model which has familiar properties is called a* ***theory.***

4. *Testing.* Once a seemingly satisfactory theory is developed, it must be tested and retested to establish its validity. In fact, the scientist continually tests observational and experimental data and predictions based on known

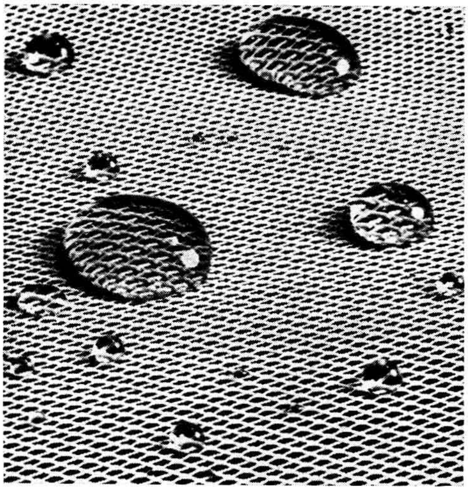


Fig. 1-3. This water-repellent, silicone-treated material is a product of chemical research. (Dow-Corning)

principles by subjecting them to new and ingenious experiments. A theory is retained only so long as it is useful and it may be discarded or modified as a result of new experimentation. A theory that stands up under scientific testing is a valuable asset to scientists because it stimulates the imagination and serves as a basis for predicting behavior not previously investigated. This is the heart of the scientific method and the real stimulus for the tremendous growth of science.

The principles of chemistry are studied most effectively and understood most easily when the laws and experimental evidence making up a body of related knowledge are brought together to form a general theory concerning the behavior of matter. In this way the term "theory" is often used by chemists in a broad sense. Some examples of chemical theories which you will soon study in this sense are the *kinetic theory,* the *atomic theory,* and the *theory of ionization.*

2. MATTER AND ENERGY

4. The concept of matter. All materials about us consist of matter. With our senses—sight, touch, taste, and smell—we recognize various kinds of matter. This book, your desk, the air you breathe, the water you drink are examples of matter. Some kinds of matter are easily observed. A stone or a piece of wood may be seen and held in the hand. Other kinds of matter are recognized less readily, such as the air or even water in a quiet pool. However, we ride on compressed air in automobile tires. We know of the tremendous damage which can be caused by rapidly moving air (see Fig. 1-4).

We say that ***matter*** *is anything which occupies space and has mass.* Matter possesses ***inertia,*** a resistance to change of position or motion. The concept of inertia as a property of matter is quite important in the study of physics. Imagine a basketball being used in a bowling alley as a substitute for a bowling ball. The effect on the pins would not be the same at all. Although they are approximately the same size, the bowling ball has a greater mass since it contains more matter than the basketball. Its inertia is correspondingly higher and thus its tendency to remain in motion, once set in motion, is greater.

Matter may be acted on by ***forces*** which may set it in motion, or change its motion. While all these statements are descriptive of matter, they do not provide us with a completely satisfactory definition. Scientists, with their great knowledge of the properties and behavior of matter, are not yet able to define it precisely. Many secrets of nature still challenge the minds of men.

5. Mass and weight. *The quantity of matter which a body possesses is known*