CHEMISTRY

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W. W. NORTON & COMPANY, INC., NEW YORK

Library of Congress Catalog Card No. 64–10890

Published simultaneously in
Canada by George J. McLeod Limited, Toronto
SBN 393 09511 8
Printed in the United States of America
7 8 9 0

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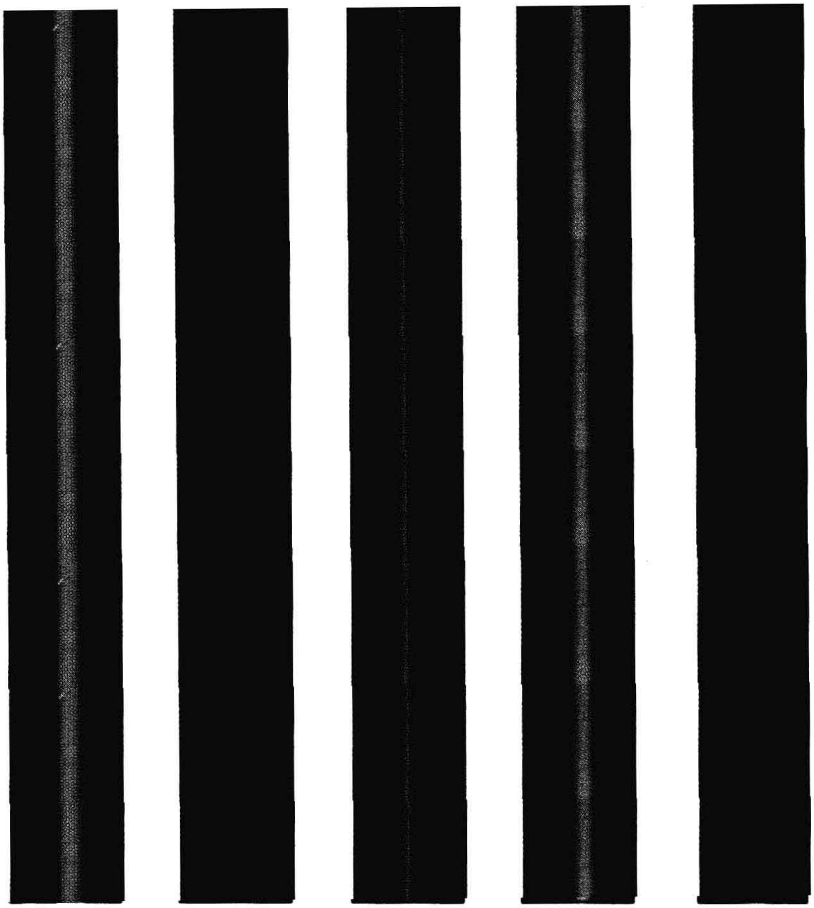

Helium (He) | Neon (Ne) | Argon (A) | Krypton (Kr) | Xenon (Xe)

The characteristic colors of the inert gases in discharge. Inert gas atoms (and, indeed, all atoms) absorb energy when subjected to an electrical discharge and re-emit this energy as light. Since the amount of energy absorbed depends upon the number and distribution of electrons about the nucleus of the atom and each atom of an element has a different distribution of electrons, each element will exhibit light of a characteristic color that can be used for identification purposes.

Preface

Those who undertake the study of chemistry fall into two rather distinct groups. One includes those who will pursue chemistry as a career or who will use it while working in such areas as engineering or the biological and medical sciences. The other group includes those whose primary interests lie in nonscience areas and whose principal activities are less likely to be directly influenced by the knowledge of a science such as chemistry. It is self-evident that the needs of these two groups are decidedly different.

The initial study of chemistry by the science-oriented student is necessarily limited in scope. Because of the need to explore each topic in depth and to lay a firm foundation for more advanced study, the first course in chemistry for those students usually covers only a small segment of the entire field. For the other group, however, it is essential in the first course to provide a broad orientation with respect to the science of chemistry as a whole. It is for the needs of this latter group that the present volume, like its predecessor *The Science of Chemistry,* is addressed.

Even though those whose main interests are the arts, the humanities, business, the law, etc., may have only very limited need for a day-to-day application of chemistry to their work, some knowledge of this physical science nevertheless can be a very real asset. The impact of science upon modern society is so profound and widespread as to be inescapable. It is no exaggeration to say that at least a limited knowledge of chemistry is essential to any reasonable understanding of the multitude of changes that are occurring in the world today.

The principal objectives in the study of chemistry by the nonscience-oriented student are clearly defined. Since chemistry is basically an experimental science it should be an example of a way of thinking. The student should come to understand how the chemist plans experiments, why he performs them, and how he interprets the results and uses them to design still other experiments. Chemistry should also show how new knowledge accrues from objective reasoning in terms of things that can be measured and expressed in numbers. Thus the student may learn something of the relationship between chemistry and other areas of learning and of the ways in which chemistry has contributed to man's understanding of the entire physical universe.

There are also somewhat more prosaic gains. In our daily lives we are surrounded by chemical products and processes. The press and other media of communication continually make us aware of much that we need to understand if only to distinguish better between fact and fallacy. This entails some appreciation of the methods of science, of past accomplishments, and of future objectives.

It follows that the study of chemistry by those not primarily interested in science should have sufficient depth to avoid superficiality. At the same time there should be sufficient breadth to provide an overall orientation while maintaining a proper balance between the theoretical and the practical. It is our hope that the present volume attains these goals.

We wish to express our gratitude to all those who assisted in securing illustration materials used in this book. We are especially grateful to Dr. C. Gordon Skinner, Dr. Jeanne M. Lagowski, and Dr. E. M. Lansford, Jr., for their assistance in preparing certain portions of the manuscript.

Austin, Texas
November, 1963

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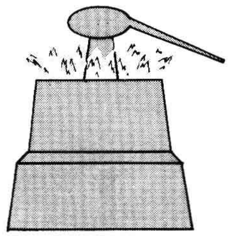

CHAPTER 1.

Historical Background

The past two decades have been a period of unprecedented progress in the physical sciences. We have witnessed the development of atomic weapons and at least a good beginning toward the use of atomic energy for nonmilitary purposes. Other technical advances include solar batteries, intercontinental ballistic missiles, electronic devices of a wide variety, and the means for man's first exploration of outer space. Thus there have evolved technological developments that may contribute to man's well-being or to his destruction. In an effort to view the impact of these advances in a proper perspective, it is interesting to recall a statement made nearly two thousand years ago. In his *Natural History,* the Roman philosopher Pliny (A.D. 23–79) wrote as follows:

> It is by the aid of iron that we construct houses, cleave rocks, and perform so many other useful offices of life. But it is with iron also that wars, murders, and robberies are effected, and this, not only hand to hand, but from a distance even, by the aid of weapons and winged weapons, now hurled by the human arm, now launched from engines,

and now furnished with feathery wings. This last I regard as the most criminal artifice that has been devised by the human mind; for, as if to bring death upon man with still greater rapidity, we have given wings to iron and taught it to fly. Let us, therefore, acquit Nature of a charge that belongs to man himself.

This and similar writings show that, throughout recorded history, mankind has been concerned about the impact of scientific developments upon civilization and that these developments have had strong moral, sociological, political, and economic overtones.

If we are to gain some appreciation of the impact of science upon society, it would seem accomplished best against the background of history.

The Ancient Arts

The emergence of chemistry as a true science cannot be assigned any exact date. Numerous lines of evidence, however, show that the development of chemistry included certain very early practices that were based on chance discovery and were not integrated into any logical framework designed to achieve a deeper understanding of natural processes. These practices are best designated as arts and crafts. Metal working, for example, was known in both Egypt and Mesopotamia before 3400 B.C. A well-preserved copper bull's head (*ca.* 3000 B.C.) is on display in the British Museum, and other products of Sumerian art, including copper scimitars, have been discovered. A Minoan cup fabricated of gold and many other gold vessels have been found; these specimens of ancient art demonstrate that gold working was highly developed as early as 1500 B.C. Gold ornaments found together with Stone Age implements suggest that this was probably the first metal used by man.

Both gold and silver are mentioned in the Old Testament, and for a long time silver was considered more precious than gold. In the book of Genesis it is recorded that Abraham bartered silver for a burial place for Sarah. The discovery and use of still other metals had great historical significance. As early as 1500 B.C. the Hittites were skilled in the working of iron, and their iron weapons gave them great advantage in battle. The metals mercury, tin, and lead were also known to ancient man, and articles made of bronze were in use as early as 2500 B.C. The early Romans fabricated water pipes of lead and, incidentally, made the grievous error of fashioning cooking utensils of this same metal. It seems highly probable that this latter practice led to the premature death of many a stalwart Roman as a result of lead poisoning.

Not all the early arts and crafts were concerned with metals. Carbon was most certainly known in prehistoric times in the form of soot and charcoal; the Bible contains reference to another form of carbon, the diamond. Sulfur, referred to in the Bible as brimstone, was early used as a medicine. It is also well established that the manufacture and use of glass and pottery, the production of alcoholic beverages, and the coloring of fabrics with dyes extracted from materials of natural origin were included among the early arts and crafts.

Knowledge concerning these practices was perpetuated only as it was passed verbally from one generation to another. These crafts were the province of illiterate artisans. Those who were capable of independent thought and the preparation of written records were apparently unacquainted with the practical arts and uninterested in anything in the nature of experiments. For example, Aristotle stated that a barrel full of ashes will hold as much water as an empty barrel! Apparently it never occurred to Aristotle or any of his contemporaries to perform the obvious experiment in an effort to confirm or disprove the statement. Social distinctions of the times permitted no common meeting ground for the artisan and the philosopher, whose position was one of dignity and whose efforts were restricted to processes of pure thought. It is a remarkable fact that this aggrandizement of the purely mental and the disdain of manual labor were more or less prevalent throughout the succeeding centuries and are far from unknown in modern society. As late as the sixteenth century, teachers of anatomy considered dissection as unworthy of their exalted position; the task was performed by barbers.

In any event, the net result of this sharp segregation of theory and practice was a period of little progress, at least as far as the chemical arts were concerned. Much more significant progress was made in the more abstract areas of learning, such as mathematics and astronomy. More rapid strides toward progress in chemistry were destined to await a clear recognition of the value of experimentation.

▶ Alchemy

From these fragmentary beginnings, it is not to be anticipated that the Middle Ages could have contributed much toward real progress. Particularly during the decline of the Roman Empire, there was a decidedly downward trend in accomplishment in all intellectual pursuits. To a limited extent progress was possible in literature and philosophy, since these fields enjoyed the tolerance if not the unlimited approval of the Church.

Nevertheless the period from A.D. 500–1400 is significant because it witnessed the rise of alchemy. The etymology of the term provides a clue to certain characteristic activities included within its scope; that is, alchemy was commonly referred to as the Egyptian black art. Despite this implication as to its origin, there is other evidence that alchemy was practiced early in China and may actually have originated there.

Since the writings of the alchemists are so intertwined with mysticism, superstition, religious ritual, and apparently deliberate efforts at concealment, all the objectives of the alchemists cannot be deduced from their rather unintelligible ramblings. Even so, it seems clear that the main objective was to transform common metals (for example, lead, copper, iron) into gold. As a means of accomplishing this end, the alchemists sought some sort of *materia prima,* commonly referred to as the *philosopher's stone.* It was believed that this mysterious and all-powerful something would not only turn other metals into gold, but would also cure all human ills, endow its discoverer with riches and supernatural qualities, and perform many other wonders. This so-called philosopher's stone was sought in almost every imaginable material source and with a zeal that is to be admired for its fervor if not for its rationality. Jaffe gives an interesting but possibly somewhat imaginative account of the alchemist Bernard Trevisan

> . . . in the act of hardening two thousand hens' eggs in huge pots of boiling water. Carefully he removes the shells and gathers them into

a great heap. These he heats in a gentle flame until they are white as snow, while his co-laborer separates the whites from the yolks and purifies them all in the manure of white horses. For eight long years the strange products are distilled and redistilled for the extraction of a mysterious white liquid and a red oil.[1]

Needless to add, neither the white liquid nor the red oil proved to be the philosopher's stone, but the failure of this experiment doubtless did little to deter Trevisan from concocting other equally strange products by even stranger processes.

No account of alchemy would be complete without recognition of some of the practices that it spawned. The very fact that gold was an objective suggests the possibility of chicanery. Indeed, the history of alchemy is replete with examples of fraud, trickery, and deception of a high order. Various alchemists at one time or another claimed to have made the great discovery, and many a gullible citizen was separated from his life savings after having witnessed a spurious but cleverly conducted demonstration. Such swindles must have been common. It is said that Frederick of Wurzburg provided a special gallows that was reserved for alchemists, and as late as 1404 the English Parliament passed an act forbidding the production of gold by alchemical methods. Henry VI, however, was more astute. He not only permitted but openly encouraged such efforts, since he perceived therein a possible means of absolving an embarrassing indebtedness.

Despite these and other features, the alchemical period was not without its accomplishments. Many new and useful substances were discovered—by accident to be sure—but these discoveries loom large to the extent that they foreshadowed far more significant events. The weird practices of alchemy brought to light such materials as arsenic, sulfuric acid, borax, and plaster of Paris. In addition, numerous articles of equipment and several common laboratory processes and procedures had their origin in that distant period. Judged in terms of twentieth-century standards, the yield of new knowledge was indeed meager in relation to the magnitude of the effort expended. On the other hand, perhaps the same may come to be said of twentieth-century progress after the lapse of a comparable interval of time.

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[1] Reprinted from *Crucibles* by permission of Simon and Schuster, Inc., publishers. Copyright, 1930, by Bernard Jaffe.

▸Chemistry and Medicine

Alchemy came by no means to an abrupt end. The search for the philosopher's stone continued on an abated scale while new motivations appeared on the horizon. Realization of the alchemist's dream of transformation of other metals into gold was destined to await and become an accomplishment of twentieth-century science.

The revival of learning that began in the fourteenth but became more evident in the fifteenth century set the stage for the evolution of chemistry as a true science. In the period A.D. 1400–1700, a single development overshadowed all others. It was in this interval that the experimental method came to occupy a position of prime importance. No longer were purely abstract ideas to be accepted without any effort at verification. Those who worked with their hands began to think for themselves; they had ideas, albeit crude ones, and it became respectable to perform experiments.

Early in that period the search for the philosopher's stone was progressively replaced by the quest for the *elixir of life.* Many alchemists and physicians alike turned their attention to the search for a universal medicine, which they believed would not only cure all the ills of mankind but also restore youth to the aged and prolong life so that man could live for hundreds of years. This suggests a close interrelationship of chemistry and medicine, and indeed the histories of the two throughout the period in question are scarcely distinguishable. The practice of medicine in that time was based largely upon the teachings of the early Greek physicians Galen (A.D. 130–200?) and Hippocrates (460–359 or 377? B.C.) and consisted of the treatment of ills by methods that now seem little short of barbaric. Despite the fact that the teachings of Galen and Hippocrates were steeped in superstition and were largely without experimental foundation, their influence was most profound.

Reform in medicine and a new impetus in chemistry were paralleled by other evidences of a rebirth of intellectual activity. The invention of printing by Johannes Gutenberg stimulated writing and the exchange of information and ideas. The discovery of the new world by Christopher Columbus in 1492 was another evidence of the brand of curiosity that makes for progress. The Protestant Reformation had its origin in the same period, when Martin Luther nailed his ninety-five theses on the door of the Castle church in

Wittenberg in 1517. At about the same time, Copernicus came forth with the novel idea that the sun, and not the earth, is the center of the physical universe. This was indeed a period of renaissance.

Much of the improved outlook in chemistry and medicine was due to one called Paracelsus (1493–1541) but whose full name was Philippus Aureolus Paracelsus Theophrastus Bombastus Eremite von Hohenheim. Vain, vitriolic, and vulgar of speech, Paracelsus throughout his lifetime waged a one-man war for reform in medicine and heaped condemnation upon the physicians and apothecaries who subscribed to the teachings of Galen and Hippocrates. Merely to record that Paracelsus was hated by most of the physicians of his time is a gross understatement. He described their remedies and prescriptions as "foul broths" and to the physicians he said, "You are not worthy that a dog shall lift his hind leg against you."

Paracelsus was probably the first to recognize that life processes are fundamentally chemical. He strove for the application of chemicals to medicine, and his efforts led to vast improvement in the methods for the treatment of disease. He was the first to use preparations containing mercury, he introduced to medicine the use of opium (which he called *laudanum*), and he initiated the use of other remedies containing arsenic, copper, and lead. Of more far-reaching importance, however, was his contribution to the evolution of the experimental approach to the solution of all kinds of problems. Almost unaided, he forced upon men of his time a realization of the value of experimentation. His viewpoint is clear from the following quotation from his writings

> I admonish you not to reject the method of experiment, but, within the limits of your abilities, follow it without prejudice. Every experiment is like a weapon which must be used according to its particular virtue, as a spear to thrust, a club to strike; so also is it with experiments.

These and other developments during the renaissance period were destined to give birth to chemistry as a science worthy of the name. Still other noteworthy contributions were made during the seventeenth century. Among these were the discovery of the barometer by Torricelli in 1643, the discovery of the laws of gravitation by Newton in 1665, the invention of logarithms by Napier in 1614, and Robert Boyle's classical work on the properties of gases and in other phases of physical and chemical science. So revolutionary were the effects of Boyle's discoveries that he is often referred to as the father of modern chemistry. By the beginning of the eighteenth century, the sciences were truly on the threshold of momentous events; chemistry was about to come of age.

Chemistry in the Eighteenth Century

Chemical science of the early eighteenth century is perhaps more aptly described as chemical philosophy. Many phenomena now considered simple and elementary were misinterpreted and incompletely understood. Wholly different interpretations, for example, were given to the nature of fire and the process of combustion. The nature of the atmosphere and of simple materials such as water was unknown. The infant science of chemistry was still impeded by an inheritance of vague and contradictory ideas that were destined to persist for nearly a century. It had become, however, a truly experimental science, and therein lay the key to progress. Out of this thick fog of confusion there arose in the latter part of the eighteenth century the first real evidence of orderliness; even the language and terminology of chemistry showed signs of systematization.

The period that gave birth to the French Revolution and saw it brought to fruition witnessed also something akin to a revolution in chemical thought. Although many contributed to this new order in science, a few names and accomplishments are particularly worthy of note. The English clergyman Joseph Priestley (1733–1804) turned his attention to science when his religious views brought him into popular disfavor. He is credited with the independent discovery of oxygen and contributed much to the development of improved methods for the conduct of a wide variety of chemical experiments. Incidentally, he was the first to prepare what is now known as "soda water." He was a contemporary and friend of the Scotch engineer James Watt, who invented the steam engine. Both before and after he came to America in 1794, Priestley conferred on numerous occasions with Benjamin Franklin. Priestley was also a friend of George Washington, and of Thomas Jefferson, who once