CHEMISTRY
BASIC CONCEPTS AND CONTEMPORARY APPLICATIONS
LEONARD S. WASSERMAN

CHEMISTRY

BASIC CONCEPTS AND CONTEMPORARY APPLICATIONS

Leonard S. Wasserman
El Camino College

Wadsworth Publishing Company, Inc.
Belmont, California

To my wife Rose

Designer: Gary A. Head
Technical Illustrators: Carl Brown, Mark Schroeder, Darwen Hennings, Vally Hennings

ISBN 0-534-00298-6
L. C. Cat. Card No. 73-91293
Printed in the United States of America
2 3 4 5 6 7 8 9 10—78 77 76 75

Wadsworth Series in Chemistry

General Chemistry by Gordon Barrow
Barrow's Clippings Booklet by Gordon Barrow
Organic Chemistry by Ronald Brown
Energetics, Kinetics, and Life: An Ecological Approach by G. Tyler Miller, Jr.
Replenish the Earth: A Primer in Human Ecology by G. Tyler Miller, Jr.
Organic Chemistry by Bernard Baker
Fundamentals of Physical Chemistry by Wayne Wentworth and Jules Ladner
Laboratory Manual for Chemistry: Basic Concepts and Contemporary Applications by Leonard S. Wasserman

Cover: A detail of the chemical reaction of rust.

Electronic configuration (principal levels): 2 5
7: Atomic number
N: Atomic symbol
14.01: Atomic mass

		s		d										p					
		Light		Heavy metals										Nonmetals					Noble gases
				Transition elements															
	Number of elements	I A	II A	III B	IV B	V B	VI B	VII B	VIII	VIII	VIII	I B	II B	III A	IV A	V A	VI A	VII A	VIII A
1	2									1 1 H 1.008									2 2 He 4.003
2	8	2 1 3 Li 6.940	2 2 4 Be 9.013											2 3 5 B 10.82	2 4 6 C 12.010	2 5 7 N 14.008	2 6 8 O 15.999	2 7 9 F 19.00	2 8 10 Ne 20.183
3	8	2 8 1 11 Na 22.997	2 8 2 12 Mg 24.32											2 8 3 13 Al 26.98	2 8 4 14 Si 28.09	2 8 5 15 P 30.975	2 8 6 16 S 32.066	2 8 7 17 Cl 35.457	2 8 8 18 Ar 39.944
4	18	2 8 8 1 19 K 39.100	2 8 8 2 20 Ca 40.08	2 8 9 2 21 Sc 44.96	2 8 10 2 22 Ti 47.90	2 8 11 2 23 V 50.95	2 8 13 1 24 Cr 52.01	2 8 13 2 25 Mn 54.93	2 8 14 2 26 Fe 55.85	2 8 15 2 27 Co 58.94	2 8 16 2 28 Ni 58.69	2 8 18 1 29 Cu 63.54	2 8 18 2 30 Zn 65.38	2 8 18 3 31 Ga 69.72	2 8 18 4 32 Ge 72.60	2 8 18 5 33 As 74.91	2 8 18 6 34 Se 78.96	2 8 18 7 35 Br 79.916	2 8 18 8 36 Kr 83.80
5	18	2 8 18 8 1 37 Rb 85.48	2 8 18 8 2 38 Sr 87.63	2 8 18 9 2 39 Y 88.92	2 8 18 10 2 40 Zr 91.22	2 8 18 12 1 41 Nb 92.91	2 8 18 13 1 42 Mo 95.95	2 8 18 13 2 43 Tc [99]	2 8 18 15 1 44 Ru 101.7	2 8 18 16 1 45 Rh 102.91	2 8 18 18 46 Pd 106.7	2 8 18 18 1 47 Ag 107.880	2 8 18 18 2 48 Cd 112.41	2 8 18 18 3 49 In 114.76	2 8 18 18 4 50 Sn 118.70	2 8 18 18 5 51 Sb 121.76	2 8 18 18 6 52 Te 127.61	2 8 18 18 7 53 I 126.91	2 8 18 18 8 54 Xe 131.3
6	32	2 8 18 18 8 1 55 Cs 132.91	2 8 18 18 8 2 56 Ba 137.36	57–71 See lanthanide series	2 8 18 32 10 2 72 Hf 178.6	2 8 18 32 11 2 73 Ta 180.88	2 8 18 32 12 2 74 W 183.92	2 8 18 32 13 2 75 Re 186.31	2 8 18 32 14 2 76 Os 190.2	2 8 18 32 17 77 Ir 193.1	2 8 18 32 17 1 78 Pt 195.23	2 8 18 32 18 1 79 Au 197.2	2 8 18 32 18 2 80 Hg 200.61	2 8 18 32 18 3 81 Tl 204.39	2 8 18 32 18 4 82 Pb 207.21	2 8 18 32 18 5 83 Bi 209.00	2 8 18 32 18 6 84 Po [210]	2 8 18 32 18 7 85 At [210]	2 8 18 32 18 8 86 Rn [222]
7	17	2 8 18 32 18 8 1 87 Fr [223]	2 8 18 32 18 8 2 88 Ra [226.05]	89–103 See actinide series															

f orbitals

Lanthanide series (rare-earth elements)	2 8 18 18 9 2 57 La 138.92	2 8 18 19 9 2 58 Ce 140.13	2 8 18 20 9 2 59 Pr 140.92	2 8 18 22 8 2 60 Nd 144.27	2 8 18 23 8 2 61 Pm [145]	2 8 18 24 8 2 62 Sm 150.43	2 8 18 25 8 2 63 Eu 152.0	2 8 18 25 9 2 64 Gd 156.9	2 8 18 26 9 2 65 Tb 159.2	2 8 18 28 8 2 66 Dy 162.46	2 8 18 29 8 2 67 Ho 164.94	2 8 18 30 8 2 68 Er 167.2	2 8 18 31 8 2 69 Tm 169.6	2 8 18 32 8 2 70 Yb 173.04	2 8 18 32 9 2 71 Lu 174.99
Actinide series	2 8 18 32 18 9 2 89 Ac 227	2 8 18 32 19 9 2 90 Th 232.12	2 8 18 32 20 9 2 91 Pa 231	2 8 18 32 21 9 2 92 U 238.07	2 8 18 32 22 9 2 93 Np [237]	2 8 18 32 23 9 2 94 Pu [242]	2 8 18 32 24 9 2 95 Am [243]	2 8 18 32 25 9 2 96 Cm [243]	2 8 18 32 26 9 2 97 Bk [245]	2 8 18 32 27 9 2 98 Cf [246]	99 Es [254]	100 Fm [253]	101 Md [256]	102 No [253]	103 Lw [257]

Table of atomic masses (Based on Carbon-12)

Values in parentheses are mass numbers of isotopes of longest half-life except Tc, Pm, and Po, where those for the best known isotopes are listed.

Name	Symbol	Atomic No.	Atomic Weight
Actinium	Ac	89	(227)
Aluminum	Al	13	26.98
Americium	Am	95	(243)
Antimony	Sb	51	121.75
Argon	Ar	18	39.95
Arsenic	As	33	74.92
Astatine	At	85	(210)
Barium	Ba	56	137.34
Berkelium	Bk	97	(247)
Beryllium	Be	4	9.01
Bismuth	Bi	83	208.98
Boron	B	5	10.81
Bromine	Br	35	79.90
Cadmium	Cd	48	112.40
Calcium	Ca	20	40.08
Californium	Cf	98	(251)
Carbon	C	6	12.01
Cerium	Ce	58	140.12
Cesium	Cs	55	132.90
Chlorine	Cl	17	35.45
Chromium	Cr	24	52.00
Cobalt	Co	27	58.93
Copper	Cu	29	63.55
Curium	Cm	96	(247)
Dysprosium	Dy	66	162.50
Einsteinium	Es	99	(254)
Erbium	Er	68	167.26
Europium	Eu	63	151.96
Fermium	Fm	100	(253)
Fluorine	F	9	19.00
Francium	Fr	87	(223)
Gadolinium	Gd	64	157.25
Gallium	Ga	31	69.72
Germanium	Ge	32	72.59
Gold	Au	79	196.97
Hafnium	Hf	72	178.49
Helium	He	2	4.00
Holmium	Ho	67	164.93
Hydrogen	H	1	1.01
Indium	In	49	114.82
Iodine	I	53	126.90
Iridium	Ir	77	192.2
Iron	Fe	26	55.85
Krypton	Kr	36	83.80
Lanthanum	La	57	138.91
Lawrencium	Lr	103	(257)
Lead	Pb	82	207.19
Lithium	Li	3	6.94
Lutetium	Lu	71	174.97
Magnesium	Mg	12	24.31
Manganese	Mn	25	54.94
Mendelevium	Md	101	(256)
Mercury	Hg	80	200.59
Molybdenum	Mo	42	95.94
Neodymium	Nd	60	144.24
Neon	Ne	10	20.18
Neptunium	Np	93	(237)
Nickel	Ni	28	58.71
Niobium	Nb	41	92.91
Nitrogen	N	7	14.01
Nobelium	No	102	(254)
Osmium	Os	76	190.2
Oxygen	O	8	16.00
Palladium	Pd	46	106.4
Phosphorus	P	15	31.00
Platinum	Pt	78	195.09
Plutonium	Pu	94	(242)
Polonium	Po	84	(210)
Potassium	K	19	39.10
Praseodymium	Pr	59	140.91
Promethium	Pm	61	(147)
Protactinium	Pa	91	(231)
Radium	Ra	88	(226)
Radon	Rn	86	(222)
Rhenium	Re	75	186.2
Rhodium	Rh	45	102.90
Rubidium	Rb	37	85.47
Ruthenium	Ru	44	101.07
Samarium	Sm	62	150.35
Scandium	Sc	21	44.96
Selenium	Se	34	78.96
Silicon	Si	14	28.09
Silver	Ag	47	107.87
Sodium	Na	11	23.00
Strontium	Sr	38	87.62
Sulfur	S	16	32.06
Tantalum	Ta	73	180.95
Technetium	Tc	43	(99)
Tellurium	Te	52	127.60
Terbium	Tb	65	158.92
Thallium	Tl	81	204.37
Thorium	Th	90	232.04
Thulium	Tm	69	168.93
Tin	Sn	50	118.69
Titanium	Ti	22	47.90
Tungsten	W	74	183.85
Uranium	U	92	238.03
Vanadium	V	23	50.94
Xenon	Xe	54	131.30
Ytterbium	Yb	70	173.04
Yttrium	Y	39	88.90
Zinc	Zn	30	65.37
Zirconium	Zr	40	91.22

Preface

Beginning chemistry students are known to approach the subject with self-doubt, for they often come to introductory chemistry courses with little or no background in science and scant confidence in their technical prowess. Unfortunately, such fears are frequently borne out by the encyclopedic textbooks beginning students are expected to digest. *Chemistry: Basic Concepts and Contemporary Applications* was written with an eye to breaking down some of the standard textbook barriers to learning chemistry. I designed the book specifically to satisfy the needs of students who are intimidated by a surplus of information and seek more integration.

In order to effectively balance the needs of both students and instructors, I spent considerable time going over each page of the preliminary edition of this book with many students, while Wadsworth backed up my efforts by consulting more than 120 instructors about the teachability and coverage of the material.

As a result, I have attempted to introduce major concepts in as digestible a form as possible, presenting only the essentials of each topic and emphasizing explanation over excessive detail. To tie these concepts to the "real world," I have integrated everyday applications into the text from the first chapter on. Chapter 1, for example, includes applications of chemistry to medicine; Chapter 2 on atoms discusses the biological consequences of ionizing reactions. Subjects of topical interest are also integrated into the material in order to make the concepts more accessible to contemporary students. Drugs, nutrition, food additives, nuclear chemistry, cosmetics, water, and air pollution are among the contemporary topics discussed.

In addition to seeking the most palatable way to present the core material to students, I have introduced several study devices. Key terms are underlined and defined throughout the text, as well as defined in an extensive review glossary at the end of the book. Review exercises at the end of each section within a chapter also test the student's grasp of the underlined terms and present further review of the section through short-answer questions. Review of each chapter is provided in the form of a list of chapter objectives followed by exercises that serve as chapter summary statements. Also, summaries in tabular form are included throughout the book to provide students with a quick visual review of concepts and their relationships.

For those students and instructors who wish to extend the boundaries of the beginning chemistry course, I have introduced optional enrichment material in "Additional topic of interest" sections that briefly discuss such topics as nuclear fission and fusion, orbital structure, and shapes of molecules. These self-contained sections are not referred to in later chapters and thus allow the instructor flexibility in his coverage.

As a final aid to the student, an appendix at the end of the book includes a detailed review of the mathematics necessary to grasp the concepts and problems presented in the text. The appendix presents additional examples of solved problems as well as exercises with unsolved problems for the student to work out. Thus, instructors have the option of building on the quantitative base in the text, and students with rusty math skills need not flounder unnecessarily.

My hope is that these learning devices taken together with the substance of the text will not only help students learn the fundamentals of chemistry but also help them maintain a clear focus on the role of chemistry in their everyday world.

Several reviewers of the manuscript were particularly helpful in their comments: James Campbell, El Camino College; Roscoe Lancaster, Golden West College; Richard McDonald, Fullerton Junior College; Phillip Meyer, Skyline College; James T. Rozolis, El Camino College; Howard Taub, Allied Health Professional Project, Division of Vocational Education, U.C.L.A.; Karen Timberlake, Los Angeles Valley College.

I also wish to acknowledge the assistance I received from the students who read my text from the student's point of view. My many thanks to Ellie Sweder, the "wizard" of the typewriter, who sometimes had to be half typist, half chemist to translate my scrawls into type. Finally, thanks to my wife for her valuable assistance.

Contents

Contents

8 An Introduction to Organic Chemistry and the Hydrocarbon Family 210

9 Alcohols, Phenols, Ethers, Aldehydes, and Ketones 258

10 Acids, Acid Derivatives, Heterocyclic Compounds, and a Summary of Organic Compounds 278

1 Introduction to the Science of Matter

1–1 From cave man to space man

As the cave man, ages ago, stood at the entrance of his cave and watched a lightning bolt strike a tree, he must have been awed as the tree burst into flame and disappeared from view. Undoubtedly he was fascinated by what happened to the tree. Was the fire a "spirit" that whisked away the tree into an unseen world? He was also probably puzzled when he observed small ponds of water disappear in the heat of the sun. Was this disappearance also the work of another unfriendly "spirit"? He had no way of knowing that the tree had not really disappeared into another world but rather that the tree's matter had simply changed into another form. Somewhat similarly the small pond had only evaporated into water vapor and thus became invisible to the naked eye.

By contrast, science today has given man the sophisticated instruments and knowledge not only to answer these questions but to use fire and water to advance his civilization. Unfortunately some of these advances have led to new problems such as the population explosion and pollution of air, water, soil, and natural foods. Science has perfected the technology of matter to the point where man has been able to leave the earth and explore the moon and the space beyond. Never before has man been able to present a subject with so many fascinating aspects. The contemporary college student is now able to discover the answers to questions that the most brilliant chemists of the nineteenth century could not have imagined.

Development of modern chemistry Chemistry, in some form, began with the dawn of human intelligence. As man became conscious of the materials of the world around him, he started to practice a rudimentary form of chemistry, which is evidenced in the many skills and arts known to the ancient civilizations: the smelting of iron, the preparation of tile enamels, the production of gold, glass, copper, bronze, dyes, ceramics, soaps, cosmetics, beer, and so on. The necessary skills to produce these products were based on experience gained from their accidental discovery. Because there was little understanding of how and why these changes took place, the real science of chemistry could not yet exist.

Atomic theory—from imagination to experimental confirmation During the height of the Greek culture, about 600–150 B.C., serious attempts were made to give plausible reasons for the occurrence of certain phenomena in nature. Aristotle, an outstanding Greek philosopher of this time, theorized the existence of four elements: earth, fire, air, and water. Democritus, also a Greek philosopher, suggested that all matter was composed of atoms. These explanations were incorrect. Although the Greek philosophers gathered observational data and rejected mysticism, they did not experiment. Much later, in 1802, John Dalton, an English chemist, revived

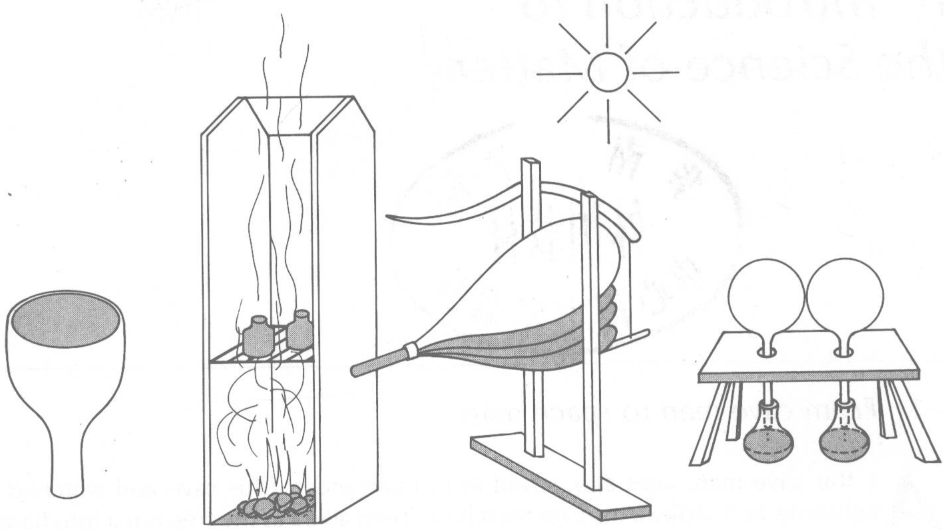

Figure 1–1 The experimental equipment of an alchemist.

the theory that matter is composed of distinct particles called *atoms*, but this time the concept of the atom was used to explain experimental facts.

Alchemists—wizards of chemical miracles The word *chemistry* originated in 400 B.C. from the Greek word *chēmeia,* which designated the art of metal working. At a later time the Arabs added the prefix *al.* The new word *alchemy* signified the art of chemistry in general. Most of the royal courts employed alchemists and had great faith in their ability to perform chemical "miracles." Alchemy was a semimagical speculative science tinged with religious and philosophical ideas. Most alchemists believed that most metals were coarse, but that gold was "pure" and "noble." Consequently they were intensely preoccupied with converting other metals to gold (see figure 1–1).

About A.D. 300–400 the Egyptians supposedly used sorcery to convert base metals to gold. Today we know the Egyptian alchemists could not have succeeded because such a conversion is not chemically possible. Later the Arabs assimilated the Egyptian civilization with all its arts. Around A.D. 700 the Arabs conquered a large portion of Spain and introduced many of their arts, including alchemy. In Spain, Geber (721–766), an Arab physician, claimed that all base metals consisted only of brimstone (sulfur) and mercury. To make the metal less coarse, the sulfur had to be driven out. According to the alchemists, gold contained almost no sulfur. The *philosophers' stone* was a mysterious substance that men believed would change base metals to gold. Although the alchemists failed, modern chemists have actually been able to synthesize gold by nuclear means. Unfortunately artificial production of gold is more costly than mining natural gold.

Contributions versus goals of alchemy In addition to their desire to change metals into gold, the alchemists wanted to discover the "elixir" of life, which they hoped would serve as a "cure-all" for physical ailments and permit man to attain eternal youth. Eventually many alchemists fell into complete disrepute when they were exposed as pretenders to medical knowledge who took advantage of gullible

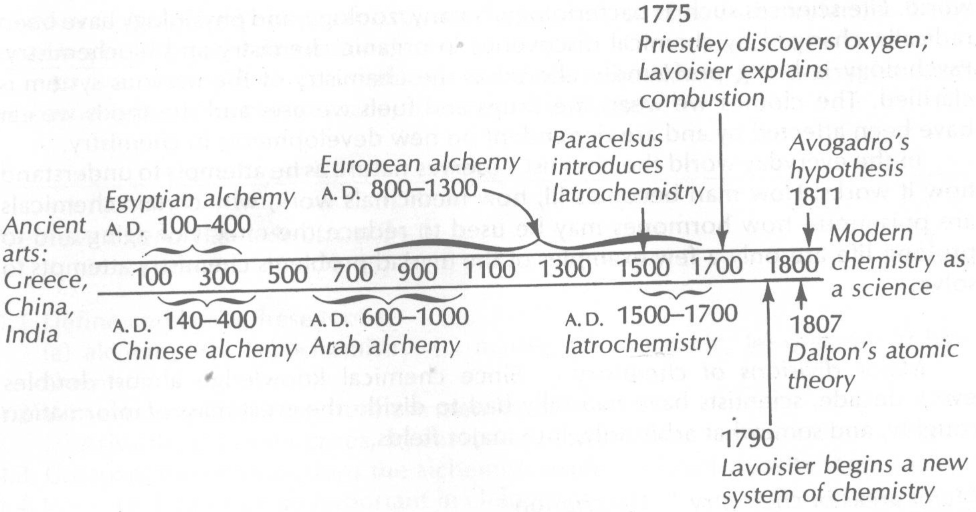

Figure 1–2 *Evolution of chemistry*

and superstitious persons. However, many other alchemists were sincere in their scientific interest, and they made two important contributions to the evolution of chemistry—the *experimental approach* and the *application of chemistry to medicine.*

Chemistry applied to medicine, then and now Philippus Paracelsus, a Swiss-born alchemist and physician of the sixteenth century, was critical of both doctors and alchemists. He persuaded many alchemists that their only salvation was in the discovery of remedies to cure the sick. By encouraging the use of chemistry in medicine, Paracelsus initiated iatrochemistry, a branch of chemistry applied to medicine (see figure 1–2). This shift of interest resulted in the decline of alchemy.

The beginning of medicinal chemistry is important because our present culture is so drug oriented. We use pills to put us to sleep, to wake us up, to elevate our mood, to soothe our "nerves," and to modify many of our other bodily functions. Therefore it is essential that we understand the benefits as well as the dangers of drugs; this can be accomplished only if we know their chemical makeup and their effects on the body.

Dawn of modern chemistry Around 1700, many scientists believed that a substance called phlogiston escaped from a material in the form of a flame and caused that material to burn. In 1774, Joseph Priestley undermined this theory by discovering oxygen, an essential element in burning. In 1775, Antoine Lavoisier proved the true nature of burning through experimentation and accurate determination of mass. The work of these two men marked the beginning of modern chemistry.

Chemistry for a better understanding of the life sciences Much of our present-day technology is concerned with the production of medicinals, synthetic fibers, fuels, plastics, and so on. Chemistry is essential in understanding other sciences and all fields in our technical world—the living as well as the material world. Life sciences such as bacteriology, botany, zoology, and physiology have been radically changed by chemical discoveries in organic chemistry and biochemistry. Psychology is being profoundly altered as the chemistry of the nervous system is clarified. The clothes we wear, the drugs and fuels we use, and the foods we eat have been affected by and are dependent on new developments in chemistry.

In the everyday world the chemist observes nature as he attempts to understand how it works. How man becomes ill, how medicinals work, why certain chemicals are poisonous, how hormones may be used to reduce the effects of aging and to prolong life are only a few examples of the myriad problems chemistry attempts to solve.

Major divisions of chemistry Since chemical knowledge almost doubles every decade, scientists have naturally had to divide the great mass of information roughly, and somewhat arbitrarily, into major fields.

Major areas of chemistry	*Description*
Inorganic chemistry	Metal and nonmetal elements
Organic chemistry	Compounds of carbon and hydrogen and their derivatives
Biochemistry	Living processes in health and disease

Divisions of major areas	*Description*
Analytical	Methods for analyzing
Qualitative	Methods for identifying the composition and structure of matter
Quantitative	Methods for determining the quantities of the components
Physical	Methods for establishing fundamental laws and theories

The divisions describe more completely the major areas. For example, more descriptive divisions might be: qualitative organic chemistry, quantitative organic chemistry, and quantitative inorganic chemistry.

Code used by chemists Like all other sciences, chemistry has its own language, which must be clearly and universally understood. To avoid confusion, a stated principle or a description of a chemical phenomenon must mean the same to the person who reads it as it does to the person who writes it. To guarantee an accurate understanding, scientists agree on restricted and limited meanings for words—even if the terms are commonly used.

Our everyday language is filled with words taken from the sciences. For example, the word *compound* is defined several ways in the dictionary, but its meaning in chemistry is definite and restricted. Consequently the successful student of chemistry must learn the specialized definition of a word or words so that he will be proficient in the special language of the science.

Definition of chemistry Chemistry is a fundamental science because it deals with the matter of the universe. Matter is anything that occupies space and has mass. Chemistry is concerned with the structure, properties, and uses of matter; its changes in energy and in composition; and its importance in our daily lives. If someone were to offer you a glass which he said contained a solution of chemicals, would you drink the substance? On the other hand if someone were to offer you the same glass which he said contained fruit juice, would you drink the juice? And yet fruit juice is a