CHEMISTRY

a modern approach

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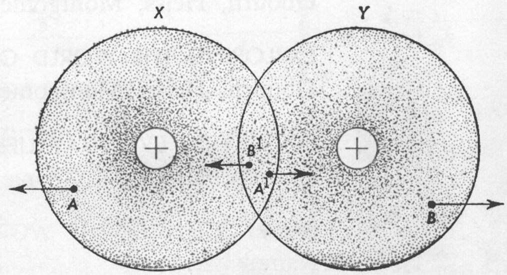

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PREFACE

Within the past several years two different groups of investigators, including chemistry teachers from both the high school and college levels, have examined the traditional first-year chemistry course of study. Their purpose has been the revision of the course to reflect changed and changing conditions in pedagogy, chemistry itself and last but not least the objectives of the beginning chemistry course. Their findings are expressed in two textbooks which have tried to answer the two fundamental questions, What shall be taught in a first-year chemistry course? How shall it be taught?

It is generally agreed that the old curricula were too concerned with unrelated facts and with the application of these facts to technological processes. Today the emphasis is on imaginative thinking, on the endless questioning of how and why, on logical prediction rather than on guess-work.

The new approach places a greater emphasis upon the quantum picture of atomic structure, a picture based upon the probability distribution of electrons in negatively charged clouds. Does this imply that the older atomic models of Dalton and Bohr should be cast into limbo? No one knows what an atom really looks like, and it is reasonably certain that later models will emerge as new discoveries are made. Models of atoms will be ever changing and the authors believe that the most satisfactory model is the one that gives the simplest "picture" for the purpose at hand. Dalton thought of atoms as miniature billiard balls. This picture was adequate for the work of the analytical chemists in the 19th century. A Bohr atom gives a vivid picture of energy levels and it accounts for the emission and absorption of packages of energy when an electron jumps from one orbit to another. A Bohr atom, however, does not satisfactorily explain a covalent bond or the geometry of molecules. Only a quantum atom can do this. The quantum atom is based upon quantum mechanics which, in turn, is associated with wave equations, an abstruse branch of mathematics beyond the reach of high school students. The authors have used all three atomic models, whichever best describes the operation under consideration. The mathematical treatment of quantum mechanics has, however, been omitted entirely.

This changing picture of the atom illustrates the way scientific knowledge advances. Scientific frontiers are ever changing, not static; scientific knowledge is gleaned a little at a time. The present scientific front should not be presented as a fait accompli but rather as a culmination of a train of related events, an historical sequence in fact. Modern chemistry has a rich heritage and the authors have not hesitated to adopt the historical approach when a deeper comprehension of underlying principles is enhanced by doing so.

All chemical knowledge has been derived from experiments and it is reasonable to emphasize experimentation in teaching chemistry, even a general course such as this. There are two approaches to the experimental method, (1) through individual work in the laboratory and (2) by class demonstrations. Both play their part. Individual laboratory work undoubtedly has the greater value; it offers the greater challenge to the student. The laboratory manual that accompanies this text offers a wide variety of experiments to the student. Although demonstrations lack the personal touch of laboratory work yet, if well performed by the teacher, the student learns many manual techniques. Moreover, demonstrations are a valuable teaching method through which the student acquires keener observation and more critical judgment. Numerous class demonstrations are scattered throughout the text. It is recommended that, in general, before a demonstration is performed, the underlying principles be discussed. The students should, at least, answer the questions, What do you expect to happen? Why do you expect it to happen? The experiment itself should be done with deliberation and the teacher should call attention to the various situations as they develop. At the completion of the experiment there should be a recapitulation and further questioning. Were our predictions valid? Were there any unexpected happenings and, if so, how can they be accounted for?

The text itself is divided into ten progressively arranged units. Unit I is introductory. It includes a chapter on the slide rule which is a great time-saver in solving problems. It also includes a discussion of weight and volume, topics of prime importance in experimental work. Significant figures are likewise discussed. Without a concept of significant figures a student cannot interpret data intelligently.

To understand the various chemical processes some knowledge of physics is necessary. This is provided in Unit II. Every chemical reaction takes place with an evolution or absorption of energy, usually either heat energy or electrical energy. Electrons are also discussed in some detail because every chemical reaction involves a disturbance of electrons about the nucleus of an atom. And because a knowledge of the structure of atoms has been determined largely through a study of their bright-line spectra, there is a chapter on optical spectra. If this chemistry course has been preceded by a course in physics, a study of Unit II will probably serve little purpose, and the unit can safely be omitted.

The study of chemistry really began in the 19th century with the formulation of Dalton's atomic theory. This is discussed in Unit III. By inductive and deductive reasoning a number of natural laws were discovered which elevated chemistry to the rank of quantitative science.

Unit IV deals with approximately the same time period as Unit III. However, Unit III is concerned with the weights of reacting chemicals, whereas Unit IV deals with their volumes. Both the gas laws and Avogadro's law concern the volumes of gases; they will be frequently referred to in later units.

Atomic structure is the subject of Unit V, the models of both Bohr and quantum atoms being discussed at some length. In forming compounds atoms are bonded together electrically. An ionic bond is explained in terms of the Bohr model in Chapter 22; a covalent bond is explained in terms of the quantum model in Chapter 23.

The peculiar and unique structure of carbon atoms is discussed in Unit VI. Carbon atoms form tens of thousands of compounds which constitute a branch of chemistry known as organic chemistry. The lower members of the Paraffin Series are highly combustible and the heat released in these reactions is the source of power in many types of engines.

Unit VII is concerned with ionization and with the absorption or release of electrical energy in chemical reactions. The reaction in an electrolytic cell corresponds to an endothermic reaction; the reaction in a voltaic cell corresponds to an exothermic reaction.

Unit VIII is at the heart of chemistry teaching. The atomic structure of the elements determines the arrangements of these elements in families, and makes it possible to predict their properties.

Unit IX deals with the practical applications of some reactions on an industrial scale.

In the strict sense of the word Unit X is not chemistry, since it deals with the nuclei of atoms. However, students find an absorbing interest in radioactivity, transmutation, and the vast amounts of energy locked up in the nuclei of atoms. The authors have devoted the last four chapters to a study of the nucleus but the teachers must decide if it is reasonable to include "nuclear chemistry" in their particular courses.

PERIODIC TABLE OF THE ELEMENTS

The atomic number is shown above the symbol and the electronic configuration is shown below it. The horizontal rows are called Periods (indicated by Principal Quantum Number), and the vertical columns are called Groups (Group O,

Transition Elements

Principal Quantum Number	I A	II A	III B	IV B	V B	VI B	VII B	
1	1 H 1							
2	3 Li 2 1	4 Be 2 2						
3	11 Na 2 8 1	12 Mg 2 8 2						
4	19 K 2 8 8 1	20 Ca 2 8 8 2	21 Sc 2 8 9 2	22 Ti 2 8 10 2	23 V 2 8 11 2	24 Cr 2 8 13 1	25 Mn 2 8 13 2	26 Fe 2 8 14 2
5	37 Rb 2 8 18 8 1	38 Sr 2 8 18 8 2	39 Y 2 8 18 9 2	40 Zr 2 8 18 10 2	41 Nb 2 8 18 12 1	42 Mo 2 8 18 13 1	43 Tc 2 8 18 13 2	44 Ru 2 8 18 15 1
6	55 Cs 2 8 18 18 8 1	56 Ba 2 8 18 18 8 2	57 to 71	72 Hf 2 8 18 32 10 2	73 Ta 2 8 18 32 11 2	74 W 2 8 18 32 12 2	75 Re 2 8 18 32 13 2	76 Os 2 8 18 32 14 2
7	87 Fr 2 8 18 32 18 8 1	88 Ra 2 8 18 32 18 8 2	89 to 103					

57-71 RARE EARTHS OR LANTHANIDE SERIES	57 La 2 8 18 18 9 2	58 Ce 2 8 18 19 9 2	59 Pr 2 8 18 21 8 2	60 Nd 2 8 18 22 8 2	61 Pm 2 8 18 23 8 2
89-103 ACTINIDE SERIES	89 Ac 2 8 18 32 18 9 2	90 Th 2 8 18 32 18 10 2	91 Pa 2 8 18 32 20 9 2	92 U 2 8 18 32 21 9 2	93 Np 2 8 18 32 22 9 2

PERIODIC TABLE OF THE ELEMENTS (Continued)

for example, consists of the inert elements, and Group VII A consists of the halogens). The metals appear to the left of the heavy zig-zag line, and the nonmetals to the right.

VIII	VIII	I B	II B	III A	IV A	V A	VI A	VII A	0
									2 He 2
				5 B 2 3	6 C 2 4	7 N 2 5	8 O 2 6	9 F 2 7	10 Ne 2 8
				13 Al 2 8 3	14 Si 2 8 4	15 P 2 8 5	16 S 2 8 6	17 Cl 2 8 7	18 Ar 2 8 8
27 Co 2 8 15 2	28 Ni 2 8 16 2	29 Cu 2 8 18 1	30 Zn 2 8 18 2	31 Ga 2 8 18 3	32 Ge 2 8 18 4	33 As 2 8 18 5	34 Se 2 8 18 6	35 Br 2 8 18 7	36 Kr 2 8 18 8
45 Rh 2 8 18 16 1	46 Pd 2 8 18 18	47 Ag 2 8 18 18 1	48 Cd 2 8 18 18 2	49 In 2 8 18 18 3	50 Sn 2 8 18 18 4	51 Sb 2 8 18 18 5	52 Te 2 8 18 18 6	53 I 2 8 18 18 7	54 Xe 2 8 18 18 8
77 Ir 2 8 18 32 15 2	78 Pt 2 8 18 32 17 1	79 Au 2 8 18 32 18 1	80 Hg 2 8 18 32 18 2	81 Tl 2 8 18 32 18 3	82 Pb 2 8 18 32 18 4	83 Bi 2 8 18 32 18 5	84 Po 2 8 18 32 18 6	85 At 2 8 18 32 18 7	86 Rn 2 8 18 32 18 8

62 Sm 2 8 18 24 8 2	63 Eu 2 8 18 25 8 2	64 Gd 2 8 18 25 9 2	65 Tb 2 8 18 26 9 2	66 Dy 2 8 18 28 8 2	67 Ho 2 8 18 29 8 2	68 Er 2 8 18 30 8 2	69 Tm 2 8 18 31 8 2	70 Yb 2 8 18 32 8 2	71 Lu 2 8 18 32 9 2
94 Pu 2 8 18 32 23 9 2	95 Am 2 8 18 32 24 9 2	96 Cm 2 8 18 32 25 9 2	97 Bk 2 8 18 32 26 9 2	98 Cf 2 8 18 32 27 9 2	99 Es 2 8 18 32 28 9 2	100 Fm 2 8 18 32 29 9 2	101 Md 2 8 18 32 30 9 2	102 No 2 8 18 32 31 9 2	103 Lw 2 8 18 32 32 9 2

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unit I

INTRODUCTORY

preview to UNIT I

Chemistry is an experimental science and all chemical knowledge is derived from experiments. The experimental approach, which is emphasized throughout the text, is discussed in Chapter 1.

In most of the laboratory experiments data are collected and a computation is necessary, a computation that usually involves multiplication and division. A student will waste a great deal of time if he multiplies and divides by arithmetic processes. He should learn to use a slide rule. A slide rule is a great labor-saving device and a student will get much satisfaction by availing himself of the advantages it offers.

In particular the student will be concerned with measurements of weight and volume. To what degree of accuracy should these measurements be made? A popular idea with a beginner is that a "good" result in a laboratory exercise is one that very closely approximates the accuracy as expressed in scientific tables. Nothing could be more misleading. The expected accuracy in any experiment depends upon the nature of the equipment. If the equipment gives readings that are only approximately accurate, the result itself will be only approximately accurate. In other words, the student must learn at the outset to appraise the "significance" of his data; he must not expect data to yield a result more "accurate" than the data itself.

1 What Is Chemistry?

If we look up the meaning of the word ***chemistry*** in a dictionary, we find something like the following: "Chemistry is the branch of science that deals with the composition of substances and with the various changes that can occur in these substances." This statement, although acceptable as a dictionary definition, actually says very little. Indeed, it raises a number of questions in our minds. What is a substance? What is meant by the composition of a substance? What is meant by a change in a substance? What causes a change in a substance?

Before we can answer the question, What is chemistry?, we must first investigate the field. Man as an intelligent being has always been curious about his environment. Through the ages he has made discoveries that have given him more and more control over his environment. A scientific discovery is, as one might expect, discovering something that is already there; it adds to our knowledge concerning the ways in which nature behaves. A knowledge of nature consists of many branches, and one of them concerns the stuff the earth (or the universe) is made of. This particular branch, with its many ramifications, is called the science of chemistry.

Chemistry and Matter. Chemistry, then, is concerned with stuff or, as it is usually called, with matter. Water, air, coal, all kinds of rocks, and even ordinary salt are forms of matter. Let us consider, very briefly, one kind of matter, say iron, that we are already familiar with.

When we speak of iron we usually mean steel which is about 90 per cent iron. The uses of iron exceed, by far, the uses of any other metal; it is used in all kinds of constructions—skyscrapers, chemical refineries, automobiles, and even in wooden houses. Yet, in spite of the wide applications of this metal, it does not occur free, or uncombined, in nature. Iron comes from minerals (or ores) which, in the United States, are mined chiefly in Minnesota.

The extraction of metals from their ores is clearly a part of the science of chemistry. Such being the case, we might conclude that the art of extracting iron from its ores was something learned relatively recently. But this is not so. The preparation of iron from iron ore was known to the Egyptians and Syrians more than 3000 years ago. Many iron tools such as axes, saws, and nails are even mentioned in the Old Testament. We find an interesting reference to iron in First Chronicles 22:3, written about

1000 B.C., concerning David's plans for building a temple. It reads "And David prepared iron in abundance for the nails and the doors of the gates, and for the joinings."

You may also have heard of the famous Damascus steel swords made by the Syrians more than two thousand years ago. In these early days, steel used in swords was either so brittle that it broke under a sharp blow, or so soft that it bent under impact. But the Damascus swordmakers learned how to temper steel. The steel of the Damascus swords was strong and flexible and, as you probably know, it was a decisive weapon in battle.

Since iron has an ancient history, one might reasonably ask if anything has been learned about iron or steel that was not known to these early Damascus metallurgists. The answer is "Yes, a great deal." The Syrians discovered the tempering process by the method of trial and error. They learned that tempering increased the strength and flexibility of steel, but they knew nothing about the underlying causes. That is to say, they knew some facts but no theory. Through the years scientists, by various chemical methods and by using microscopes, X rays and other tools, have examined the inner structure of steel and have learned how to change its properties. Good steel is strong, tough, elastic and resistant to corrosion. This is a far cry from the Damascus steel of the early centuries. Nevertheless, the mere fact that steel, even inferior steel, could be made so many centuries ago was an extraordinary achievement.

Now let us turn to another metal, the metal aluminum. Aluminum, like iron, occurs only in mineral form—in the common ore called ***bauxite***. Aluminum in bauxite is far more plentiful than all the iron in the numerous ores of iron. Yet there is no reference to aluminum in the Old Testament, nor in the New Testament for that matter. Indeed, the way to make aluminum from its ore was not discovered until the latter part of the 19th century. Why did aluminum remain a "hidden" metal for so many centuries?

To separate iron from an ore such as hematite the ancient steelmakers simply mixed the ore with charcoal and heated the mixture to a very high temperature. But when they heated a mixture of bauxite and charcoal to a high temperature nothing happened. Why not? It looked as though the hot carbon of charcoal was not "powerful" enough to release the aluminum from its ore. This indeed turned out to be the case, and before aluminum could be "won" from its ore an entirely new metallurgical process had to be devised. This process required large electric currents which were unknown until the 19th century. Consequently, the metal aluminum was unknown until relatively recent times.

The Experimental Method. As we shall read in a later chapter, aluminum was finally extracted from its ore only after years of experimentation. Experimentation is essential in all branches of chemistry; it is the method of the research worker who operates on the frontiers of scientific knowledge. Every single experiment gives some useful information and, at the same time, it poses other questions which need to be investigated. That is to say, the experimental method, by its very nature, is continually expanding both the areas of inquiry and knowledge.

For precisely these reasons the experimental method is a stimulating way to learn chemistry. Even the experiments performed in a classroom are an invaluable aid to understanding this new science. First, there is observation itself. And, as we shall find out, the art of "seeing" things as they really are comes only with practice. Observation, in turn, promotes curiosity and inquiry—inquiry reaching far beyond