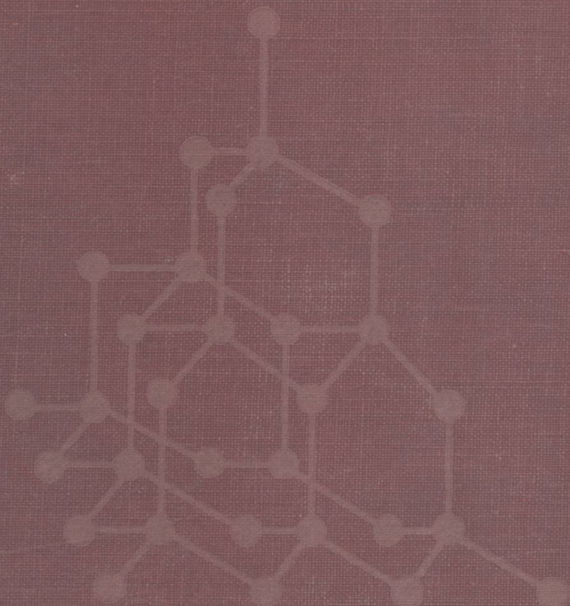

ESSENTIALS OF CHEMISTRY

SECOND EDITION

FOREWORD

To THE STUDENT. Here is an invitation to an intellectual adventure. Like the mountain climber, you will see new horizons and, like the explorer, you will learn of new worlds. This text is an introduction to the science of chemistry which is an interpretation of the physical world.

An intellectual adventure can be thrilling, and the knowledge and experience gained from it can be useful in many ways throughout life. But the adventure will not be easy; no real adventure is.

To THE STUDENT AND THE TEACHER. The choice and arrangement of subject matter in this text has been selected to a large extent in terms of the authors' answer to the question, "What should a student gain from the study of science that will make him a happier, better-informed citizen of his community?" The answer is to be found in the following objectives which we believe should be realized, at least in part:

1. A student should gain knowledge of the evolutionary processes that have altered the organic and inorganic world over the eras of time.
2. A student should gain knowledge of the organic and physical world around him.
3. A student should gain an awareness of the impact of the new scientific developments upon social, economic, and political problems.
4. A student should gain experience in the way science solves problems and training in the use of the scientific method.
5. A student should gain a perspective on what can be expected of science in the future.
6. A student should become acquainted with some of the world's great scientific ideas; the written expression of these ideas represents some of the world's great literature.
7. A student should come to realize that science is power, but should also understand its limitations.

These objectives cannot be realized solely by the use of any one textbook; careful observation, clearness of thought, the desire to learn, and the inspiration of great teachers are also of tremendous importance. The custom and practice of wide reading of reliable literature will also be of considerable aid in attaining these objectives. To that end the authors recommend that this textbook be used as a guide rather than as a sole authority. The authors have selected a reading list of several books and journals to which constant reference is made.

The choice of material was directed by the intention of presenting an outline of the field of chemistry for students who do not intend to specialize in this field. This does not make for a "soft course." The presentation can be as rigorously scientific as in any course. The difference between this text and the more usual general chemistry text which is written on the assumption that further chemistry courses will be taken lies in the more qualitative nature of much of the presentation and in the breadth and choice of subject matter covered.

The classical approach has been by-passed in several instances for brevity and for perspective. The unit system has been used to afford continuity in a field that now covers such a wide variety of subjects. The early units introduce the student to the elementary chemical interpretation of the origin of the earth, the formation and composition of the earth's crust, the minerals, and the atmosphere. An entire unit is given to a discussion of radioactivity and atomic structure.

The descriptive chemistry of the metals, the nonmetals, and their compounds has been expanded in this revision, over the previous edition, but it is still condensed to a great extent in comparison with most general chemistry texts. The descriptive chemistry is closely related to the concept of atomic and molecular structure wherever possible, and thus illustrates the general principles relating properties to structure.

The subject of atomic weights is presented by defining an atomic-weight unit (a.w.u.), a device which places the meaning of atomic weight on the same basis as any unit of measurement.

Increased attention is given to the section on organic chemistry. This is of particular interest to those students who take no more courses in chemistry. This field deals with so many materials of everyday life that it seems to deserve a more prominent place in the student's early chemical experience. The emphasis in the organic section has been put on the structure of molecules and the types of compounds rather than on synthesis and mechanism of reactions. Revision of this section includes new information on antiknock agents, high polymers, vitamins, and medicinals.

The last three chapters are devoted to the chemistry of everyday life, and it is felt that these chapters will add greatly to an enriched awareness of the world in which we live. The solar battery and the nuclear battery are described in this revision.

Such items as equation writing and chemical arithmetic, and derivation of formulas, have been placed in the Appendix. These items are useful; that is why they are included. But it is believed that they frequently destroy continuity when included in the main body of subject matter.

The authors believe that basic to an understanding of science is a knowledge of the facts of science. They further believe that subject matter and method should be woven together into a continually repeating pattern of observation, classification, hypothesis, experimentation, and theory.

THE AUTHORS

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UNIT SEVEN · ORGANIC CHEMISTRY: THE CHEMISTRY OF THE COMPOUNDS OF CARBON

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Science and the Future

Today the magnificent achievements, the horrendous dangers, and the golden promise of science and technology are in the minds and hearts of men everywhere, as perhaps never before.

By the 21st century science and scientists will have profoundly influenced and shaped the mind of man, his outlook on life, his attitude toward his neighbors in the next block and across the seas, his understanding of himself as an individual.

David Lilienthal

A Scientist's Creed

Relying upon a faith that our universe is not a chaos, but an ordered cosmos,

I believe that through sincere and courageous effort man can learn what is true.

I believe that inherent in what is true is that which will serve creation in its highest form, which is humanity.

I believe that truth shall make man free—free from the ills of the flesh and the spirit.

I rely upon an unfolding knowledge of the truth to provide a solution for the problems and conflicts that vex humanity.

I therefore dedicate myself to the task of seeking the truth, fearlessly and zealously, and to the application of what knowledge I may gain for the establishment of a peaceful, just, and orderly civilization on earth.

Arthur H. Compton

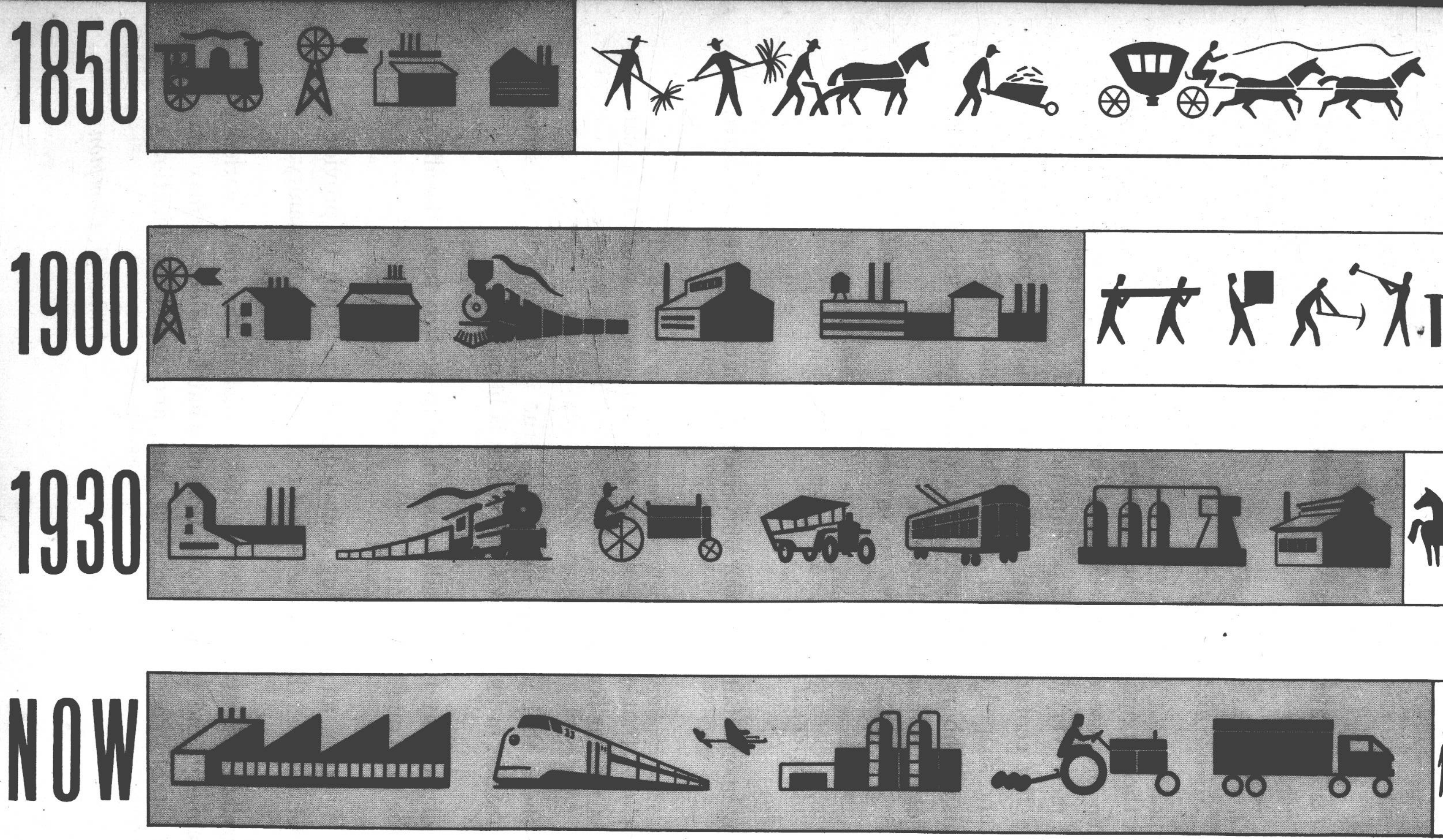

Fig. 1-1. In 100 Years Machines Have Taken Over Most of Our Heavy Work. In 1850 they did about 35 per cent of heavy work in the United States. Men and animals did the rest. In 1900, machines accounted for 73 per cent; in 1930, for 97 per cent; and today they do 99 per cent of our work

chapter 1

THE SCIENCE OF CHEMISTRY

You live in one of the most interesting periods in the whole history of mankind. It is called the atomic age; it is the age of science. Science has been defined as a body of knowledge so classified as to be of value in the search for truth. In the science of chemistry that search is directed toward the understanding and interpretation of the structures, compositions, and modes of reaction of all the substances found in the physical and biological world or made in the laboratory or in the manufacturing plant. Much progress has been made in realizing that objective, but much more remains to be done.

Science has harnessed waterfalls for the generation of electric power.

Science has converted mountains of iron ore into factories, ships, and machines.

Science has discovered the source of the energy of the sun and the stars and has released it on a large scale on the earth.

Science has improved on many of nature's materials, and has made many new products, such as synthetic fibers, rubber, plastics, drugs, and alloys.

Science has improved living conditions and created many new industries.

SCIENCE HAS MADE MANY CHANGES IN OUR STANDARD OF LIVING

In 1492 it required three months to cross the Atlantic Ocean; now it can be done in a few hours.

As late as 150 years ago we had no anesthetics, vaccines, or electric lights, or even oil lights, railroads, automobiles, radios, airplanes, or television. Here are the dates of some important discoveries and inventions:

Discovery

1774 Explanation of combustion
1842 Use of anesthetics
1849 Discovery of petroleum in America
1865 Antiseptic treatment in hospital surgery
1888 Use of serum therapy
1896 Discovery of X rays and radioactivity
1918 Discovery of vitamin C
1922 Discovery of insulin
1938 Discovery of penicillin
1939 Discovery of atomic fission

Invention

1769 Invention of steam engine
1855 Building railroads through midwest
1876 Invention of the telephone
1878 Invention of the electric light
1892 Invention of the automobile
1902 Invention of the radio
1903 First airplane flight
1925 (about) Invention of television
1948 Invention of transistor

Before the steel plow was invented it required eight men working from dawn to dusk six days a week to make a living for ten; now, in this scientific age, two men can do the same amount of work in a forty-hour week.

During the time of the Civil War fifty per cent of human deaths were of children under five years of age. Now only twelve per cent of the deaths are in this age group. The life expectancy of a newborn child in the United States has changed in the last eighty years from 35 to 70 years.

A few years ago the United States imported most of its nitrate fertilizers from Chile and its rubber and silk from the Far East; now all these materials can be synthesized if necessary.

Only a few years ago there was no definite cure for gas gangrene, osteomyelitis, peritonitis, pneumonia, or blood poisoning; now such antibiotic drugs as penicillin, streptomycin, aureomycin, and the sulfa drugs offer a cure for those dreaded infections.

These are but a few of the many accomplishments of science.

DISCOVERIES IN SCIENCE

Among the long list of scientific discoveries during the past century and a half are some outstanding chemical developments. How have such discoveries been made? How are new ideas born? How do scientists think? Let us recall some well-known discoveries as we seek an answer to these questions.

Example 1. The discovery of the vulcanization of rubber. Charles Goodyear was a hardware merchant who became interested in finding a method of making pure rubber strong and useful. One day, in 1837, while he was working with a mixture of rubber and sulfur, he accidently dropped it on a hot stove. He retrieved it and noticed that it charred without melting; it stretched and snapped back to its original shape; it did not become brittle when cooled. This led to the process of improving the property of pure rubber by heating it with sulfur, which is called vulcanization. This was discovery by accident.

Example 2. The discovery of radium. Marie Curie, a young Polish girl, was a student at the Sorbonne in Paris (p. 216). She had heard of Professor Becquerel's discovery, in 1896, that a strange radiation from a uranium ore would affect a photographic plate. He, in turn, had observed that this girl was an excellent research worker. He showed her a piece of uranium ore, called pitchblende, and asked her whether, for her Doctor's degree problem, she would be willing to analyze this ore and find out what there was in it that caused it to produce streaks in photographic plates. This young woman, Marie Curie, together with her husband, Pierre, planned a systematic method of dissolving the ore, then separating and testing one group of components after another. After careful work they finally found that the unknown substance which affected the photographic plates was precipitated with the group of elements called calcium, strontium, and barium.

By careful separation they found that the unknown substance was precipitated with the element barium. The two young scientists then tested pure barium and found that it did not give off radiations that affected photographic plates. They reasoned that the precipitate must contain, as an impurity, a new element similar to barium. After careful and painstaking work they isolated the new element, polonium, and somewhat later, the element radium. This was discovery by planned research.

Example 3. The discovery of lead tetraethyl. In 1919 two young engineers, Thomas Midgely and T. A. Boyd, were given the problem by their company of finding something which could be added to gasoline to prevent it from "knocking." They set up a test engine in their laboratory and proceeded to test each material that they could find that was soluble in gasoline. After many tests by trial and error they found several compounds that would prevent knocking. One of the best of these was a compound of selenium, called selenium oxychloride. Following this was diethyl tellurium, which was found to be several times better than any discovered up to that time.

Now their work shifted from a trial-and-error procedure to planned research. They and their fellow workers planned a systematic study of the antiknock properties of compounds of elements on the basis of the position of the elements in the periodic table (see page 259), and concentrated their attention on the elements near selenium and tellurium. After many tests they found that an organic compound of lead, called lead tetraethyl, was an excellent antiknock agent for gasoline. That was the discovery that led to "ethyl" gasoline and the use of lead tetraethyl in almost all gasoline. The early part of this research was by trial and error, and the latter part planned research.

Example 4. The discovery of atomic fission. In the late 1930's scientists were trying to make an element heavier than the heaviest element known to occur in nature, uranium. They were bombarding uranium with the tiny nuclear particles called neutrons in attempts to make the neutrons enter the nucleus of uranium and produce a new element heavier than uranium. But the chemical tests which they used in an attempt to identify the new element indicated that the element barium was formed which is only a little over half as heavy as uranium. As Lisa Meitner sought for an explanation it occurred to her, "If we assume that the neutron causes the atom to split and form fragments about half as heavy as uranium the results can be accounted for." The birth of this idea of the interaction of neutrons with uranium-235 led to the great era of atomic fuels and atomic energy. This was discovery by accident but associated with planned research.

Methods of discovery. These examples illustrate several ways in which discoveries are made. Some are made by "trial and error" research, some by accidental discovery, and still others by carefully planned research that follows a rigorous procedure called the scientific method. They have, however, one thing in common, the ability of a trained observer to see the implications of his results. The clue or secret to the success of discovery by trial and error and by accident is perhaps given by the words of Pasteur, "Chance favors a prepared mind." That, too, is very important in the various steps of the scientific method.

The scientific method. The validity of the conclusions reached in a carefully planned scientific study results from the rigorous method used by science in arriving at these conclusions. The scientific method involves the following five steps:

Step 1. Observing a phenomenon.
Step 2. Collecting and organizing facts regarding the phenomenon.
Step 3. Devising a hypothesis to explain the phenomenon.
Step 4. Testing the hypothesis experimentally.
Step 5. Altering or rejecting the hypothesis or accepting it as a theory.

Let us examine these steps in more detail, and illustrate each by an example.

1. **Observing a phenomenon.** Any natural phenomenon may interest a scientist. Newton is said to have been interested in the fall of an apple; Franklin was fascinated by lightning; Watt by the steam issuing from a teakettle; Galileo by the apparent motion of the stars and the planets. No phenomenon of nature is too big or too small to be an object of interest to a scientist.

2. **Collecting and organizing facts about the phenomenon.** In studying a natural phenomenon the scientist makes a great variety of observations and he endeavors to discover any regularities about the phenomenon. He tries to determine what sequence of events and what sets of conditions are necessary in order that the phenomenon may occur. Any regularities which he observes or any general statements he is able to make concerning the cause-and-effect relationships which exist about the phenomenon may be expressed as *laws*.

Fig. 1-2. Galileo Demonstrates a Telescope

Fig. 1-3. Franklin and His Kite. By the use of a kite Franklin demonstrated that lightning is electrical

A law in science is a statement of an observed pattern in nature, the expression of an observed regularity or order in natural phenomena. When we speak, for example, of the "laws of motion," we refer not to laws which are rules to be obeyed in a legal sense but to statements of fact which have no authority in themselves but which experience has shown to be so universally true that they may confidently be used as bases for prediction or calculation. These laws are subject to revision as our observations become more precise or our knowledge more nearly complete.

3. **Devising a hypothesis to explain the phenomenon.** As soon as a considerable body of facts has been collected about the phenomenon being studied and, in particular, when one or more laws have been shown to express a certain regularity about the phenomenon, the scientist looks for some plausible explanation for, or some mental picture of, the phenomenon. This explanation he calls a *hypothesis*.

A hypothesis in science is a tentative theory or supposition provisionally adopted to explain certain facts or laws and to guide in the investigation of others. This is frequently called a "working hypothesis" because, as we may see in the next paragraph, the scientist uses it to predict results and gauges its truth from the accuracy of the predictions. The great value of a hypothesis lies in the fact that it suggests research.

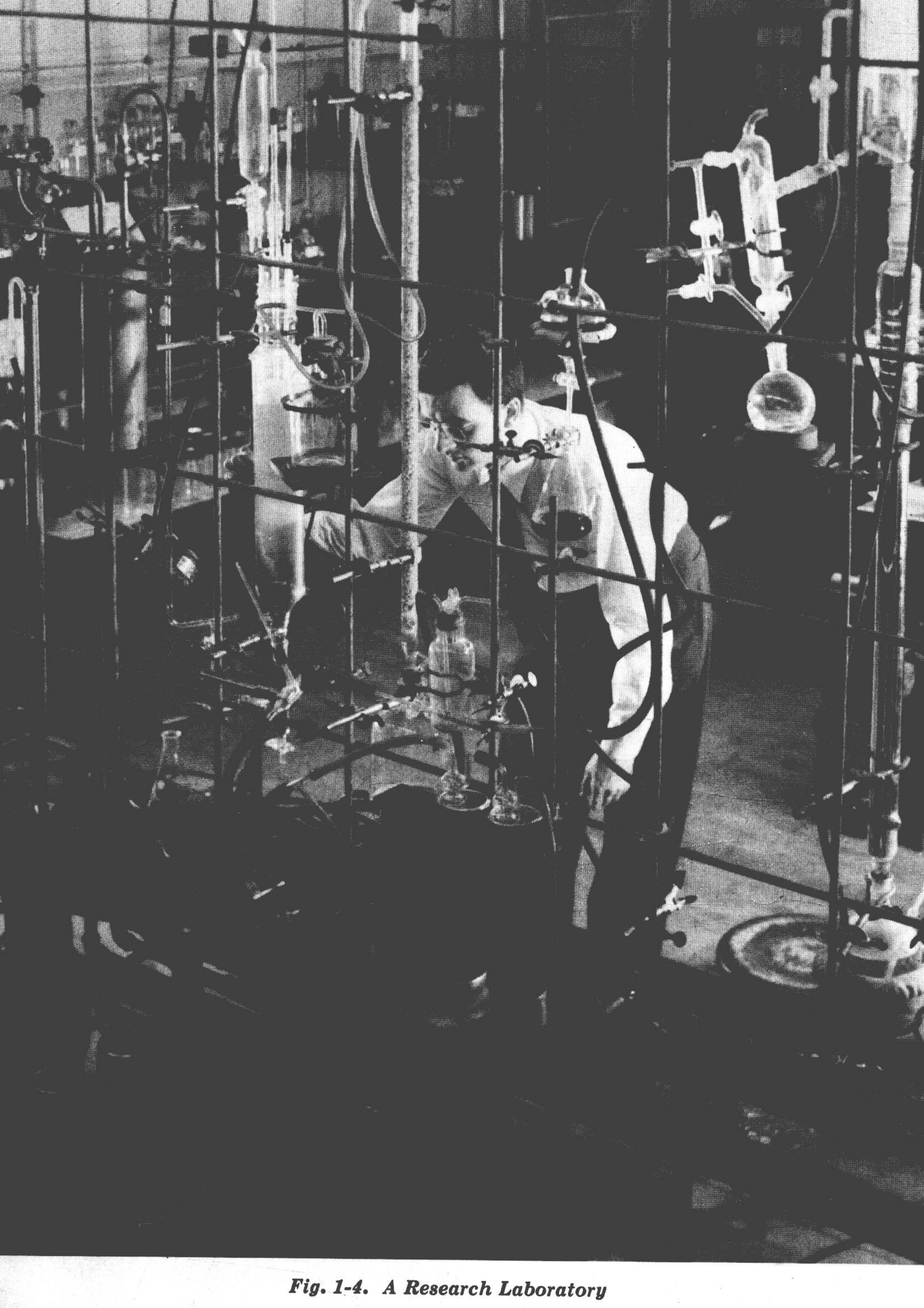

Fig. 1-4. A Research Laboratory

4. **Testing the hypothesis experimentally.** Thus far the steps in the scientific method are inductive; that is, the reasoning has been from facts to hypothesis. The next step in the method is deductive. The scientist tests his newly formed hypothesis by reasoning from it deductively to make predictions. He then sets up experiments to check the validity of his predictions.

5. **Altering or rejecting the hypothesis or accepting it as a theory.** If experiments give results greatly at variance with those predicted the scientist discards his hypothesis. At times the results will suggest a modification of the hypothesis, which will then be checked, as modified, by further experiment. If, however, repeated experiments check consistently with predicted results, the scientist accepts the hypothesis as probably true and it is called a *theory*.

A theory in science is a general principle offered to explain phenomena, and one which has been shown to be more or less probable by evidence from facts and by the completeness with which it can be used to predict results of experiment.

ILLUSTRATION OF THE USE OF THE SCIENTIFIC METHOD

The application of the various steps outlined above can be illustrated by the evolution of the modern theory of combustion—the nature of fire.

Fig. 1-5. A Forest Fire

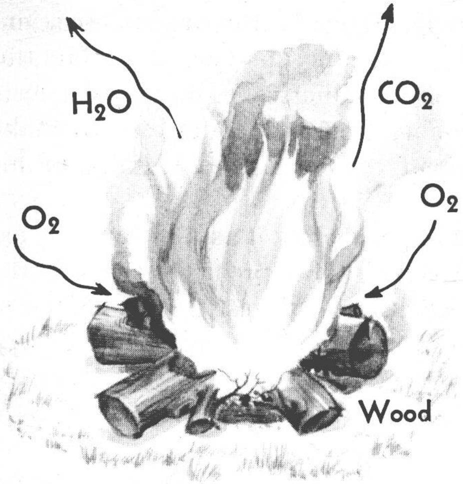

Fig. 1-6. Oxygen Combines with a Combustible Substance to Produce Heat and Light

Man in the early stone age observed a flame (*Step 1*) which was probably started by lightning. At first he was afraid and cringed before it. Later he learned many things about the flame (*Step 2*); he learned that it seemed to come from such things as wood or grass, that it gave off heat, that it could be extinguished by water, and that it left ashes. Still later, other men proposed an explanation (hypothesis) of the flame (*Step 3*). This hypothesis was that the flame represented the escape from the burning substance of a material to which the name *phlogiston* was given. It was shown that many facts regarding combustion could be explained satisfactorily by this assumption and it acquired, for a time, the status of a theory. However, repeated experiments devised to check this theory (*Step 4*) failed to identify phlogiston. In fact, it was shown that the products of burning weigh more than the fuel. Later still, other scientists showed that a substance called oxygen is necessary for a fuel to burn. The phlogiston theory was therefore rejected (*Step 5*) and the hypothesis of combustion through union of oxygen with the burning substance developed. This is the present *theory* of combustion.

Such is the scientific method. It stands in sharp contrast to other methods of formulation of ideas concerning the physical world which are based on preconceived, untested notions without reference to critical observation or experiment.

INDUCTIVE AND DEDUCTIVE METHODS

It should be noted that the "scientific method," just described, is an *inductive* method. It reasons from facts to a conclusion, which is usually expressed as a theory. This is, of course, only a part of the process of reasoning used in science. The other part is the *deductive* process; it is a process of reasoning away from the theory. Thus, once we have established that combustion consists of the union of oxygen with a burning substance, we can devise methods to produce bigger and hotter fires (for example, the oxygen-hydrogen blowtorch) by a process of logical deduction from the theory.

Of all the sciences, chemistry is, perhaps, the one most evenly balanced between the inductive and deductive processes of reasoning. Mathematics, the exact science, is now almost entirely deductive. No one bothers, now, to prove that "two and two make four" or that "equals multiplied by equals give equals." Physics and astronomy are highly mathematical and the reasoning in these sciences is, perhaps, more deductive than inductive. The biological and social sciences are still in the inductive stage in which careful collection of data and analysis of facts together with the setting up of hypotheses provide the greater part of the science. As time moves on, these sciences may be expected to develop as mathematics has in the past, as physics has in more recent times, and as chemistry is now doing. That is how a science develops.

THE SCIENCE OF CHEMISTRY

Chemistry is the science which deals with the composition and structure of the matter of which the universe is made and with the changes that occur in its composition, structure, and energy. In this study the chemist follows the scientific method. Chemistry is called a *physical* science, distinguishing it from botany or zoology, which are called *biological* sciences; chemistry, botany, and zoology are called *natural* sciences, distinguishing them from sociology, which is called a *social* science.

The relationships among the various major sciences may be shown by means of the following diagram:

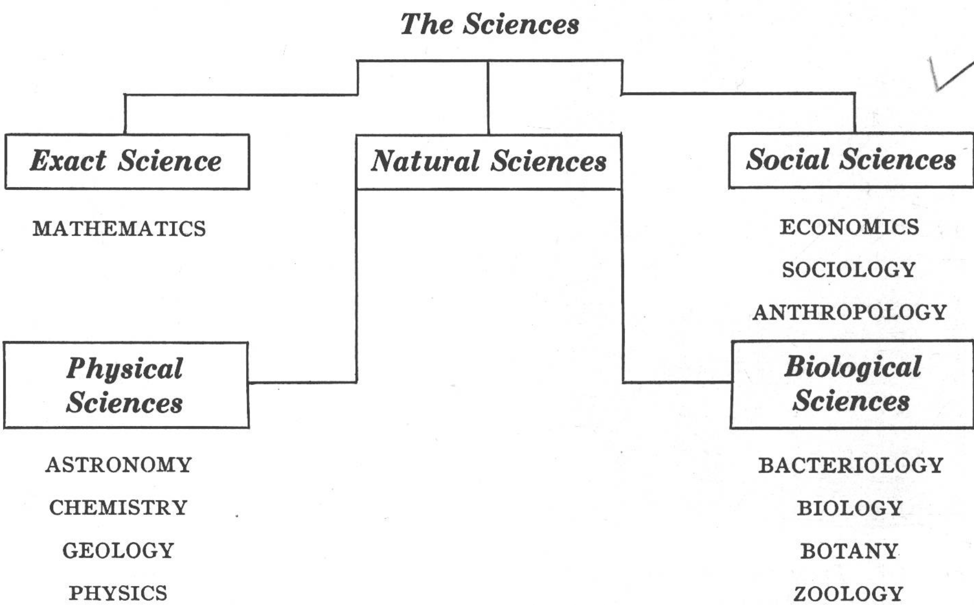

Fig. 1-7. Francesco de' Medici (1541-1587) Supervising Work in His Chemistry Laboratory. From a painting by Giovanni Stradano