GENERAL CHEMISTRY

H. G. DEMING

FIFTH EDITION

GENERAL CHEMISTRY

AN ELEMENTARY SURVEY

EMPHASIZING INDUSTRIAL APPLICATIONS OF FUNDAMENTAL PRINCIPLES

BY

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FIFTH EDITION
Eighth Printing

NEW YORK

JOHN WILEY & SONS, INC.

LONDON: CHAPMAN & HALL, LIMITED

FIFTH EDITION
Eighth Printing, January, 1947

PRINTED IN THE UNITED STATES OF AMERICA

PREFACE TO THE FIFTH EDITION

In this edition the treatment of fundamental principles has been simplified and curtailed to gain space for a discussion of industrial applications. A wealth of new material has been included, dealing with numerous topics that are intimately related to America's war effort: welding; dehydration of foods; the atmosphere at high elevations; industrial sources of hydrogen; syntheses based on hydrogen; industries using sulfur and salt; water softening and conditioning; calorimetry and fuels; motor fuels; lubricants; combustion in the internal combustion engine; wetting agents and detergents; explosives; plastics; synthetic elastomers; rapid hardening cement; portland cement and concrete; light metals and their alloys; iron and steel; corrosion; electroplating.

The fifth edition has had the benefit of the criticism of many teachers who have used the previous editions, in some instances continuously for twenty years. Among these, Prof. W. A. Van Winkle of Kansas State College has been particularly active in suggesting improvements. He read the entire book in manuscript. Many details tending to make the treatment more appealing to students in engineering are the result of his efforts. Mr. Chesman A. Lee has also been of assistance in making the book more useful to students preparing for careers in chemical engineering.

H. G. D.

Lincoln, Nebraska
October, 1943

PREFACE TO THE FIRST EDITION

College courses in general chemistry differ widely in their content and method of development. Some take up element after element and compound after compound, in a purely descriptive way, after the manner of a seed catalogue. Others chiefly emphasize applications of chemistry in the industries. Others, again, with students of some previous training in chemistry, are largely concerned with general principles.

Even when the common ingredients of a course are present in definite proportions, there may be great differences in the manner of their intermingling. In some we have what appears to be a true solution of general principles and industrial applications in descriptive chemistry as a solvent. In such a course the mention of phosphoric acid is seized upon as a pretext for a discussion of the ionization of acids in stages, and copper ferrocyanide occasions a dissertation on osmosis. In other instances the ingredients have a lower degree of dispersion; at times they constitute a coarse mixture, readily separable by mechanical means.

Such extreme differences in the content of introductory courses or in the method of their development are of course to be deplored, but to some extent they reflect real differences in the needs of the students who pass through them. A special effort has therefore been made to give the present textbook *flexibility*. The purpose has been to encourage the instructor to teach what he wishes to teach, in the order that seems best to suit the past preparation and future needs of his students.

It seemed that this result might best be achieved if general principles were presented in separate chapters, and not too completely scrambled with descriptions of individual chemical substances and applications to industry. Numerous cross references link up the more theoretical portions of the text with descriptive material that may furnish illustrations of the general principles. The cross references, furthermore, lessen the danger that wholesale omissions or changes in the order of presentation may render the text unintelligible. Indeed, whenever previous material is very necessary to an understanding of a given topic, the student is given definite instructions to turn back and review.

It is hoped that this book may be appreciated for the things it has left unsaid. Most texts contain too much matter that properly belongs in a course in descriptive inorganic chemistry for students specializing in chemistry. By sacrificing such museum material as hypobromous acid, phosphoryl chloride, hydrazoic acid, and the usual long catalogue of variously colored inorganic salts, space has been gained for the development of such topics of lively interest as hydrogen ion concentration and its applications, electrochemical principles, and the constitution of matter. This last-named topic, too frequently left as a sort of afterthought, to be presented in a concluding chapter, has been interwoven with the text in such a way that the student examines oxidation and reduction, almost from the beginning, from the modern point of view.

It should, nevertheless, be emphasized that the wide range of topics thus introduced, while providing the means whereby the present text may be adapted to the needs of students of diverse types, makes it more than ever necessary that a selection should be made. The sequence of the descriptive chapters is a common one, but may readily be altered to conform to a laboratory schedule.

In the exercises at the close of each chapter there is especial need for discrimination. Many of these exercises are too difficult for the average student, and were included for the benefit of those of more than average preparation or capacity. Students receiving a superior grade in the course may be required to demonstrate their ability to solve exercises of this kind. In every class of beginners there are a few who are able to do work superior in quality to that done by others who have had a full year of preliminary preparation. Students of this order of ability are entitled to more consideration than they commonly get. It is easier to hold their interest if the text contains some material difficult enough to try their mettle; all the members of the class then carry away a better appreciation of what chemistry means, and more respect for its position as a science, than would be possible if they obtained only the mutilated view of the subject that too highly simplified texts present.

For classes without a previous high school course in chemistry, it is best not to introduce the more highly generalized or theoretical topics until some familiarity with the ordinary facts of descriptive chemistry has been acquired. Such students should proceed through Part I at a rather leisurely pace, omitting many of the more difficult portions of the text. The final month of the first semester may then be devoted to a review of the descriptive topics, at which time the theoretical ones, previously omitted, may be taken up.

On the other hand, students with a year of good preliminary training may make rather rapid progress through the descriptive matter, and specialize on the very topics that beginners must postpone or omit. Those who have not had a course in high school chemistry commonly recite more frequently than those who have; hence the two classes of students should be about equally advanced from about the middle of the second semester. The year may then be closed with a review of the important general principles (tabulated at the close of the Table of Contents) or devoted to a study of the special topics most likely to be useful in the students' future work. Much of the descriptive chemistry of the metals may commonly be omitted, except in so far as it may be used to enliven discussions of general principles.

Indeed, though the course may well begin by being largely descriptive, general principles should receive chief emphasis in the end. Even with students who are to specialize in chemistry, the purpose of a first course is not so much to impart information as to disclose a point of view. The facts of chemistry are but the raw materials from which must be synthesized a certain state and quality of mind.

H. G. D.

Lincoln, Nebraska
May 28, 1923

CHEMISTRY FOR USE

(Topics for a Brief Course)

The following list suggests assignments for a brief course, designed to prepare the student, as quickly as possible, to put chemistry to use. It emphasizes principles, experimental methods, and methods of calculation rather than the descriptive chemistry of the elements and their compounds. It can be completed in twenty-four weeks. When supplemented by twelve weeks of laboratory work, devoted to the reactions of the most important elements and their compounds, it covers the ground outlined for courses 205 and 206 in the AST program.

Students who have completed the work here outlined will have a good foundation for any further assignments that may seem desirable during the remaining three months of the academic year.

CHAPTERS	
1–4	*Preliminary, §§ 1–42*
5, 6	*Oxygen and Combustion, §§ 43–65*
7	*Properties of Gases, §§ 66–77, 80–83*
8	*The Atmosphere, §§ 85–92*
9	*Water, §§ 102–115, 119–122*
10	*Liquids and Solids, §§ 123–127, 130–140*
11	*The Elements, §§ 146–150*
12, 13	*Electrons; Atomic Structure, §§ 151–156, 160, 161, 163–171*
15	*Hydrogen, §§ 186–189, 196, 198–201*
16	*Acids, §§ 202–212*
17	*Bases and Salts, §§ 218–229*
18, 19	*Titration; Hydrogen Ion Concentration, §§ 230–234, 235–240*
20	*Chlorine, §§ 248–254, 259–261*
21	*Oxidation and Reduction, §§ 262–269*
29	*Reaction Rate, §§ 365–367, 370, 371, 376, 377*

CONTENTS

1

WHAT CHEMISTRY IS ABOUT

1. Chemistry a Study of Materials. The different kinds of matter that compose the universe are termed *materials.* Iron is one material, water another, glass—or, indeed, each special kind of glass—another. Each material has its own distinguishing characteristics, otherwise termed its *properties,* that enable it to be recognized or separated from other materials. Iron has the property of rusting in moist air; water, the property of dissolving sugar; sugar, the property of being dissolved by water; glass, the properties of brittleness and transparency.

Note that size, shape, and weight are not properties of materials, but attributes of particular *objects* (samples of matter).

The study of materials is the joint concern of chemistry and physics. These two sciences are so closely related that no one can learn very much about either without considerable training in the other. In many of their applications it is hard to tell where the one science leaves off and the other begins.

Roughly stated, physics is concerned (1) with *the general properties of matter and energy* and (2) with events which result in what are termed *physical changes* (those in which materials are not so thoroughly altered as to be converted into other materials, distinct from those present at the beginning).

Chemistry, by contrast, is chiefly concerned (1) with *properties that distinguish materials from one another* and (2) with events that result in *chemical changes* (those in which materials are transformed into completely different materials). Who but a chemist would ever guess that common salt can be resolved into a greenish gas and a silvery white metal? Or that two odorless gases, nitrogen and hydrogen, can be combined to form ammonia? Or that ordinary air and water can be converted into nitric acid? Or that coal tar contains ingredients that can be transformed into dyestuffs and perfumes?

Such thoroughgoing transformations, in which all the properties of a material are altered, so that a completely different material is obtained, are called *chemical transformations, chemical changes,* or *chemical reactions.*

2. Chemistry as an Art. Chemistry as an art is concerned with *identifying, separating,* and *transforming* materials, in applying them to definite uses. When prehistoric man learned that vessels fashioned from plastic clay might be permanently hardened by being heated in a fire, or that hides might be dehaired by lime, then transformed into leather, or that food might be rendered more palatable by cooking he was making a beginning in the chemical arts. Chemical skill, usually quite unconscious, is manifested by anyone who can cook a meal, stoke a furnace, raise a garden, fatten an animal, or mix a batch of concrete—for in each of these occupations materials are selected to serve in transformations that result in new materials, each so different from the original materials as to deserve a new name.

Anyone who is chiefly interested in the practical applications of chemistry—in other words, in chemistry as an art—needs to collect information about materials and their properties under five chief headings:

1. *What properties are demanded by materials that are to serve designated uses.* In an airplane's wing, for example, or as tools for cutting steel, as dyestuffs for uniforms, or as local anesthetics in minor surgical operations.

2. *What materials possess or come nearest to possessing each desired combination of properties.* For example, should the fuselage of an airplane be constructed of sheets of light metallic alloys, or of plywood cemented with phenolic resin, or perhaps of some transparent plastic material? Each step in the design of this or any other engineering structure calls for a very active sort of chemical intelligence.

3. *How materials of all sorts may have their properties modified, either slightly or profoundly, to fit them for specified uses.* For example, how may we modify the properties of steel, by quenching or annealing, to make it tougher and stronger (§ 614)? How may we render explosives less sensitive to shocks? How may nitrogen, obtained from ordinary air, be made to combine with hydrogen, to produce ammonia; and how may ammonia, in its turn, be converted into nitric acid, to serve in the manufacture of dyestuffs and explosives?

4. *How materials of all sorts may be protected against a gradual alteration of properties, in transformations that may finally ruin or destroy them.* We must hinder or prevent, as best we may, the rusting of iron and steel, the corrosion of alloys by acids or salt spray, the embrittling of paper and fabrics by exposure to air and sunlight, the decay of wood, the softening or cracking of rubber, the disintegration of concrete by running water, the gradual weakening of repeatedly strained metals by "fatigue." Our national defense depends in no small degree on the protection of structural materials against slow deterioration.

So much for the services of the chemical arts in the creation of new materials, the application of these to new uses, and their protection when in use. Not only engineering, but also pharmacy, medicine, and agriculture depend on these services, since the transformations of materials accomplished by living plants and animals are governed by the same principles as those of importance to engineering.

To the preceding services of the chemical arts may be added a fifth, which lends assistance to the rest:

5. *How may different materials, encountered in nature or industry, be identified, and how may they be separated, when intermingled or combined with one another?* Identification is the task of *analytical chemistry.* It serves engineering and manufacturing, in providing methods by which the purity and quality of raw materials and manufactured products of every imaginable sort may be tested and controlled. You may send a properly qualified analytical chemist almost anything, from a patent medicine to a rare mineral, and get from him a pretty accurate statement of what materials are in it. Yet every analyst has his own specialty, and we should not expect one specializing in minerals to have more than very vague ideas about medicinal substances. There are numberless different materials in the world about us, and no one, however diligent, can hope to become personally familiar with the properties of more than a very few of them.

3. Chemistry as a Science. Since distinguishable materials are numberless, chemistry would be bewildering and hopeless were we not able to simplify it by classifying the materials of nature and industry into *groups of related materials.* The different metals possess certain properties (§ 141) that distinguish them as a group, rather sharply, from non-metals. All substances classed as acids possess certain properties in common (§ 203) which place them in sharp contrast with substances classed as bases. And the properties of any one alcohol suggest at least roughly what sort of chemical behavior is to be expected of alcohols in general.

By thus classifying materials into groups of related materials, and indeed by classifying facts of all kinds into groups of related facts, the ancient chemical arts, many of which had their beginnings before the dawn of history, gradually became unified and interrelated into chemical science. This is concerned (1) with correlating and interpreting facts observed in the practice of chemistry as an art, (2) with obtaining new facts that seem likely to prove useful in explaining those already known, and (3) with developing *general points of view* that explain multitudes of facts, perhaps not easily recognized as being related.

In brief, *chemical science is a manner of thinking about transformations of materials which helps us to understand, predict, and control them.* It furnishes directing intelligence in the use of materials. This, and not the discovery of new materials, is the chief contribution of modern chemistry to human welfare and progress. Our own age is chiefly distinguished not so much by its possessing more materials than were known in ancient times as by its ability to make more intelligent use of the materials that it has.

4. The Chief Problems of Chemistry Considered as a Science. The chief problems of chemistry, considered as a science, are quite distinct from its problems when considered as an art. This is because *science is chiefly concerned with generalizing and explaining, whereas an art is content with doing.* Yet no one need suppose that chemical science is any less practical and useful than such obviously practical and useful chemical arts as metallurgy,* tanning, dyeing, and the ceramic † industries. Quite the reverse is true. These ancient chemical arts were slowly developed, during uncounted centuries, before the dawn of history. Yet they remained unrelated because the methods they used and the results they got remained unexplained. For this reason, skills won by the slow experience of centuries were often completely lost, and many a useful art perished and was forgotten, then perhaps was rediscovered.

It is only since the beginnings of chemical science, about two centuries ago, that the different chemical arts became correlated, unified, and explained. Progress in any of them then often led to progress in the rest. As the blind following of recipes gave place to ordered thinking about the properties and transformations of materials, the useful arts no longer ran any risk of being forgotten, but instead pressed forward to triumphs of achievement of which people of past centuries never dreamed.

Considered as a science, chemistry has two chief problems:

1. *To explain why different materials have the properties that they do.* Why does chromium resist corrosion, why is rubber elastic, why is carbon monoxide poisonous? Explaining properties puts us in the way of finding or creating other materials that possess them, when they are useful properties; or of altering or controlling them when they are to be avoided.

2. *To study the transformations of materials that are the special concern of chemistry, in an effort to determine what transformations are possible, and under what conditions.* Can lead be converted into gold? Can starch, or even sawdust, be converted into a sugar? Can petroleum, or materials contained in it, be converted into alcohol? Can air and water be converted into nitric acid? The answer to the first of these questions is *no* or, at least, *not yet.* The answer to the others is yes. Immediately

* *Metallurgy,* the art or science of winning metals from their ores.

† *Ceramic,* relating to clay.

we ask, *by what means can such transformations be made to take place, and under what conditions?* To answer this question concerning all possible chemical transformations is one of the chief concerns of chemical science.

5. Chemical Principles or Laws. The numberless transformations of the materials encountered in nature and industry cannot all be studied individually. There are far too many of them. Instead, we try to discover *general principles* or *scientific laws* * that apply to all transformations, wherever encountered, or at least to all transformations of a given type. For example, we discover that *chemical transformations leave the total weight unchanged, even though all the properties of the transformed materials are altered.* This is the *Law of Conservation of Mass or Weight* (§ 26). We also find that increasing the pressure under which a gas is confined always decreases the volume of the gas in very nearly the same proportion, provided the temperature remains unchanged. This is the Law of Boyle (§ 76).

So all the numberless facts about individual materials and individual transformations of materials have been marshaled under a few great laws and principles. As students of chemistry our attention should be centered on laws and principles rather than on individual facts; but we do not deny that a good collection of chemical facts, in the back of our minds, will be found very helpful in making application of the laws and principles that are our chief concern.

6. Scientific Theories. The effort of chemical science, and indeed of any science, is to classify and interrelate facts under a few general laws or guiding principles. Yet that is not the end of it. A law merely states that events always happen thus and so, or in a particular sequence. Intelligence asks *why?* So science attempts explanations of its laws and is particularly pleased when it finds an explanation for several laws at once. Such explanations or interpretations of laws are called scientific theories.

Scientific theories have nearly always taken the form of a *detailed description* of the thing we are attempting to explain. We *describe* a given process as taking place in a number of successive steps, leading to an observed invariable result; or we *describe* matter as consisting of small particles called molecules, having properties which, as far as we can see, would compel matter to behave as it does. Or we *describe* heat as consisting of the motion of molecules, and thus find it easier

* A *scientific law* is merely a concise general statement with regard to things and events we believe always occur together or in definite sequences. The term *scientific principle* has about the same meaning, except that it may be given in a less formal way and may be less capable of being expressed as a mathematical equation.

to understand why all other forms of energy tend to take the form of heat energy; or we *describe* electricity as existing in small individual negative charges called electrons, which we conceive of as possessing properties that account for electrical phenomena in general.

In Greek, *theoria* means insight; theoretical views are those that enable us to look beneath the surface of things to get at their real inner nature. Theories, when properly understood, are accordingly the most practically useful information one can possess:

1. Theories connect each law with a general point of view, and so help us to remember it.

2. Theories make plain the relationship to each other, and thus the deeper meaning, of laws which, standing alone, would not be properly understood.

3. Theories suggest new directions in which discoveries are likely to be made.

Scientific discoveries are not made by chance, but are the result of systematic search for new facts and laws, guided by the intelligent use of theories. This is *scientific research.*

7. The Subdivisions of Chemistry. The progress of chemistry has been so very rapid that no one person can now hope to master all of it. Instead, each chemist specializes in a certain portion of the field, cooperating with workers in the other sciences that border on chemistry and make use of its results.

The chemical problem of *identifying* is now so well advanced that more than 700,000 distinct kinds of matter have been recognized and listed, with their chief characteristics, in the great catalogs of *descriptive chemistry.* The search for means of *separating* has resulted in the numerous procedures of *analytical chemistry*, which enable the chemist to proceed systematically in finding out what things are made of. A study of means and conditions for *transforming* one kind of matter into another has resulted in the discovery of tens of thousands of new kinds of matter. This is *synthetic chemistry*, classified as *organic* if it deals with products containing carbon, and otherwise as *inorganic.*

Finally, we have *theoretical* or *physical chemistry.* This takes note of the general principles or scientific laws that govern transformations of matter. Since physical chemistry tries to get at the reasons why things happen as they do, every discovery in this field, however far removed from everyday affairs, is apt to have some unexpected practical results.

The course that the student is here beginning can give only a hasty glimpse of the broad outlines of the subject—a knowledge of chemistry comparable to the knowledge of a university that one might acquire from