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Chemistry and its Uses

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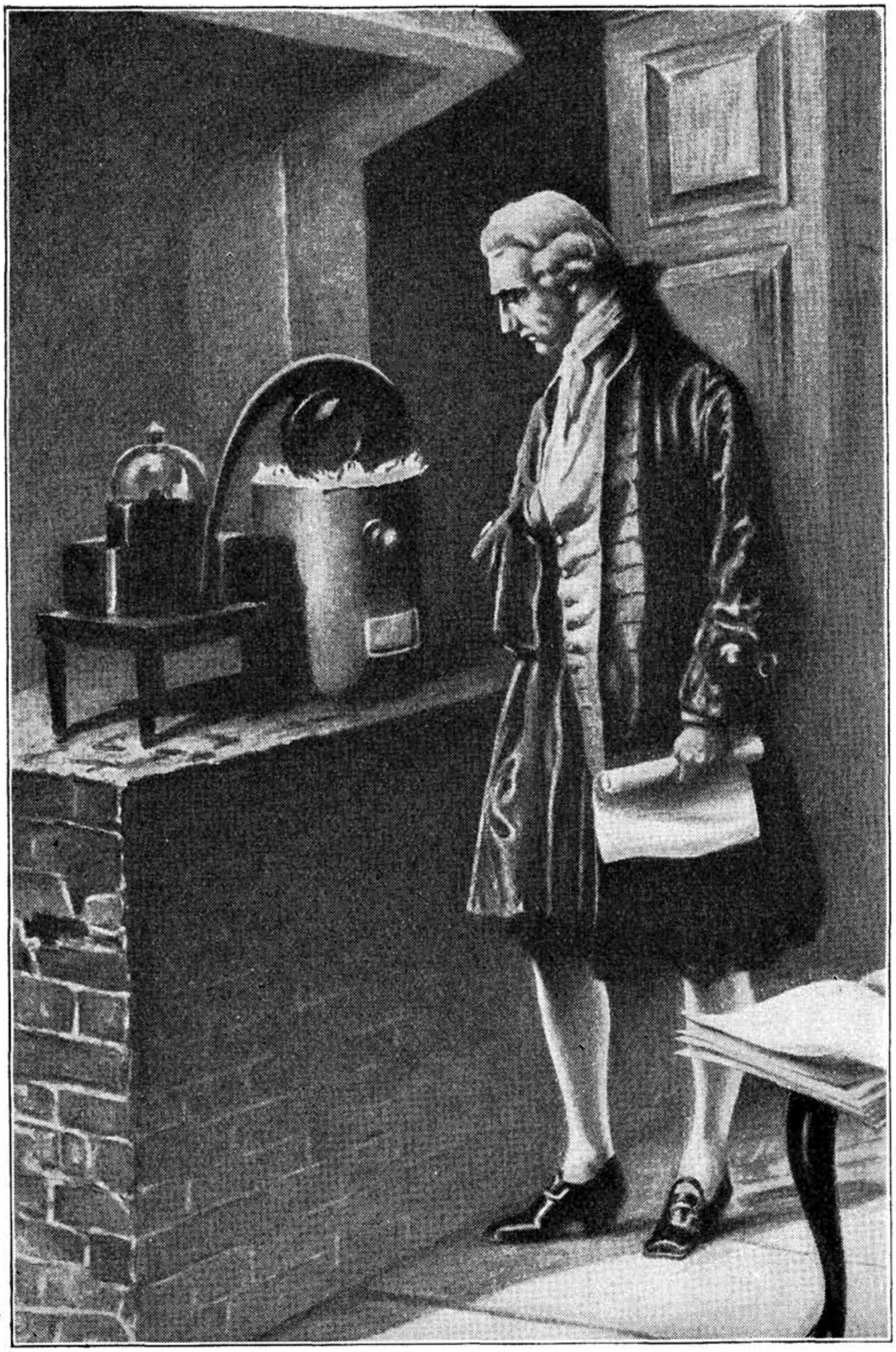

Lavoisier (1743–1794)

The great French chemist, Antoine Laurent Lavoisier, the founder of modern chemistry, is here shown in his laboratory conducting the famous experiments by which he proved the true nature of combustion. He was guillotined during the French Revolution because of his connection with the government

CHEMISTRY AND ITS USES

A TEXTBOOK FOR SECONDARY SCHOOLS

BY

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AND

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PREFACE

Every teacher of chemistry in the high school realizes that the watchword of the present day is the practical rather than the theoretical, the application rather than the abstract principle, the pictorial rather than the descriptive. Just how far this tendency should be followed each author and each teacher must decide for himself; this volume represents the opinion of the present authors. The text abounds in the practical applications of chemistry in the arts and industries as well as in everyday life, and no effort has been spared to have the illustrations as attractive, as instructive, and as accurate as possible. The authors have also kept before them the practical aim of presenting the occupation of the chemist as one that is very attractive to a boy who is thinking about what he will do in the world.

To the teachers using this book the authors wish to emphasize the conviction that the practical applications of chemistry have a place in high-school instruction largely in as far as they are used to illustrate the principles of the science and the way in which pure chemical knowledge can be turned to the uses of society. The main object of the course in chemistry must always be *to train young people to think and to imagine in the realm of chemical facts and laws*, and the teacher who finds at the end of the course that his pupil has acquired what seems to be a fund of useful information, but has little ability to think for himself how he would solve a simple chemical problem, should feel dissatisfied with his effort.

The utilization of chemical knowledge in the problems that developed during the World War is a fascinating story, and many paragraphs have been devoted to this theme. It is hoped that the student will be led to see how chemistry can solve new problems when new conditions arise and will not rest content in merely contemplating the chemical triumphs of the war, great as these were.

Throughout the text a great many items of interesting information as well as supplementary explanation have been thrown into subordinate type. It is believed that the matter in large type is complete in itself and nowhere dependent on the subordinate paragraphs. However, it is thought that so much of interest will be found in these paragraphs that the teacher can easily induce the student to read them even if they are regarded as excess material. Directions for laboratory work will be found in a separate volume.

The authors are indebted to a large number of firms for assistance in securing photographs. Among these are the following: the Corning Glass Works, the American Rolling Mill Company, the Eastman Kodak Company, the Anaconda Copper Mining Company, the American Cyanamide Company, the H. V. Bretney Leather Company, the Goodrich Rubber Company, and the Koppers Company. Many high-school teachers have offered valued suggestions, and the authors desire to express their hearty appreciation to all these. We are especially indebted to our colleague, Mr. William Lloyd Evans, to Mr. George M. Strong, and to Mr. Robert W. Collins, instructors in chemistry in the East High School of Columbus, Ohio, and to Mr. Charles S. Pease and Mr. Julius Stone, Jr., of the Department of Chemistry, the Ohio State University. Mr. Strong and Mr. Stone not only read the proof but offered many suggestions as well.

THE AUTHORS

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CHEMISTRY AND ITS USES

CHAPTER I

CHEMISTRY AND THE WORK OF THE CHEMIST

The general field of chemistry. At the beginning of any new study it is well to get at least a general idea of the work ahead. So we may say at the outset of the course in chemistry that we shall be interested in the changes that the material things around us undergo. In some cases we notice that things change because they wear out or are broken, but they undergo no change in composition. Thus a dish may break and be valueless as a dish, but the pieces will have the same composition as the original dish. We shall have but little interest in such changes.

In most of the changes taking place around us it is evident that the very nature of the matter is changed. Thus, nearly all the metals tend to rust or corrode; coal and wood burn to form ashes and invisible gases; the constituents of the soil and the air are built up into a vast variety of living organisms; the food we eat is changed into fat and bone and muscle. In all these examples the materials undergo a change in composition, and it is in such changes that the chemist is especially interested. *The science of chemistry deals with all those changes that result in altering the composition of materials.*

Relation of chemistry to the other sciences. Since all the studies we call *natural sciences*, such as physics, biology, geology, and physical geography, in part deal with changes in the composition of materials, it is evident that chemistry is fundamental to all of them. We cannot study electrical changes, or digestion, or rock disintegration without a knowledge of the exact changes that take place as well as of the general result of the changes. Physics and chemistry are really one science. Physics deals chiefly with what we call *energy*, — that is, with motion, heat, light, sound, electricity, — while chemistry deals with changes in the composition of *matter*. But almost every occurrence in nature that causes a change in matter causes a change in energy as well, and we cannot separate the two from each other. Moreover, the chemist is often interested quite as much in the energy set free when matter undergoes a change as in the change itself. For example, he is often called upon to measure the heat given off by burning a given sample of coal, for it is this that determines the value of the coal, and not the products that are formed.

The alchemists. In the earliest days of chemistry the chief chemical occupations were those of producing the metals from their ores, making glasses and enamels, and dyeing fabrics. There was no understanding of what happens in these processes, and the only guide was experience. In time the idea took a strong hold on the minds of these workers that the various metals are not really different things, but are merely stages in the purification of the one metal *gold*, and they thought that it ought to be possible to change all metals into gold in stages. These early chemists were called *alchemists*. It took centuries of work for them to become convinced that one metal cannot be changed into another. But in their efforts the alchemists found out many new facts, made many new compounds, and devised new processes, all of which had great practical value.

Almost at the time when the American Revolution for independence was starting, the great discovery of oxygen was made (1774), and the nature of the process we call *burning* or *combustion* became understood. This provided a sound foundation for the understanding of chemical processes of all kinds, and chemistry developed rapidly into a true science.

Nature supplies raw materials only. Very few of the materials found in nature are suited to the needs of man advanced beyond the most primitive stages of development. From the beginning he has had to match his wits against nature to gain materials better suited to his needs. At first he relied upon merely sorting out the best material and rejecting that of poor quality. For example, he pulled out the fine fibers from the stem of the flax plant, and he hammered or melted the small particles of gold found in sands into larger pieces. But he could not go very far in this way alone.

New materials from plants and animals. Man's most pressing need has always been for food and clothing. When natural species failed to supply his needs, he set about to improve on nature. The grains and vegetables and fruits we now grow for food and the plants that give us textile fibers bear little resemblance to the original plants of nature. The original beet had just enough sugar in it to suggest an idea; the modern beet has as much as 16 per cent. The cotton plant of nature would not be recognized beside the long-fibered plant of Arizona today. So, too, with the animals that supply us with meat, fat, milk, and wool. They have been very highly developed from primitive stock.

Very little of this work has been done by the chemist. Yet it must not be overlooked that each plant and animal is doing just what the chemist does in his laboratory. It takes the raw materials supplied by nature and builds them up by chemical changes into very diversified products. *All living organisms are therefore chemical laboratories* — much more wonderful and efficient than the ones we build. So in improving a plant or animal we are really improving a chemical process.

New materials from inanimate products. The chemist for the most part works with matter that is not living; namely, with the minerals supplied by nature and with the products of life such as fats, oils, sugars, starch, and hundreds of similar products, From these he has developed countless new materials for human needs. From the rocks he has prepared a large array of useful metals and such indispensable things as lime and cement. From coal he has manufactured thousands of dyes, medicinal preparations, fertilizers, paints, and other useful but less familiar materials. From petroleum and wood and the saps of trees, from milk and hides and hoofs, he has fashioned the materials that make the physical comforts surrounding the lives of even the poorest luxurious when compared with the possessions of the kings of the past.

Chemical industries. All the industries that transform a raw material of nature into a finished product for human use are essentially chemical industries. They must rest on the principles of chemical science, and they must be supervised by someone who understands chemistry. It is only as our knowledge of chemistry increases that these industries can be conducted more economically and expanded into more efficient and diversified ones. *The industrial advancement of a country can be judged fairly well by the extent to which chemistry is cultivated in its schools and universities.*

The work of the chemist. Some chemists will always be chiefly interested in adding to our knowledge of chemistry as a science. Others will have as their greatest interest some definite industrial plant (Fig. 4). Such a one must supervise the process used in the industry and devise improvements. He must find out the composition of each new lot of raw material and modify the process accordingly. He must be able to guarantee the composition and the properties of the output of the factory so that its value may be known. He must study the possibilities of making something useful out of the waste products of the business. For example, he has taken the formerly useless cotton seed and from it has made most valuable oils, fats, soaps, and cattle feeds. Since industry has such a wide range of raw materials employed, there is almost no limit to the variety of the work of the chemist. The chemist also helps to preserve the health of the people by finding out the kinds and amounts of food best adapted to our bodies, by devising methods for purifying our water supplies and for disposing of sewage, and by preparing various substances that are useful in combating diseases.

Chemical knowledge incomplete. While we seem to know a good deal about changes in matter, we have really just made a good beginning. For example, our knowledge of what takes place in growing plants and animals is very limited, though we are learning fast. Plants manufacture sugar and starch and cellulose chiefly from air and water, but we cannot do this in the most expensively equipped laboratories, nor do we understand how the commonest plant accomplishes this seeming miracle. Even in well-understood processes there is usually some detail that is not yet clear.

The future of chemistry. There is a wealth of unsolved problems of vast importance to human comfort and happiness to attract the student to the life pursuit of chemistry. For example, we are rapidly using up our reserves of easily available raw materials, such as coal, oil, gas, wood, and metal ores, and substitutes must be found. We are exhausting our fertile lands, and we must learn better how to keep them in productive condition. Every line of material progress along which we are moving is full of these problems, and as a result the number of those engaged in chemical occupations is increasing very fast. In every progressive country the national chemical society is one of the largest of the scientific organizations. The American Chemical Society is the largest scientific society in the world, having more than 15,000 members.

CHAPTER II

MATTER AND ITS CLASSIFICATION

Definition of matter. Since the chemist is interested primarily in matter and the changes it undergoes, it is important for us to get a clear idea of just what we mean by matter. For our purposes we may define matter *as anything that has weight or occupies space.* This not only includes solid and liquid materials that we can see and touch but also the various gases, such as those that make up the atmosphere and which, although invisible, are very real and fit the definition of matter just given.

Classification of matter. From the standpoint of its physical state it is customary to classify matter under three headings: namely, *solids*, *liquids*, and *gases.* The chemist, however, is interested in matter from the standpoint of its composition, and from this standpoint it may be classified under two headings: *elements* and *compounds.*

Elements. There are a number of different substances, some of them well known to all of us, — such as iron, copper, and gold, — that have resisted all efforts to decompose them into simpler substances. On this account they are called *elementary substances* or, more briefly, *elements.* We may therefore define an element as *a substance which cannot be decomposed into simpler substances.* About ninety such elements are known.

It is not always easy to prove that a given substance is really an element. Some way as yet untried may be successful in decomposing it into other simpler forms of matter. Water, lime, and many other familiar substances were at one time thought to be elements, but are now known to contain two or more elements. Most of the elements are solids, a few are gases, and only two — bromine and mercury — are liquids under ordinary conditions.

Compounds. On the other hand, there are many thousands of substances that are made up of two or more elements. Thus, if a current of electricity is passed through water (Fig. 9), the water is decomposed into two elements (both of which are invisible gases), known respectively as *oxygen* and *hydrogen*. Moreover, if we cause these two elements to combine, water is formed. Again, the ordinary iron ore known as hematite can be shown to consist of the two elements iron and oxygen. The sugar with which we sweeten our food is composed of the three elements carbon, hydrogen, and oxygen. *Compounds, however, are not only made up of two or more elements but each compound has a perfectly definite composition.* For example, we shall see later that water is made up of hydrogen and oxygen in the ratio of one part by weight of hydrogen to 7.94 parts by weight of oxygen. It makes no difference what the source of the water is, provided only that it is pure; the composition is always the same. This constancy of composition is characteristic of all compounds. We may therefore define a compound as *a substance made up of two or more elements combined in definite proportions by weight.* We shall learn of other characteristics of compounds as we proceed.

Illustration. We might, in a very general way, compare the elements to the letters of the alphabet. Just as the printed matter on this page is made up of single letters and of combinations of letters to form words, so matter is made up of elements and of combinations of elements in the form of compounds. Just as there are a great many more words than letters, so there are a great many more compounds than elements.

Chemical changes — chemical action. We may best illustrate the meaning of these terms by a simple illustration. If we place in a test tube one or two grams of the red solid substance known as *mercuric oxide* and heat it (Fig. 5), we find that the color gradually changes and that there is left in the tube little drops of a silverlike liquid which we recognize as *mercury*, or quicksilver, as it is often called, which is used in thermometers and barometers. If during the heating we thrust into the mouth of the tube a glowing splint, the wood will burst into a flame. Experiments show that this bursting into flame is due to the presence of the invisible gas, *oxygen*, which is evolved on heating the mercuric oxide. The red solid, mercuric oxide, then has been decomposed by the heat into two elements, the one a silverlike liquid and the other an invisible gas. A change like this is known as a *chemical change*, and in describing it we say that *chemical action* has taken place. Such changes are taking place all about us, and they are the ones in which the chemist is particularly interested. Thus, coal and wood burn, being changed in the process into ashes and invisible gases. The food we eat is changed into the tissues of the body. *In all such changes the substances resulting from the chemical action differ in composition from the substances originally present and usually differ from them in appearance as well.* We shall see later on that there are other important changes which always accompany chemical action. *At present, for our purposes, we may define a chemical change as one that is attended by a change in the composition of matter.*

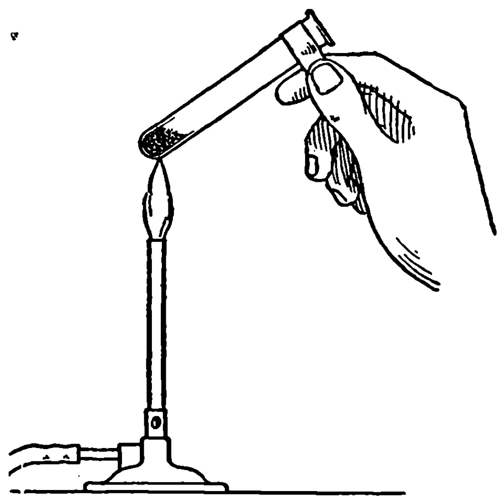

FIG. 5. The decomposition of mercuric oxide into mercury and oxygen by heat

Changes that are not attended by a change in the composition of matter, such as the breaking of a piece of glass or the powdering of a lump of coal, are known as *physical changes.*

It follows from the statements made above that the appearance of a compound gives no clue as to what elements are present in it. Thus the red solid, mercuric oxide, is formed by the union of the silverlike liquid, mercury, with the invisible

Fig. 1. Ira Remsen
(1846–)

For many years director of chemical research at the Johns Hopkins University, later president of that institution; known equally well as a great chemist, an inspiring teacher, and an educational leader; editor of an important chemical journal and the author of an important series of books; president of the American Chemical Society (1902); member and officer in many of the important scientific societies of this country as well as foreign member of many European societies

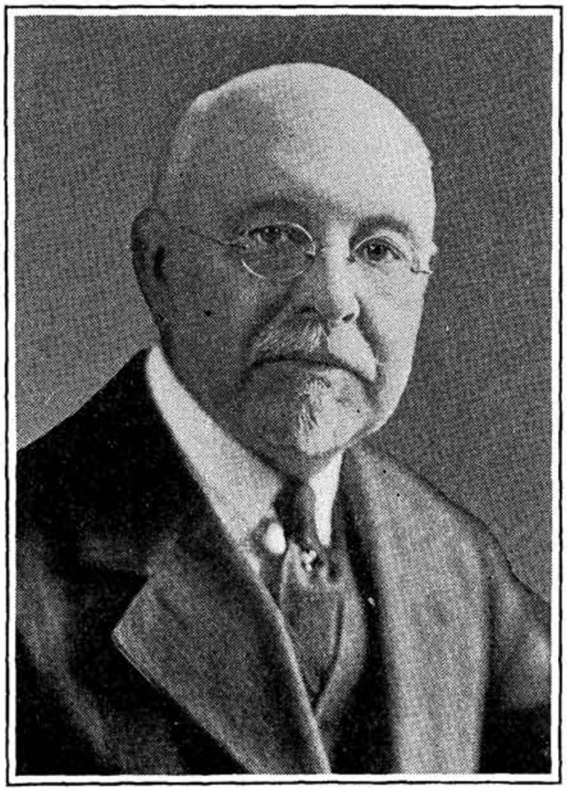

Fig. 2. Edgar Fahs Smith
(1856–)

For many years director of chemical research at the University of Pennsylvania and later president of that institution; noted for his contributions to electrochemistry and to our knowledge of the rarer elements; a writer of fascinating interest on the early history of chemistry in the United States; president of the American Chemical Society (1895, 1921, and 1922); member and officer in many scientific societies in this country and abroad

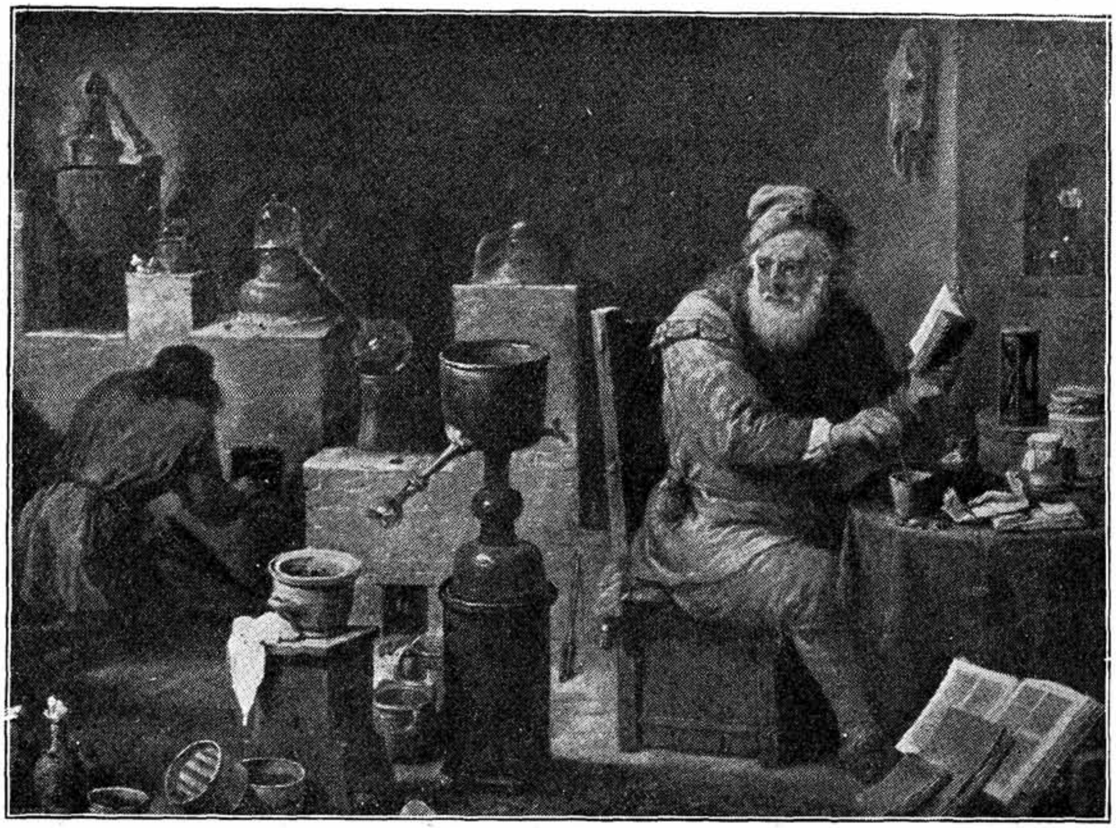

Fig. 3. An alchemist in his laboratory

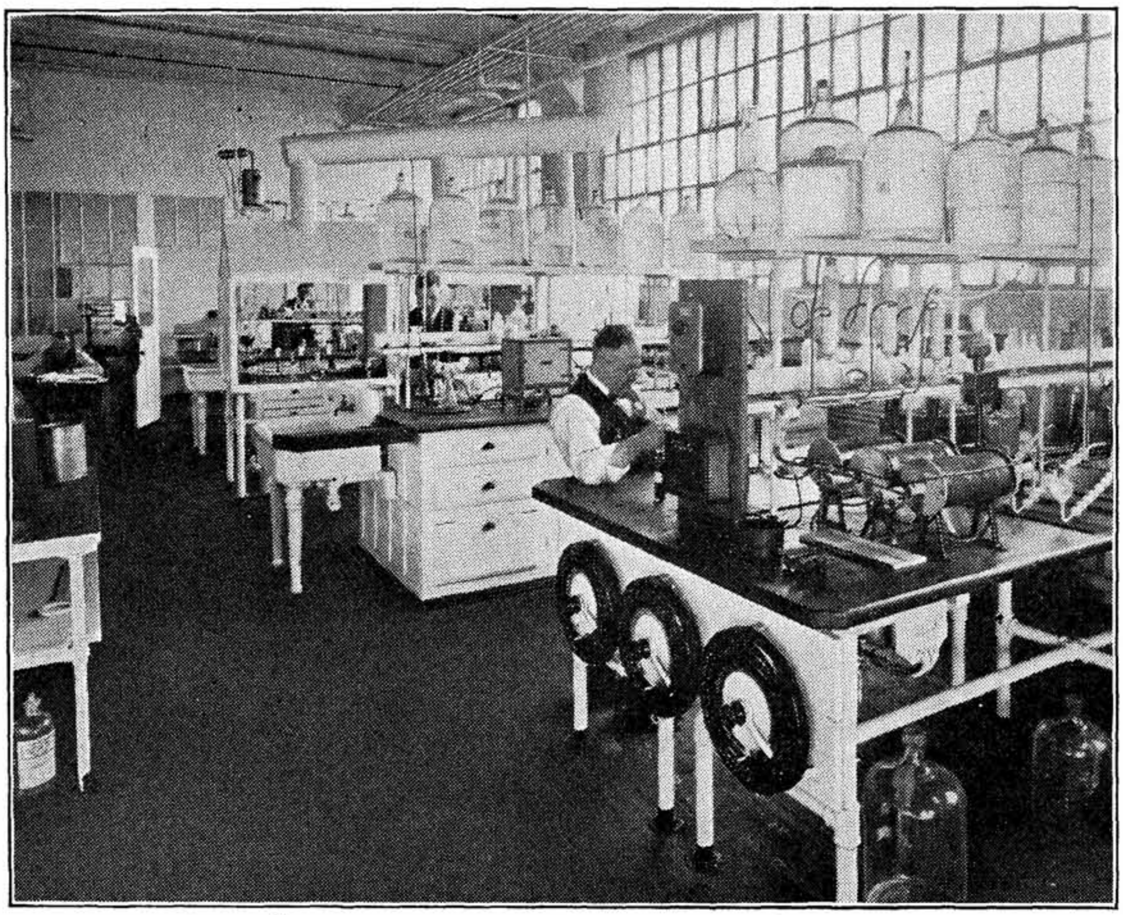

Fig. 4. A typical laboratory of a modern automobile plant

gas, oxygen. Water, a colorless liquid, is formed by the union of two invisible gases, oxygen and hydrogen. No one would ever suspect simply from appearance that sugar contains the black solid element carbon, and yet if we heat sugar the hydrogen and oxygen with which the carbon is combined in the sugar are expelled and the black carbon remains.

Chemical affinity. *The force that causes elements to unite and holds them in combination in compounds is called chemical affinity.* We know very little about the nature of this force, just as we know very little about the force of gravitation. It is evident, however, that there is such a force, and it is convenient to have a name by which we can refer to it.

Number of elements. The number of substances now considered to be elements is not large — about ninety in all. Many of these are rare, and in some cases not more than a few grams have been obtained pure. Clarke makes the following estimate of the composition of the solid portion of the earth's crust:

COMPOSITION OF THE EARTH'S CRUST

Oxygen	47.33%	Magnesium	2.24%
Silicon	27.74%	Sodium	2.46%
Aluminium	7.85%	Potassium	2.46%
Iron	4.50%	Hydrogen	0.22%
Calcium	3.47%	Other elements	1.73%

A complete list of the elements is given on the back cover page. It is not necessary to study more than one third of the total number of elements to gain a very good knowledge of chemistry.

Elements in the human body. Comparatively few of the elements appear to be essential to life. The following table, compiled by Sherman, gives the average composition of the human body. So far as we can judge, these are the only ones upon which living organisms are dependent, though traces of others may be necessary.

AVERAGE COMPOSITION OF THE HUMAN BODY

Oxygen .	65.00%	Phosphorus	1.00%	Magnesium .	0.05%
Carbon . .	18.00%	Potassium .	0.35%	Iron . . .	0.004%
Hydrogen .	10.00%	Sulfur . .	0.25%	Iodine . .	traces
Nitrogen .	3.00%	Sodium . .	0.15%	Fluorine . .	traces
Calcium .	2.00%	Chlorine .	0.15%	Silicon . .	traces

Occurrence of the elements. Most of the elements occur in nature not as uncombined substances but in the form of chemical compounds. When an element does occur uncombined, as is the case with gold and sulfur, we say that it occurs *in the free state*, or *native*; when it is combined with other substances in the form of compounds, we say that it occurs *in the combined state*, or *in combination.* The elements present in our bodies are all in the form of compounds, of which water is the most abundant.

Names of elements. The names given to the elements have been selected in a great many different ways. Some names, such as iron and gold, are very old, and their original meaning is obscure. Many names indicate some striking property of the element. The name *bromine*, for example, means "stench," referring to the extremely unpleasant odor of the substance. Other elements are named from countries or localities, as germanium and scandium. Still others are named from some mythological character, as thorium and tantalum.

Symbols. In indicating the elements chemists have adopted a system of abbreviations. These are known as *symbols*, each element having a distinctive symbol. Sometimes the initial letter of the name is adopted to indicate the element. Thus, I stands for iodine, C for carbon. Usually it is necessary to add some other characteristic letter to the symbol, since several names may begin with the same letter. Thus, C stands for carbon, Cl for chlorine, Cd for cadmium. Sometimes the symbol is an abbreviation of the name in some other language.