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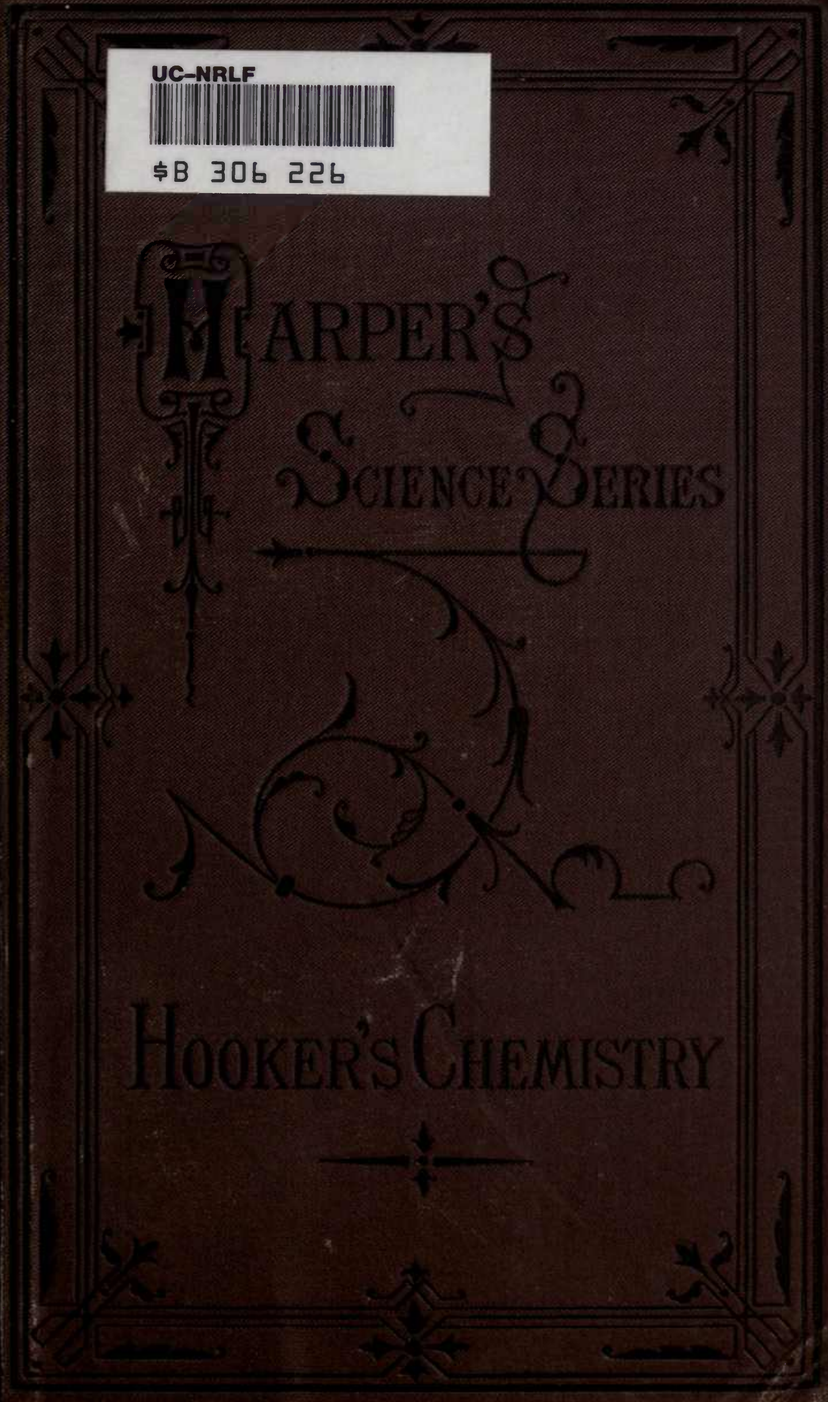
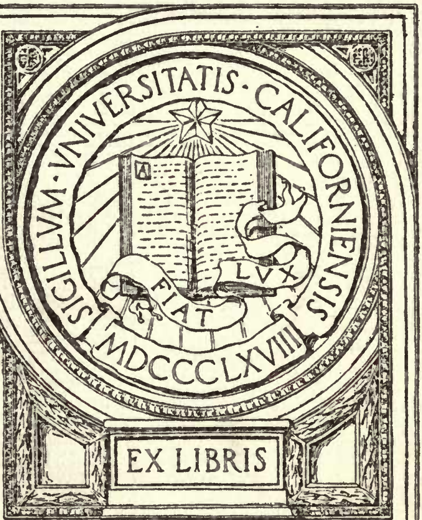
HOOKER'S CHEMISTRY

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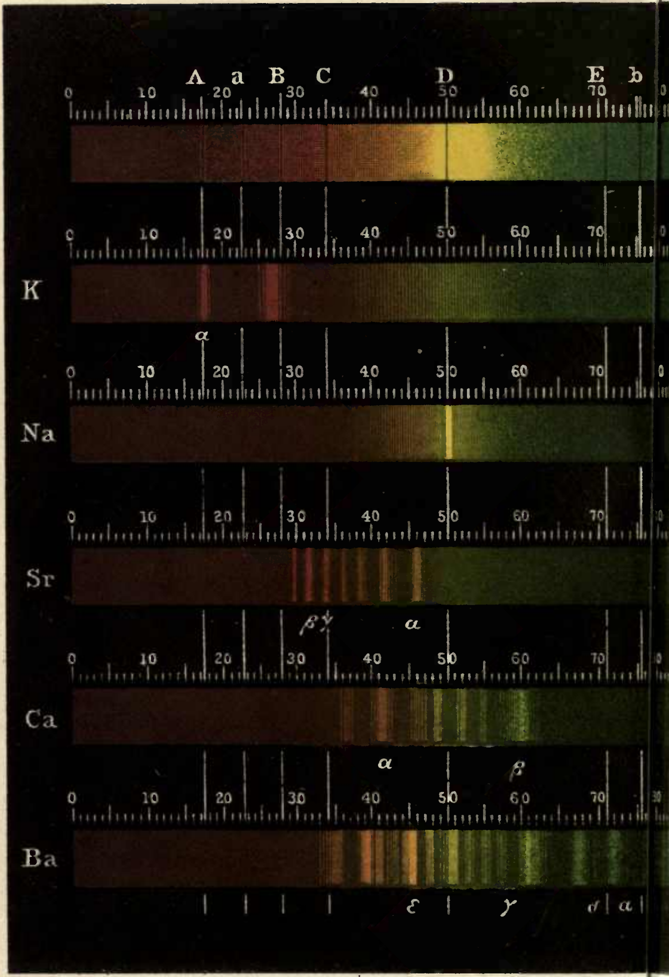

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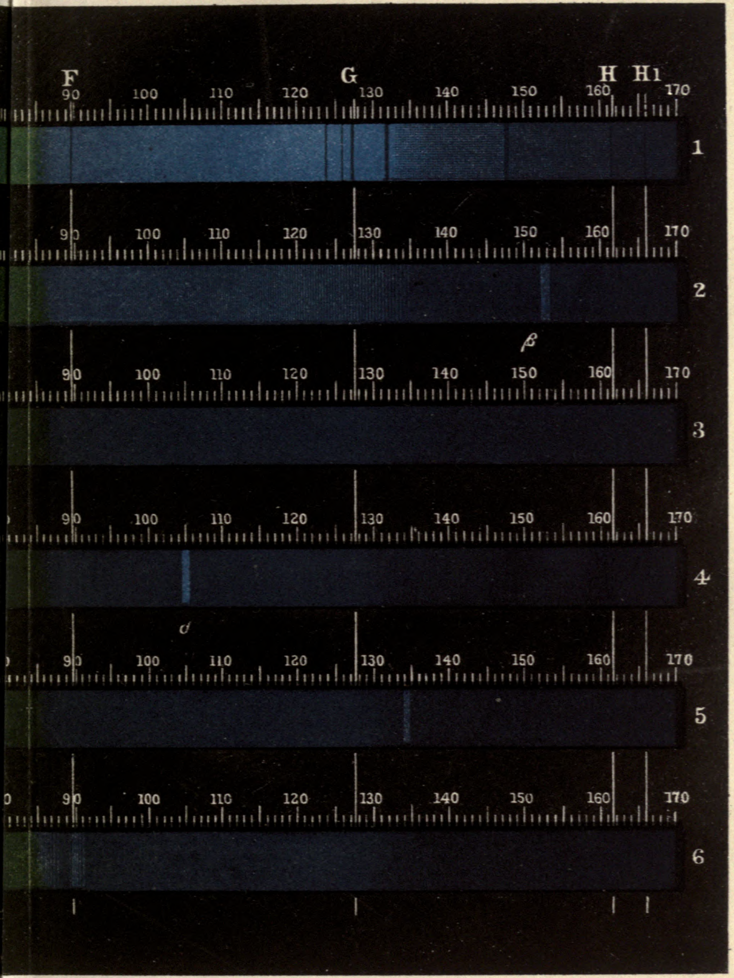
1. Solar Spectrum.
2. Spectrum of Potassium.

3. Spec
4. Spec

Harpe



purple
or
violet

yellow

~~red~~
crimson

red

bright
green

m. of Sodium.
m. of Strontium.

5. Spectrum of Calcium.
6. Spectrum of Barium.

See page 286.

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SCIENCE

FOR THE

SCHOOL AND FAMILY.

PART II.

CHEMISTRY.

BY

WORTHINGTON HOOKER, M.D.,

PROFESSOR OF THE THEORY AND PRACTICE OF MEDICINE IN YALE COLLEGE,
AUTHOR OF "HUMAN PHYSIOLOGY," "CHILD'S BOOK OF NATURE,"
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PREFACE TO THE FIRST EDITION.

THIS book differs from all other text-books on Chemistry in several particulars.

1*st*. *It includes only that which every well-informed person ought to know on the subject*, and excludes whatever is of value only to those who are to be chemists, or who intend to apply chemistry to specific branches of business, as medicine, metallurgy, etc. For the extended and specific knowledge required for such purposes other books can be studied afterward, this book being suitable for a preliminary preparation. I will give a single example of the sort of selection I have practiced in carrying out my plan. I exclude the consideration of the tests of the presence of arsenic in cases of poisoning, because the application of them is so complicated that none but a professed chemist can make the investigation. On the other hand, I notice very particularly the chemical action of the whites of eggs upon corrosive sublimate, because, as poisoning with this substance is quite frequent, and promptness in the use of the antidote is all-important, every one ought to know what the antidote is, and he will certainly be the more prompt to apply it if he understand its *modus operandi*.

2*d*. I recognize fully *the distinction between a book for reference and a book for study*. The pupil should have his book specially adapted for study; and the teacher should have, in addition to this, books for reference, so that his knowledge may be wider than that included in the text-book, in order that he may meet any inquiries that may arise, or add to the facts and illustrations which the text-book furnishes, as occasion may offer. Most text-books are too extensive, because the distinction referred to is not observed. The attempt sometimes made to draw the line between the matter for the pupil to learn and other matter not so essential by a difference in type is always awkward, and is not fully effectual.

3d. While most books on Chemistry are illustrated chiefly from phenomena developed in the laboratory of the chemist, I have taken great pains to have abundant illustrations from common every-day phenomena, so that this book is largely a Chemistry of Common Things. As an illustration of the general neglect on this point, I find that very few of all who have studied ordinary chemical books, or have attended lectures, can explain the chemistry of so very common a thing as striking fire.

4th. The arrangement of topics is entirely different from that of any other text-book on Chemistry. *It is such that the most simple and interesting topics come first, and each page enables the pupil to understand better the pages that follow.* I begin with making the pupil familiar with the four grand elements, oxygen, nitrogen, carbon, and hydrogen, and their combinations with each other. This brings out fully those most interesting of chemical subjects, combustion, water, and the chemistry of the atmosphere. I then pass to the combinations of these four elements with other elements, and the combinations of these latter with each other. In this portion of the book I notice first the metals and their compounds with oxygen—the oxides; then the metalloids sulphur, phosphorus, etc., and their combinations with oxygen—the oxygen acids, and also the hydrogen acids. Then in natural sequence come to view the salts formed by the union of these acids and oxides, and in connection with these the salts of the chlorine family. Now follows a development of the laws of chemical affinity, the examples being taken from the facts already brought out, so that we have here in part a review of what is gone before, which is of great advantage to the student. In this connection I introduce the consideration of chemical equivalents, symbols, and the atomic theory. All of this is commonly introduced into the first part of Chemistry, and hence is generally but partially understood, and is very dry and uninteresting; but on the plan which I have adopted the pupil easily comprehends it, and is interested at every step. Then comes in naturally the influence of the *modifiers* of chemical affinity—heat, light, electricity, and magnetism—which before have been alluded to here and there, but now are fully treated of. The book concludes with the consideration of Organic Chemistry.

The only text-book which has any resemblance to this in its plan is Stöckhardt's, and the resemblance touches only a few points. The coincidence, so far as it goes, gave me great gratification when my attention was called to it by a friend to whom I was developing my plan.

A large proportion of the experiments can be tried with very simple apparatus, and a few dollars' worth of materials obtained from the druggist; but it will be well for the teacher to purchase a few articles—such as retorts, a retort-stand, thin flasks, glass tubes, etc.—at some chemical shop, and also such materials as druggists do not usually have — as potassium, sodium, oxide of manganese, phosphorus, etc. A pneumatic trough can be easily made by any tinman or cabinet-maker from the teacher's directions, or he can even construct one himself by fixing a perforated shelf in a small tub. At the same time, it may be said that the book can be profitably read or studied with only trying such experiments as the most common materials and apparatus which any household may furnish, because the illustrations are drawn so abundantly from ordinary phenomena within the observation of all. There are around us, and even within us, chemical reactions which are the counterpart of a large proportion of the experiments which the chemist performs in the laboratory.

Questions are appended for the use of teachers if they desire them, and also a full Index. There is a glossary, or rather a list of terms, with the numbers of the sections where their explanation may be found.

With the present degree of instruction in natural science in our general system of education, this book is rather too far advanced for the oldest scholars in common schools, though it would not be if they had gone through with the previous books of the series* which I have prepared. Until the different gradations which I have aimed at in this series are fairly introduced, the proper place for this book and Part III. is the High School and the Academy, while Part I. is within the comprehension of the next grade below. But it is to be hoped that the time will very soon come when natural science shall have its due prominence during the whole course of education, and then the books of this series, or other similar books, will find

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* All the books of this series are mentioned in the Preface of Part I. See also back of the title of the present volume.

their appropriate places; and thus those pupils who in so large numbers stop short of the High School and Academy, will not go out into the world, as they now do, destitute of that knowledge which not only embraces the principles lying at the basis of the arts and trades into which many of them will enter, but will add greatly to their usefulness and happiness, even if their business be such as to call for no practical application of this knowledge.

W. HOOKER.

November, 1863.

PREFACE TO THE SECOND EDITION.

THE rapid progress made by Chemistry within the last decade, and the changes in the methods of instruction, have necessitated a new edition of this standard work. The alterations deemed advisable have been chiefly of four kinds — omission of sections, insertion of new ones, introduction of the latest nomenclature and chemical formulæ throughout, and a complete rearrangement of the matter. A rearrangement of the chapters relating to Organic Chemistry on a strictly scientific basis was found impracticable, consequently the empirical plan adopted by the author has been retained, while the editor has endeavored to point out the desirable method of classification of organic bodies in Chapter XXIV.

The sections relating to Chemical Philosophy, especially in Chapters II., III., and IV., have been entirely rewritten; the chapter on Galvanism in the first edition has been omitted, the subject being now treated in connection with Physics; a brief chapter on Spectrum Analysis has been added; and, lastly, the Metric System of Weights and Measures and the Centigrade Thermometer have been adopted as standards throughout the work. Tables explaining these standards are given in an Appendix.

Many wood-cuts have been added, and nearly all are new. The introduction of two sizes of type may aid the teacher in the instruction of younger scholars. The questions in this edition are placed at the end of each chapter, instead of being collected at the end of the book.

Finally, the editor expresses the hope that he has not entirely obliterated the pleasant, familiar manner of treating the subject so happily adopted by the author and so successfully carried out.

H. CARRINGTON BOLTON, Ph.D.

SCHOOL OF MINES, COLUMBIA COLLEGE,
September, 1875.

CONTENTS.

CHEMISTRY.

CHAPTER I.

INTRODUCTORY.

1. Difference between Chemistry and Natural Philosophy.—Chemistry treats of the composition of substances, while in Natural Philosophy, or Physics, their mechanical conditions and relations alone are regarded. For example, in Natural Philosophy we look at the laws governing the pressure and movements of water, while in Chemistry we inquire of what water is composed, and into the composition of what substances it enters. And so of other substances—solid, liquid, and gaseous.

2. Elementary Substances.—In making its investigations, chemistry decomposes such substances as are composed of two or more things. When any substance is found that can not be decomposed or separated into two or more things, it is termed an *element*, or an elementary substance. On the other hand, all those substances which can be decomposed are called *compound*. Iron is an element, for it can not be decomposed: it is one thing. But iron rust is a compound substance composed of three things, for water and a gas called oxygen, existing in the air, unite with iron to form rust.

3. Idea of Elements among the Ancients.—The ancients supposed that there were only four elements—viz., air, water, fire, and earth. But the science of chemistry has shown us that these are not elements. We could see this to be true of earth without any chemical experiments, for what we commonly call earth is very different in different places. Then water, simple as it appears to be, is composed of two gases, one of which is the lightest of all substances. Air is neither an element nor a compound, but a mere mixture of gases. And what we call fire is merely a result of some changes that take place in various substances under certain circumstances. When wood or oil or gas, or any thing burns, the result that we see we call fire. Fire, then, is not only not an element, but it is not even a thing. It is not a substance at all, but it is merely a phenomenon or appearance.

4. Number of Elements.—Chemists have discovered sixty-three elements. More may yet be discovered; and, on the other hand, some which are now considered elements may hereafter be found to be compounds. Seventy years ago several substances were supposed to be elements that have since been decomposed by chemists. Potash, for example, formerly supposed to be an element, was discovered by Sir Humphrey Davy to be a compound composed of a gas and a metal.

Here is a list of the Elementary Substances, with their Symbols and Atomic Weights. What these symbols and numbers mean we will explain in another chapter. The most important elements in this table are printed in CAPITALS, the next in importance in *italics*, and those which are very rare in ordinary type. Do not try to commit these long names to memory all at once; you will get familiar with them by degrees.

ELEMENTARY SUBSTANCES,

THEIR SYMBOLS AND ATOMIC WEIGHTS.

ALUMINIUM	Al	27.5
Antimony	Sb	122
Arsenic	As	75
Barium	Ba	137
Bismuth	Bi	210
Boron	B	11
BROMINE	Br	80
Cadmium	Cd	112
Cæsium	Cs	133
CALCIUM	Ca	40
CARBON	C	12
Cerium	Ce	92
CHLORINE	Cl	35.5
Chromium	Cr	52.5
Cobalt	Co	59
Columbium	Cb	94
COPPER	Cu	63.5
Didymium	Di	96
Erbium	E	112.6
FLUORINE	F	19
Glucinum	G	9.5
GOLD	Au	196.6
HYDROGEN	H	1
Indium	In	75.6
IODINE	I	127
Iridium	Ir	197.1
IRON	Fe	56
Lanthanium	La	92
LEAD	Pb	207
Lithium	L	7
Magnesium	Mg	24.3
MANGANESE	Mn	55
MERCURY	Hg	200
Molybdenum	Mo	96
Nickel	Ni	59
NITROGEN	N	14
Osmium	Os	199
OXYGEN	O	16
Palladium	Pd	106.5
PHOSPHORUS	P	31
Platinum	Pt	197.1
POTASSIUM	K	39.1
Rhodium	Ro	104.3
Rubidium	Rb	85.3
Ruthenium	Ru	104.2
Selenium	Se	79.5
SILICON	Si	28
SILVER	Ag	108
SODIUM	Na	23
Strontium	Sr	87.5
SULPHUR	S	32
Tantalum	Ta	182
Tellurium	Te	129
Thallium	Tl	204
Thorinum	Th	238
TIN	Sn	118
Titanium	Ti	50
Tungsten	W	184
Uranium	U	120
Vanadium	V	51.3
Yttrium	Y	61.7
ZINC	Zn	65
Zirconium	Zr	89.5

5. Classification of the Elements.—The elements are divided into two great classes—*metallic* and *non-metallic.* The latter are often termed by chemists *metalloids*, which means substances having some resemblance to metals, the affix *oid* being derived from a Greek word meaning like; since, however, the non-metallic bodies are not at all like metals, we will not use the term metalloid, but say *non-metals.* In the preceding table the non-metals are indicated by being printed in spaced type.

Some of the elements, as arsenic, antimony, etc., seem to possess a character intermediate between the metals and non-metals; sometimes chemists reckon them in one class, and sometimes in the other. Of the sixty-three elements, forty-nine are accounted metals and fourteen as non-metals. Of the latter, five are gases—oxygen, nitrogen, chlorine, fluorine, and hydrogen; the solid non-metals are sulphur, phosphorus, carbon, iodine, silicon, boron, and the rare bodies selenium and tellurium. There is but one liquid non-metal, bromine, as there is but one liquid metal, mercury. Although hydrogen is put among the non-metallic elements in all treatises on chemistry, yet there are some reasons for regarding it as a metal in a gaseous state. Only fourteen of the elements are quite abundant, and of these the great bulk of our earth, including its water and air, is composed, the remaining forty-nine existing only in small quantities, some of them exceedingly small compared with those which are abundant. Of the forty-nine metals, only ten are quite familiar to most people — viz., iron, copper, lead, tin, zinc, silver, gold, mercury, arsenic, and bismuth. Most of the remainder are known only to the chemist, and are very rare.

6. The Elements as Found in Nature.—Generally the elements are found in nature in combination one with another. But some of them, as gold and platinum, are always found uncombined. Others are sometimes combined and sometimes not. Thus carbon in wood, in alcohol, and in starch is combined, but in the diamond and in graphite it is uncombined. So, also, nitrogen and oxygen are combined in nitric oxide, but uncombined in the air, as that is a mere mixture of these gases. Some elements, as you will see in a future chapter, are never found in an uncombined state, but are obtained in this state only by processes in the laboratory of the chemist.

7. **Variety in their Combinations.**—There is very great variety in the combinations of many of the elements, in form, in color, and in other qualities more essential than these. You will hereafter learn, in Chapter VI., that nitrogen and oxygen form five combinations very different from each other. And then one of these compounds, nitric acid, forms a vast variety of combinations with many of the metals. Take the compounds of mercury as another example. Oxygen forms with it two oxides—a gray oxide and a red oxide. Sulphur also forms with it two compounds—one a black powder, and the other black also till it is sublimed, and then it is red, and constitutes the pigment called vermilion. Besides these, there are various compounds of mercury with nitric acid, sulphuric acid, etc. As we proceed with our investigations in future chapters this variety will be developed to you, and the examples which I have given will suffice for the present. By far the greatest variety, as you will see, is shown in organic substances. Here, for the most part, there are only four elements, sometimes but three, as stated in § 407. With these few elements, what an endless variety of forms, colors, odors, tastes, and other qualities is presented by vegetable and animal substances!

8. **Difference in Form between Mineral and Organized Substances.**—The forms which the combinations of the elements assume in organized or living substances are very different from those which they have in substances which are not living. In the former the tendency is to curved lines, but in the latter, with few exceptions, to straight lines and angles.

The subject of the crystallization of minerals belongs to mineralogy, and will be fully treated in Part Third. I shall barely allude to it here. You see the tendency spoken of in almost every mineral, and it never fails in its operation except from opposing circumstances. You can often see it in the rudest stone, especially if you call to your aid the microscope. The angles and edges and faces of the half-formed crystals can be seen huddled together. In the rocks and mountains we see this crystalline tendency roughly exhibited in laminæ and pillars. The most common exhibition of it is furnished us in water as it solidifies into snow and frost and ice.

9. **Relations of Heat to the Forms of Substances.**—Most substances, whether elementary or compound, like mercury and bromine, exist in different forms at different temperatures. We are accustomed to speak of them in the form in which they usually appear to us, with the idea that this is their natural condition. And yet this condition depends wholly upon circumstances. Alter the temperature variously, and you may have them solid, liquid, or dissipated in the form of vapor. Thus we speak of iron as a solid, and mercury as a liquid; but you can heat iron so as to make it a liquid, and you can cool mercury so as to make it a solid. Indeed, in some parts of the earth, the extreme arctic regions, the natural condition of mercury is that of a solid. Then, too, you can by heat turn mercury, heavy as it is, into a vaporous or gaseous condition. Water exists in the three different forms, solid, liquid, and gaseous, according to the degree of heat. Some substances can exist in only one form, so far as we know. This is the case with some of the gases. Some substances can exist in but two forms. Thus alcohol can be only in the liquid and gaseous forms, the severest cold which man has ever produced not having been able to make it solid.

10. No Chemical Action in the Changes Noticed above.—In the alterations of form above alluded to there is no chemical change—that is, no change in composition. When iron is melted, it is still iron; when mercury freezes, it is still mercury; and when water freezes or is vaporized, it is still simply water. The change that occurs in such cases is merely in the arrangement of the particles, and not in their qualities. The change when the liquid, water, is converted into the vapor that we call steam is a great change. The particles are very much separated from each other, as you may realize by observing the alteration in bulk as represented in Fig. 1. Here the large cube represents the quantity of steam produced from a quantity of water of the bulk of the small cube. Yet with this immense change there is no alteration of the composition of the water. Let the steam be condensed, and it will be simply water.

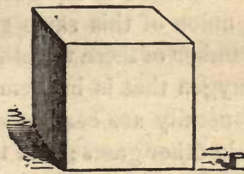

Fig. 1.

11. Forms of Matter as Affected by Chemical Causes.—Though many of the changes in the form of matter are unattended by any chemical action, there are also many others which are produced by chemical causes. One of the most striking examples of this we have in water. This liquid is composed wholly of two gases chemically united. As a large volume of steam condensed forms but a little water, so the bulk of the gases required to form a small amount of water is very great. So, too, there must be great condensation when the three gases of which nitric acid is composed unite to form that liquid. On the other hand, in some chemical combinations there are great expansions of matter. When any solid, for example, enters into the composition of a gas, it must be expanded into a very large volume. Thus when the solid, carbon, unites with the gas, oxygen, to form carbonic anhydride, in becoming invisible it must be made exceedingly thin, and therefore occupy a very large space. Many solid substances are formed by the union of a large bulk of some gas with a comparatively small bulk of some solid. Thus when iron rusts or any metal tarnishes, it is by the union of the solid with a large volume of the oxygen of the atmosphere. In a pound of iron rust there have been nearly twenty-seven gallons of oxygen condensed in the union of this gas with the iron. In quicklime we have a union of this same gas with a metal. There is a great number of these metallic compounds, called *oxides*, from the oxygen that is in them. Animal and vegetable substances generally are composed, to a great extent, of this and certain other gases; and the gases that result from combustion and decay fly off in the atmosphere only to appear again in the living forms that we see around us. This agency of gases in forming solid substances is always surprising to a beginner in the study of chemistry, and he can hardly credit the supposition of chemists that oxygen gas constitutes full one third of the solid crust of the earth.

12. **Extent and Variety of Chemical Action.**—Some of the elements are very busily at work producing changes every where. When any thing burns we see an exhibition of the chemical action of elements upon each other. The rusting of a metal is the uniting of two elements. The effects of manure, compost, lime, etc., in the soil come from chemical action effecting compositions and decompositions. Air and water are every where busy helping to produce these changes in the soil. The operations of life, both in vegetables and in animals, are in part chemical, and those which occur when death comes to either are wholly so. The sap of vegetables and the blood of animals are made up of chemical compounds of elements. Even the heat of the body is produced by a chemical process, which is like com-

bustion, except that there is no flame. The air which we breathe into our lungs acts chemically upon the blood, and life is very soon destroyed if this chemistry of the respiration be stopped. Chemistry, to a great extent, makes and prepares our food. The grains are made by a union of elements which the plant sucks up from the ground and takes from the air through the pores of its leaves; and the making of bread is in part a chemical process, upon the due performance of which the goodness of the bread depends. In these examples of chemical action you see the wide range and the practical character of the interesting subjects which chemistry presents to your view.

13. **Changes in the Rocks.**—In the midst of the chemical changes so extensively and constantly taking place there are some things which are nearly the same from year to year, and even from age to age. The rocks of "the everlasting hills" seem to remain unchanged. But it is not so; there is some change even in them. Heat, air, and water are continually at work upon them, and some portions are thus worn away even from the hardest of them to mingle with the earth. And then, by means of chemical action, these particles from stones and rocks are used in the growth of both plants and animals. The flint that gives strength to the stalks of grain and grass, the lime that is in the shells of eggs and in the bones of animals, and the iron that is in the blood, all came originally from the rocks.

14. **The Sun's Agency.**—In this chemistry, which is at work so universally, heat is one of the chief agents. And as the sun is the great source of heat, we may think of it not only as giving us light and warmth, but as constantly stimulating to the changes which are taking place among the elements that are within and around us. Not only so, but, as you will see in the course of our investigations, there is a special chemical force bound up with the light and heat

that come to us in the rays of the sun, so that every ray is a bundle of three forces united together—an illuminating, a calorific, and a chemical. The sun, therefore, with its light diffused every where, is the greatest of all the chemical agents in our earth.

15. **Summary.**—The chief characteristics by which chemical changes are distinguished are briefly summed up in the statement following:

1st. Heat is evolved during chemical combination.

2d. A more or less complete change of physical and chemical properties.

3d. A chemical compound can not be broken up by simple mechanical means.

4th. No weight is lost in chemical combination.

5th. Chemical combination takes place only in certain definite proportions by weight.

The significance of the fifth point will appear fully in Chapter III.

16. **Analysis and Synthesis.**—When a substance is separated into the parts of which it is composed by means of physical or chemical forces brought to bear upon it, the operation is called analysis, or a "loosening again," from two Greek words—*ana*, "again," and *luein*, "to loosen." Chemical analysis forms an important branch of practical chemistry of immense value in determining the composition of bodies. Synthesis, or a "putting together," also from the Greek, is the opposite of analysis—it is the basis of a large portion of chemical manufactures, which, however, pertain to both branches.

17. **Nomenclature.**—There is no science that has so appropriate and accurate a nomenclature as chemistry has at the present time. It is in direct contrast with that loose and unscientific nomenclature which was in vogue before the time of Priestley and Scheele and Lavoisier. The old names were given from some quality of the substance, or

from some fanciful idea of its nature. Thus nitric acid was called aqua fortis (strong water), because it is a liquid of such powerful acid properties; and sulphuric acid was named oil of vitriol, because it flows like oil, and was obtained from what was called green vitriol. Then the sulphates of iron, copper, and zinc were respectively named green, blue, and white vitriol, because, from their translucency, they somewhat resemble glass of these colors. Other examples might be given, but these are sufficient. In chemical books all these old names have given place to the new nomenclature introduced by Lavoisier and his compeers, though a few of them are yet retained in common language. This nomenclature, which, though it has been extended with the progress of chemical discovery, has not been essentially altered since it was first promulgated, is worthy of admiration for its beautiful clearness and simplicity. There is nothing arbitrary but the names of the elements. All the compounds have names which indicate their ingredients; and if any new compound be discovered, the discoverer gives to it a name which expresses its chemical character in accordance with the general plan of the nomenclature. Examples of the method of naming compounds will be given in the next paragraph; and as we proceed in the examination of various substances, you will have constant illustrations of this language of chemical science.

18. **Naming of Chemical Compounds.**—The names of compound bodies are derived from the elements of which they are composed; many of these names have been anticipated, but some explanation is necessary. In general, when two elements unite, the name of the compound is formed by writing the name of one element in full and placing the name of the other element after it, giving to the latter the termination *ide.* Usually the non-metallic element follows the metallic; thus potassium and oxygen form potassium *oxide;*

barium and sulphur, barium *sulphide;* sodium and chlorine, sodium *chloride.* Sometimes two sets of bodies are formed by the same elements; in such cases the name of the first component receives the termination *ous* or *ic*, according to the quantity of the *second* element combining with it. Thus nitrogen and oxygen form two compounds, *nitrous* oxide and *nitric* oxide—the former containing more nitrogen than the latter, or, if you please, the latter containing more oxygen than the former. Further explanations of the methods of naming compounds will be given in connection with the section on oxides (§ 62), and on acids, bases, and salts (§ 79).

QUESTIONS.

[The numbers refer to the sections.]

1. What is the difference between Chemistry and Natural Philosophy? Illustrate it by an example.—2. What is the difference between elementary and compound substances?—3. What were the four elements according to the ancients? Show the error of this idea.—4. How many elements are there? What is said of the possibility of some of them being compounds? Name some of the most important elements.—5. Into what two classes are the elements divided? How many gases? How many liquids? How many metals? Name the best-known metals.—6. How do the elements occur in nature? Give examples.—7. What is said of the variety of their combinations?—8. What differences in form are noticed between mineral and organized bodies?—9. State in full what is said of the influence of heat on the forms of substances.—10. Illustrate the fact that no chemical changes accompany the changes of form just mentioned.—11. Give examples of the nature of chemical changes. What is iron rust? Do gases unite with solid substances? What are oxides?—12. State in full what is said of the extent and variety of chemical action.—13. What is said of changes in the rocks?—14. What of the sun's agency in chemical changes?—15. Sum up the five characteristics of chemical change.—16. What is meant by analysis and synthesis?—17. Contrast the old and modern systems of nomenclature. Who introduced the present method? How are new compounds named?—18. On what principles are names of compound bodies formed? Give examples—sulphur and sodium? barium and chlorine? What do the terminations *ous* and *ic* signify?

CHAPTER II.

CONSTITUTION OF MATTER.

[*Note to the Teacher.*—In pursuing a logical arrangement of matter, the principles of chemical philosophy appropriately precede the descriptive portion of chemistry, and yet to some minds abstract ideas are exceedingly difficult of comprehension, and can best be grasped after having acquired a number of facts and phenomena with which to connect them. It is hardly to be expected, then, that all young pupils will be able to intelligently learn many parts of this and the two succeeding chapters; it is recommended, therefore, that these chapters be carefully *reviewed* after having completed the study of the first *ten* chapters. Nomenclature and notation should, however, be dwelt upon on the first perusal until the pupil is perfectly familiar with the systems employed.—EDITOR.]

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19. **Constitution of Matter.**—You have already learned in Part I., p. 17, that matter is in the abstract any thing which is perceptible by the senses, but that we do not know any thing of its nature; we can only observe its phenomena and learn its properties. In order to interpret facts and to aid in their classification, theories have been formed regarding the nature of matter, and one of these is of importance to us. Theories, you should bear in mind, are not to be considered as having the same weight of authority as facts, but as mere matters of convenience, which are liable to be supplanted by other and new theories so soon as the old ones prove insufficient. We do not propose to trouble you with metaphysical speculations, but will explain the so-called atomic philosophy simply and briefly, both because it is interesting and apparently true, and also because its consideration will

serve to impress upon your minds more strongly some of the great principles and facts of chemistry.

20. **Molecules.**—The atomic philosophy assumes that matter can not be infinitely divided—that is, you may cut and pulverize any thing as fine as you please, and you may then *think* the smallest attainable particles divided again and again, smaller and smaller, until you reach a certain limit, beyond which matter can not be subdivided. Hence bodies consist of an immense number of little particles called molecules—literally, little masses. These molecules do not touch each other, but are separated by empty spaces, and these void spaces are very large compared with the dimensions of the molecules themselves. These little particles are held near each other by some force, or attraction, as it is often called, and this force varies considerably in power in the three different states of matter with which you are familiar. It is supposed that if it were not for the fact that these molecules do not touch each other, we would be unable to cut any substance into pieces, for the small particles of matter are considered to be impenetrable; and when a knife-edge is forced into a body, it simply enters the void spaces between the molecules and makes them separate—it does not penetrate the substance of the molecules themselves. It seems strange at first to think of hard substances like iron and silver as made up of particles which do not touch each other; but this is a way of regarding them which you will find easier to accept the longer you study. Do not for an instant think that these little particles are ever visible to any one, even with the aid of a most powerful microscope. They are so small that we can only *think* them. What we do see are immense numbers of these molecules aggregated. To give you a faint idea of the littleness of these particles, we will tell you that philosophers have conjectured that fifty million million molecules placed in a row would occupy the

space of one inch, and the weight of a million million molecules of hydrogen gas (the lightest substance known) is supposed to be equal to about three pennyweights. Or, if you prefer another way of looking at it, imagine a drop of water the size of a pea magnified to the size of the earth, then the molecules in it increased in the same proportion would be coarser than fine shot, but probably not so coarse as cricket-balls. These speculations may seem rather extravagant; but three trains of thought have led philosophers to nearly similar conclusions. These molecules are conceived to be continually in motion, so that the interior of a body presents to our imagination some resemblance on a small scale to the vast system of the universe. In fact, we see in the latter case stars held in certain positions determined by the law of universal attraction, and revolving one about another. Repeating briefly what we have told you in this section, masses of matter are made up of excessively small particles, called molecules, separated from each other by void spaces, mutually attracting and constantly in motion.

21. **Advantages of this Theory.**—We have already alluded to the fact that this theory enables us to explain intelligently the divisibility of matter, but besides this it accounts in a satisfactory manner for many of the facts of physical science. When you heat iron, it expands; this you remember was explained fully in Part I., just as we do now by saying that the particles are put farther apart by the heat, which is really but an increase of motion imparted to them. When any thing is cooled down, on the other hand, it contracts — that is, the particles approach each other. This theory, then, accounts for the changes of volume caused by changes of temperature. Then, again, the very existence of three states of matter—solid, liquid, and gaseous—depends on the relative position of the molecules. In solid bodies,

force is required to move the molecules and separate them; in liquid bodies the relative position of the particles is no longer permanent—they glide past each other with perfect ease, and less force is required than in the case of solids; in gases the mobility of the molecules is still greater than in liquids, and the molecules tend constantly to recede from each other.

In Fig. 2 you have a rough representation of the way molecules are separated from each other by heat.

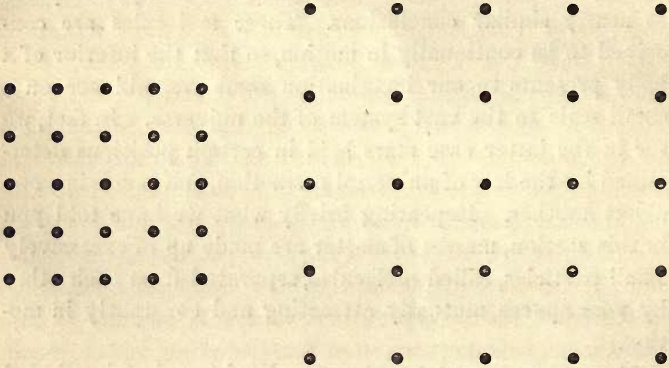


Fig. 2.

22. **Atoms.**—As minute and intangible as these molecules are, they are believed to be composed of still smaller particles called atoms. We have already alluded to the difference between Chemistry and Physics (or Natural Philosophy), but this difference is now clearer when we state that physical phenomena affect mainly the molecules, while chemical science deals with atoms. Thus the physical properties of an object refer to its condition, whether solid, liquid, or gaseous; crystalline form, color, hardness, specific gravity, transparency or opacity, and the relations of the body to heat, light, and electricity, are physical properties. These you have studied in Part I.

The phenomena of combustion, fermentation, putrefaction, decomposition, etc., belong to the science of chemistry. In short, all the phenomena in which the molecule remains unchanged belong to the science of physics, while the phenomena in which the molecule is changed or modified in its nature belong to the science of chemistry.

23. **Illustration.**—If you examine a piece of iron from a purely physical point of view, you may describe it as black or steel gray, opaque, hard, of a specific gravity of 7.8—*i. e.*, nearly eight times as heavy as water—and a fair conductor of heat, as you will find on heating one end red-hot. Besides these qualities, it is a conductor of electricity, and may be converted into a magnet possessing the power of attracting and repelling other pieces of iron. It is also fusible, malleable, ductile, elastic, capable of crystallization. In all this, however, its nature is not changed—it still remains iron, its molecules are intact. Again, here you have some sulphur: it is, physically considered, yellow, brittle, electric, easily fusible, readily crystallized, soluble in certain liquids, etc., etc. Now take some iron filings having the physical qualities named, and mix these with powdered sulphur having its own properties; mix and pulverize as fine as you please; each grain of the mixture will contain a particle of iron and a particle of sulphur. The iron may be withdrawn by a magnet, and the sulphur may be dissolved out in carbon disulphide. Examined under a powerful microscope, each particle will be seen to consist of two distinct substances, iron and sulphur. Now apply heat to this mixture, and thus set chemical force at work: the mass glows, a kind of combustion takes place, and on cooling you have a dark substance which possesses physical and chemical properties of its own. The iron has disappeared, the sulphur has gone, each has united with the other, atom to atom. The magnet will not now withdraw the iron, nor can the sulphur be dis-

solved out; the microscope reveals a homogeneous mass, and the whole is soluble in acids, evolving a very disagreeable odor. The new substance, while containing iron *and* sulphur, is *neither* iron *nor* sulphur; chemists call it sulphide of iron.

24. **Two Kinds of Molecules.**—Molecules may be compound or simple. Simple molecules are made up of atoms of one and the same substance. By exposing the sulphide of iron to the action of other substances, with the agency of heat and chemical force it may be resolved into its constituents, iron and sulphur; sulphide of iron, then, is a compound molecule composed of atoms of iron and atoms of sulphur. Iron is not capable of being decomposed, nor is sulphur—that is, their molecules are simple, or compounded only of like atoms. They are elementary bodies, as you were told in the first chapter; but you now learn to regard the elements from another and peculiar point of view.

25. **Further Properties of Atoms.**—These atoms, it is supposed, can not be destroyed or altered or divided, but have remained precisely the same since their first creation. The atoms of some elements have been continually uniting with the atoms of others, changing from one kind of combination to another, and yet, after myriads of such changes, they have not altered in shape or character. Take oxygen for example. When its atoms unite with those of hydrogen to form water, it is not by any change in the atoms themselves that a fluid so different from each of these gases is produced, but it is only by some arrangement of these atoms. So when potassium is thrown upon water, and produces fire and smoke, amid all the commotion and burning not an atom of either the potassium or oxygen or hydrogen is lost or injured, but they simply form new associations. The disturbance is the mere result of the eagerness of the atoms of oxygen and potassium to unite together.

So, too, when a mixture of oxygen and hydrogen explodes on the application of a light or electricity, the atoms of the two gases merely unite in a very hurried manner, forming water, and none of them experience the slightest change. These ultimate atoms unite together to make molecules or particles, which, unlike the atoms, can be both changed and divided if the atoms composing them be of two or more kinds, and can at least be divided if their atoms are of one kind alone.

26. **Weight of Atoms.**—A most important attribute of atoms has not yet been mentioned, viz., weight. Every elementary body is supposed to be made up of atoms of exactly the same size and weight in the same body. The weight of the atoms of different elements varies greatly; if we call the weight of the hydrogen atom 1, then that of oxygen is 16, while mercury is 200, gold 197, carbon 12, etc. How it is that chemists are able to determine that the atoms of the various elements differ in weight we can not explain to you in this work, but you must not imagine that single atoms are ever weighed, only immense numbers of them taken together. Nor is there any thing absolute with reference to their weight—it is merely relative; that is, the figures for hydrogen and oxygen named, viz., 1 and 16, do not stand for any particular quantity, say pounds or grammes, but they signify that if the hydrogen atom weighs 1 gramme or 1 pound, then the oxygen atom, being sixteen times as heavy, weighs 16 grammes or 16 pounds. Any other unit than hydrogen might be taken; and actually many years ago oxygen was placed equal to 100, and the weights of the other atoms were proportionally heavier—hydrogen becoming 12.5, since $8:100=1:12.5$. All the figures representing the relative weights of the atoms were then 12.5 times heavier. Chemists now universally adopt hydrogen as the standard, and make it unity.

QUESTIONS.

19. What is the use of theories?—20. What is said of the divisibility of matter? What are molecules? Give the reason for their not touching each other in masses. State what is given as the probable size of molecules? Are molecules motionless?—21. What are the advantages of this theory? Why do bodies expand by heat?—22. Of what are molecules made up? Show the difference between Chemistry and Physics?—23. Describe the illustration of this difference in the example given. What is sulphide of iron?—24. Explain the nature of elements with reference to the atomic theory.—25. What other properties are ascribed to atoms? Is any thing lost or destroyed when burned up?—26. What is the most important attribute of atoms? Are these absolute weights? What is the standard now adopted?

CHAPTER III.

LAWS OF CHEMICAL COMBINATION.—NOTATION.

27. **Law of Definite Proportions.**—Chemists have made innumerable experiments and analyses by which it is proved that elementary bodies unite in definite proportions by weight. Thus, if you take 32 pounds of sulphur and heat it with iron filings to make sulphide of iron, as in the experiment noticed in § 23, you will require just 56 pounds of iron, no more and no less. If you should take 32 pounds of sulphur and 60 pounds of iron, you will have four pounds of iron left over, *i. e.*, uncombined; or if you take 50 pounds of sulphur and 56 of iron, you will have 18 pounds of sulphur too much. While, therefore, there may be great indefiniteness in mere mixtures, there is none in the formation of compounds. *Every compound always has exactly the same composition.* No matter under what circumstances the compounds are produced, this exactness is preserved. The carbonic anhydride formed by combustion, by respiration,

by fermentation, or by the explosion of gunpowder, always possesses the same definite composition. This is one of the four great laws governing chemical combination, and is known as the *Law of Definite Proportions.* Before taking up the study of the other laws you must understand the meaning of chemical symbols.

28. **Chemical Symbols.**—Now turn to the table on page 13, and we will tell you how to use it. First you have a list of all the elementary substances, and opposite each name you find letters placed, which are either the first two letters of the full name or some other abbreviation, the meaning of which you will now learn. These letters are the symbols used so much in chemistry, and we will explain some of them. Take those elements whose names begin with S. We call sulphur S, and we must therefore designate the others in such a way as to distinguish them from this and from each other. We call, then, silver Ag, from *Argentum*, the Latin for silver; and sodium Na, from an old Latin name for soda, *Natrium.* Phosphorus is set down as P, being a prominent element with a name beginning with that letter. Then Potassium is designated by K, from *Kalium*, an old Latin name for potash. Several of the elements take their symbols from their Latin names. Thus the Latin for Antimony is *Stibium*, Sb; for Mercury, *Hydrargyrum*, Hg; Lead, *Plumbum*, Pb; Copper, *Cuprum*, Cu; Gold, *Aurum*, Au; Iron, *Ferrum*, Fe; and Tin, *Stannum*, Sn. Generally those which are most important are represented by a single letter; as, for example, the four grand elements, oxygen, nitrogen, carbon, and hydrogen. We use these symbols as a kind of short-hand for expressing chemical reactions, and it is necessary to become familiar with this method of writing from the very outset. Thus, instead of writing Potassium in full, we write K, or in place of Hydrogen we write H. This is not all they signify, however: each letter stands

for one *atom* of the element it represents. H, then, means one atom of hydrogen—no more and no less. If we want to express two, three, or more atoms, we place a little $_2$ or $_3$ to the right hand of the symbol; thus Na_2 stands for *two atoms* of sodium, and O_3 means *three atoms* of oxygen. Sometimes large figures are placed in front, as 5N, which means five atoms of nitrogen. Now unlike atoms unite to form molecules of new bodies, and to represent this we write the symbols alongside of each other. Thus HCl will signify the body having one atom of hydrogen united to one atom of chlorine; you will learn farther on that this body is called hydrochloric acid.

29. **The Symbols in Formulæ.**—The example given in the last paragraph, HCl, is called the *formula* of the body. In place of writing "one atom of hydrogen united to one atom of chlorine," we say "HCl," which is certainly much shorter. In the same way CO stands for a gas called carbonic oxide, containing as you see one atom of carbon and one atom of oxygen. NaCl signifies chloride of sodium; CaO, oxide of calcium. These examples anticipate of necessity the method of forming the names of compounds, which you will learn more fully in the section on nomenclature. In the examples we have taken so far, only one atom unites with one atom of another substance; it frequently happens, however, that several atoms of an element unite with one of another element, and to show this we use the little figure referred to in § 28, and which is called a *coefficient*. Thus water is made up of two atoms of hydrogen and one of oxygen, hence it is written H_2O; marsh gas is CH_4, sulphuric acid is H_2SO_4, etc., etc. Interpreting the last formula, we would say that two atoms of hydrogen, one of sulphur, and four of oxygen, held together by chemical attraction, make one molecule of sulphuric acid. Potassium nitrate is KNO_3, gypsum is $CaSO_4$, sodium carbonate is Na_2CO_3. If a sub-

stance crystallizes with water, we usually write the molecules of water separately, thus: $Na_2CO_3 . 10H_2O$, a period separating them; in place of a period, a plus sign is sometimes used. $CaSO_4+2H_2O$ is the formula, then, of crystallized gypsum, the sign + indicating that the connection between the gypsum and the water is not so close as that of the remaining elements. We know this to be a fact, because if crystallized gypsum containing water be heated red-hot, the water is driven off, but the C, the S, and the O_4 are not thus separated. Notice that the 10 prefixed to the H_2O in the case of sodium carbonate, and the 2 prefixed to the H_2O in the other formula, multiplies the O as well as the H_2; it is the same as if we had written $H_{20}O_{10}$, or H_4O_2, and means that ten and two molecules of water respectively are taken.

From what we have said about formulæ, it is plain that a group of atoms constitutes a molecule, and that the number of atoms in a molecule varies considerably; in HCl we have two, while in $Fe_2(SO_4)_3$, for example, there are seventeen. In the chapters on organic chemistry, you will learn that frequently the organic bodies contain a much larger number of atoms in a molecule.

30. **Further Explanation of Symbols.**—Since the atoms have definite weights, and elementary bodies unite in fixed proportions by weight, these symbols stand not only for the atoms of the respective elements, but also for definite weights of the elements. The third column in the Table on page 13 gives these weights. S, then, means not only one atom of sulphur, but also 32 parts by weight. Na stands for 23 parts by weight of sodium, and so on. In this light, formulæ have a new significance. HCl means 1 part by weight of hydrogen, and one atom or 35.5 parts by weight of chlorine. In sulphuric acid, or H_2SO_4, we have the following composition:

2 atoms of hydrogen, or H_2, weigh	2
1 atom of sulphur, or S, weighs	32
4 atoms of oxygen, or O_4, weigh	64
1 molecule of sulphuric acid, or H_2SO_4, weighs	98

You notice that we have drawn a line under the weights of the atoms and added them together, obtaining the weight of a molecule of sulphuric acid. Atoms, you remember, unite to form molecules, and here you see that the sum of the atomic weights of the elements composing the molecule of a body gives the weight of a molecule of that body. This is called the *Law of Molecular Weights.*

Take another example: Common limestone, you will learn farther on, is a compound of calcium, carbon, and oxygen, in the proportions represented by the formula $CaCO_3$:

1 atom of calcium, or Ca, weighs	40
1 atom of carbon, or C, weighs	12
3 atoms of oxygen, or O_3, weigh	48
1 molecule of calcium carbonate, or $CaCO_3$, weighs	100

The molecular weight of crystallized gypsum can be calculated in like manner, the weight of two molecules of water ($2H_2O=36$) being added to that of one molecule of gypsum. Use the Table on page 13 to make this calculation. These examples also make the Law of Definite Proportions much clearer.

31. **Other Laws of Chemical Combination.**—In explaining the meaning of symbols, we have somewhat anticipated the other laws of chemical combination. The *Law of Multiple Proportions* may be thus stated: When one body combines with another in several proportions, the higher proportions are multiples of the first or lowest. This results from the fact that one, two, three, or more atoms of one element often unite with a single atom of some other element, forming three or more bodies having very different properties.

Examples of this law are abundant; to take the case most familiar to us, iron and sulphur unite not only in the proportions of atom to atom, but also of one atom of iron to two atoms of sulphur—consequently in the ratio of 56 parts by weight to twice 32 parts. This is shown in the following manner:

1 atom iron, Fe,	weighing 56,	unites with 1 atom sulphur, S,	weighing 32,	to make a molecule, FeS,	weighing 88.
1 atom iron, Fe,	weighing 56,	unites with 2 atoms sulphur, S_2,	weighing 64,	to make a molecule, FeS_2,	weighing 120.

When there are two elements forming different compounds, generally one remains the same in all the combinations, while the other is varied, not irregularly, but regularly. When two elements unite to form a series of compounds, this law of multiples is very noticeable. Oxygen and nitrogen furnish such a series, which you will find on page 63. Sometimes the series is complete, as in the case of the combinations of hydrogen with oxygen and chlorine, which may be stated thus:

		Composition by weight.		
Names.	Formulæ.	Hydrogen.	Chlorine.	Oxygen.
Hydrochloric Acid	HCl	1	35.5	
Hypochlorous "	HClO	1	35.5	$16\times1=16$
Chlorous "	$HClO_2$	1	35.5	$16\times2=32$
Chloric "	$HClO_3$	1	35.5	$16\times3=48$
Perchloric "	$HClO_4$	1	35.5	$16\times4=64$

Here the proportions of oxygen, 16×1, 16×2, 16×3, 16×4, are respectively the *multiples* of 16—viz., 32, 48, and 64.

The remaining law is that of *Reciprocal Proportions*, which may be thus stated: If two bodies combine with a third, the proportions in which they combine with that third body are measures or multiples of the proportions in which they may combine with each other.

Referring again to the Table of Atomic Weights, we find that 32 parts by weight of sulphur combine with 56 parts by weight of iron and with 16 parts by weight of oxygen, consequently 56 parts by weight of iron combine with 16 parts by weight of oxygen. Or, using less wordy language, since one atom of sulphur (32) combines with one atom of iron (56) and with one atom of oxygen (16), these bodies, iron and oxygen, combine with each other atom to atom (56 and 16). Actually the relation is not quite so simple, for oxygen and sulphur combine usually in the proportion of two atoms of the former to one of the latter, and this necessitates the use of the word "multiples" in the law as just stated.

We might in a similar way go through the whole list of elements, showing that their atomic weights express their value in satisfying the demands of each other in their combinations.

32. **Summary.**—We will sum up in four propositions the facts which we have developed in this chapter in regard to the combinations of substances. 1. When substances combine with each other, it is always in certain fixed and invariable proportions. In other words, every compound always has precisely the same composition. This is called the law of *definite* proportions. 2. When two substances unite in more proportions than one, these proportions bear a simple arithmetical relation to each other. This is called the law of *multiple* proportions. Commonly, as you have seen, one of the substances remains the same, while the other is in different proportions, usually as 1, 2, 3, etc. Sometimes the relation is as $1\frac{1}{2}$, $2\frac{1}{2}$, $3\frac{1}{2}$, etc.; but this we shall speak of in another place. 3. When several substances, B, C, D, etc., unite with a substance, A, the proportions in which they unite with it are expressed by numbers, which represent the proportions in which they unite with each

other. This is called the law of *equivalent* or *reciprocal* proportions. 4. The molecular weight of a compound is the sum of the atomic weights of its constituents. This is the law of *molecular weights.*

33. **Chemical Equations.**—Returning to the symbols, there is a further great advantage to be derived from their use which we have not yet mentioned. By writing formulæ in a particular way, they place before the eye in small compass the exact changes which occur when chemical action takes place between two substances. We will give only very few examples here, but you will become familiar with them as you progress.

The formula for water, you know, is H_2O; now potassium is simply K. In Chapter XVI. you will learn that potassium decomposes water, forming potassium hydrate, and setting half the hydrogen free; this is expressed in symbols thus:

Potassium	and	Water	yield	Potassium hydrate	and	Hydrogen
K	+	H_2O	=	KHO	+	H

The plus sign between potassium and water signifies "mixed with" or "in contact with," or "acted upon by," and *not* "combined with." The sign of equality means "yields" or "produces," and has not the precise meaning of "equal to" as when used in algebra. Notice particularly that you have the same elements on both sides of the equation, viz., O, H_2, and K, but they are arranged differently. $K+H_2O$ expresses the condition of the substances before they come in contact, and KHO+H their condition after the chemical action.

The most important meaning conveyed by the chemical equations remains still to be explained. Bearing in mind that the symbols stand for definite weights of the bodies they represent (referred to hydrogen as unity), the equations give the actual proportion by weight of the elements concerned, and of the bodies produced by the chemical change. This is shown thus:

$$\begin{array}{ccccccc}\text{Potassium} & & \text{Water} & \text{yield} & \begin{array}{c}\text{Potassium}\\ \text{hydrate}\end{array} & & \text{Hydrogen}\\ K & + & H_2O & = & KHO & + & H\end{array}$$

$$\underbrace{39.1 + \underbrace{(1)_2+16}_{18}}_{57.1} = \underbrace{\underbrace{39.1+1+16}_{56.1} + 1}_{57.1}$$

The 39.1 stands for so many grammes, pounds, tons, etc., of potassium, the 18 (obtained by adding the weights of the atoms) for so many grammes, pounds, tons, etc., of water; now when chemical action takes place, nothing is lost, so we must find just as many grammes or pounds of these elements taken together, viz., 57.1, on one side of the equation as on the other. That this is the case is evident; only the atoms are arranged differently—on the right-hand side we have 56.1 grammes, pounds, or tons of potassium hydrate, and 1 pound, etc., of hydrogen.

34. **Combination by Volume.**—We have hitherto considered only the laws governing combination by weight, but the elementary bodies which exist in a gaseous state combine by volume in simple ratios, and the volume of the resulting body bears a simple ratio to the volume of its constituents. A full examination of the laws of combination by volume can not be entered upon in this work. We can give you only a few illustrations to show that the volume relations of gaseous compounds are very simple.

Thus *one* volume of H and one volume of Cl unite to form two volumes of hydrochloric acid, *two* of H and one of O form *two* of water, *three* of H and one of N form *two* of ammonia, and, finally, *four* of H and one of C form *two* of marsh gas. This, you will see, is in direct connection with the atomicity of the elements explained in § 44. Now there is a law in physical science that all molecules in the gaseous state occupy the same volume; and taking the volume of an atom of hydrogen as unity, the volume occupied by molecules is two. Chemical formulæ, then, dealing with molecules of bodies, as well as the atoms, represent the *volumes* of the constituents as well as the weights. If we represent the volumes by squares, as on the next page, this will be somewhat clearer; we take for examples the formation of the bodies HCl, H_2O, NH_3, and CH_4, just mentioned:

$$\boxed{H} + \boxed{Cl} = \boxed{H\,|\,Cl} \quad \text{or } H+Cl = HCl \text{ (hydrochloric acid).}$$

$$\begin{array}{c}\boxed{H}\\\boxed{H}\end{array} + \boxed{O} = \boxed{H_2|O} \quad \text{or } H_2+O = H_2O \text{ (water).}$$

$$\begin{array}{c}\boxed{H}\\\boxed{H}\\\boxed{H}\end{array} + \boxed{N} = \boxed{N|H_3} \quad \text{or } H_3+N = NH_3 \text{ (ammonia).}$$

$$\begin{array}{c}\boxed{H}\\\boxed{H}\\\boxed{H}\\\boxed{H}\end{array} + \boxed{C} = \boxed{C|H_4} \quad \text{or } H_4+C = CH_4 \text{ (marsh gas).}$$

35. **Significance of Equations.**—Every chemical equation expresses a great deal in an exceedingly condensed manner. It shows:

1st. What and how many elements are concerned in the reaction.

2d. How these elements are combined before and after the chemical change has taken place.

3d. The proportion by weight of every constituent in the compounds.

In the case of gases a fourth point is shown, to which we have just alluded, viz., the proportion by *volume.*

We will give you one more example to study; try to determine the application of the three points above named. The names of the bodies are not familiar, but that need not be a source of confusion:

$$\overset{\text{Calcium Carbonate.}}{CaCO_3} + \overset{\text{Hydrochloric Acid.}}{2HCl} = \overset{\text{Calcium Chloride.}}{CaCl_2} + \overset{\text{Water.}}{H_2O} + \overset{\text{Carbonic Anhydride.}}{CO_2}$$

$$\underbrace{\underbrace{40+12+(16\times3)}_{100}\quad\underbrace{2(1+35.5)}_{73}}_{173}\quad\underbrace{\underbrace{40+(35.5\times2)}_{111}\quad\underbrace{(1\times2)+16}_{18}\quad\underbrace{12+(16\times2)}_{44}}_{173}$$

36. **Mathematical Calculations.**—You have already obtained some insight into the numerical relations of the atoms; the calculations made from the atomic weights and molecular weights of bodies belong to a special branch of chemical philosophy called *stoichiometry*, a word made up of two Greek words meaning "an element" and "a measure." These mathematical calculations are of the greatest importance both to the scientific and manufacturing chemist; the former is enabled to determine the composition of new bodies, or the purity of known substances; the manufacturer is enabled to estimate how much of any given material it is necessary to use in order to manufacture a certain product. A knowledge of a few simple rules, seldom requiring higher arithmetic than Proportion, properly applied to questions of practical import in manufacturing chemical products, saves the capitalist thousands of dollars, and dollars and cents are items of no small consideration. We can not explain all these calculations to you, nor is it necessary for any one except a working chemist to master them, but you should endeavor to realize their importance. We will give only a single case, and illustrate it by two examples. Turn to page 38; you find there an equation for the reaction of potassium in water, with the numerical values of each atom and molecule attached. Now suppose this was a good method for manufacturing potassium hydrate (or caustic potash, as it is commercially known), and we should want to know how much of it can be made from 10 pounds of metallic potassium, the question would be solved thus:

From the equation cited it is evident that one atom of potassium yields one molecule of potassium hydrate; but one atom, or K, weighs 39.1, and the molecule KHO weighs 56.1, therefore we have the proportion:

$$\text{As}\left\{\begin{matrix}\text{Atomic}\\ \text{weight of}\\ \text{potassium}\end{matrix}\right\}\text{is to}\left\{\begin{matrix}\text{Molecular}\\ \text{weight of}\\ \text{potassium}\\ \text{hydrate,}\end{matrix}\right\}\text{so is}\left\{\begin{matrix}\text{The given}\\ \text{number}\\ \text{of lbs. of}\\ \text{potassium}\end{matrix}\right\}\text{to}\left\{\begin{matrix}\text{The number}\\ \text{of lbs. of}\\ \text{KHO.}\end{matrix}\right\}$$

$$39.1 \quad : \quad 56.1 \quad :: \quad 10 \quad : \quad \text{the answer;}$$

whence $\frac{56.1 \times 10}{39.1} = 14.3$; consequently 10 pounds of potassium would furnish 14.3 pounds of potassium hydrate.

Supposing, again, that this was an economical method for manufacturing hydrogen gas, how much potassium is required to make 100 grammes of hydrogen? By examining the equation on page 38, you will find as before that one atom of potassium weighing 39.1 takes place in the reaction setting free one atom of hydrogen weighing 1, hence the proportion:

$$\begin{array}{ccccccccc}\text{As}\left\{\begin{array}{c}\text{Atomic}\\ \text{weight of}\\ \text{hydrogen}\end{array}\right\} & \text{is to} & \left\{\begin{array}{c}\text{Atomic}\\ \text{weight of}\\ \text{potassium,}\end{array}\right\} & \text{so is} & \left\{\begin{array}{c}\text{The given}\\ \text{number of}\\ \text{grammes of}\\ \text{hydrogen}\end{array}\right\} & \text{to} & \left\{\begin{array}{c}\text{Number of}\\ \text{grammes of}\\ \text{potassium}\\ \text{required.}\end{array}\right\} \\ 1 & : & 39.1 & :: & 100 & : & \text{the answer;}\end{array}$$

whence $\frac{39.1\times 100}{1}=3910$ grammes of potassium. Such calculations are very useful as a discipline for students, impressing on their minds the four great laws of chemical combination, particularly the law of definite proportions. Examples may be multiplied at the discretion of the teacher, employing from time to time the equations given in different parts of the book. The questions of percentage composition and of volume relations can not be entered upon in an elementary work.

QUESTIONS.

27. How do elementary bodies unite? Illustrate by taking iron and sulphur. What is the first great law governing chemical combinations?—28. Explain the nature of symbols? How are they used? What do they signify? Write five atoms of nitrogen. How are molecules expressed?—29. What is a formula of a body? What is the formula for common salt? What of sulphuric acid? Explain the small figure in the latter formula. What is the use of the period? What of the plus sign? How are several molecules of one substance written? Do molecules ever contain several atoms?—30. What else do the symbols stand for? Explain the law of molecular weights. (The teacher should place examples on the blackboard.)—31. Give the law of multiple proportions. Illustrate with iron and sulphur. What is the law of reciprocal proportions? Explain by referring to a Table of Atomic Weights.—32. Recapitulate the four laws.—33. Give in your own language the use of chemical equations. Write the action of water on potassium. Explain this equation.—34. How do the elements combine as regards volumes?—35. What three points are expressed by equations?—36. What is stoichiometry? Calculate how many pounds of caustic potash can be made from 100 pounds of potassium. How many grammes of potassium are required to make 100 grammes of hydrogen? Explain the calculation.

CHAPTER IV.

CHEMICAL PHILOSOPHY (CONTINUED).

37. **Forces.**—The force which binds unlike molecules together is called *cohesion;* it is this power which gives rigidity to solid bodies, and which, though weaker in fluids, preserves their particles in contact. The attraction exerted between unlike molecules is called *adhesion;* this is the force which makes water adhere to solid bodies, and which you have already studied in Part I. The power which unites atoms within the molecule is called *chemical attraction*, though sometimes spoken of as *affinity.* To illustrate these different forces, we may say that the molecules of a pane of glass are held together by *co*hesion; dip the pane in water, and the water sticks to it by *ad*hesion; while the atoms of silicon, calcium, potassium, and oxygen (of which the molecules of glass are composed) are held together by chemical attraction. Observe that in the attraction of adhesion and of cohesion the particles are merely held together, without producing any change in the nature of the substances which attract each other, however different they may be. But when two substances attract each other chemically, in the union that occurs a change is produced in both. Moreover ordinary attraction operates at all distances, in masses as well as in particles, while chemical attraction operates only when the particles of substances are intimately mingled—as we usually say, in actual contact. Note, also, that chemical attraction has nothing in common with electrical or magnetic force about which you studied in Part I., for the

latter produce no change in the actual constitution of the metals themselves.

38. **Chemical Affinity.**—There is great variety in the range and degrees of chemical attraction. Between some substances there appears to be no disposition to unite under any circumstances: thus no compound of fluorine and oxygen is yet known. We say *yet* known, for such a compound may be discovered to-morrow, as we have no proof of the absolute impossibility of the union taking place. In a general way substances which are alike are not eager to unite; thus the metals form few definite compounds, their alloys being mainly mixtures. Bodies belonging to the same group, and therefore chemically similar, as chlorine, iodine, and bromine, are not very prone to form definite compounds.

The widest range of affinity is possessed by oxygen; it unites with every known element except fluorine, as just stated. Sulphur has a very wide range of attraction, uniting with nearly all the metals, forming an important class of bodies called sulphides. Oxygen and nitrogen show a marked contrast in this respect, the latter having very little tendency to enter into combination, particularly in its free state, as it exists in the atmosphere.

Chemical attraction varies much in its degrees, or power, between different substances. This is seen strikingly in the affinity of oxygen for the various metals. At one end we have the so-called noble metals, gold, platinum, etc., uniting with oxygen only under compulsion; while at the other extreme we have potassium, sodium, etc., so eager to unite with oxygen that they are never found uncombined in nature. Between these two extremes at various points we have iron, zinc, copper, lead, etc. The same variation in the degrees of the attraction of oxygen is shown in relation to other substances besides the metals; we shall learn how this is the case with sulphur, phosphorus, and carbon farther on. Oxygen has a great attraction for hydrogen, and is continually uniting with it, on every hand producing water.

Some substances can be made to unite with each other only under the most extraordinary circumstances. This is the case with oxygen and nitrogen. No degree of heat to which we may subject them together can force them to unite. Lightning does it to a small extent, as it shoots through the atmosphere, forming nitric acid. And the power of this and many other analogous compounds consists, at least for the most part, in the looseness of the affinity which holds their constituents together. They destroy by falling to pieces, their elements uniting with other substances for which they have an affinity. This is the explanation of the action of all caustics—they do not eat and themselves remain whole, but they are decomposed in the destruction which they cause. So, too, the efficacy of gunpowder depends upon looseness of affinity in the nitre, and the consequent readiness with which it furnishes one of its elements, oxygen.

39. **Providence Seen in Affinity.**—The various degrees of affinity between different substances are adjusted by the Creator, as all other forces in nature are, with an obvious reference to the comfort and welfare of man. Take, for example, the different degrees of affinity which oxygen has for hydrogen and nitrogen. With hydrogen it is uniting every where and continually to form water. This is done, as you will see, in all ordinary combustion. Now if oxygen united with nitrogen with the same ease—if the heat of ordinary combustion could cause them to combine, forming nitric anhydride—with the great abundance of these gases in the air the most disastrous effects would result every where. So, also, if sulphur had the same degree of

affinity for oxygen that phosphorus has, the abundance of this substance in the earth would occasion wide-spread conflagrations. Examples illustrating the same truth could be cited to any extent, but these will suffice.

40. **Modifiers of Chemical Attraction.**—The force of chemical attraction varies not only with respect to the different substances between which it is exerted, but it is greatly influenced by certain circumstances independent of the substances themselves. Solution has so much influence upon affinity, or the disposition of substances to act chemically upon each other, that it has given rise to a maxim set down by the older chemists, "*Corpora non agunt nisi sint soluta*"—substances do not act unless dissolved. A familiar illustration of this we have in the mixture of common soda powders. If the powders of tartaric acid and sodium carbonate be mingled dry, there will be no action; but if each be dissolved before they are mixed, the action will be immediate, producing a brisk effervescence. There are two reasons for this: First, the particles are brought nearer together in solution than they can be mixed in powder, however finely they may be pulverized; and, secondly, they are free to move about among each other. Water, aside from the chemical actions which itself produces, exerts a very great agency as a solvent in the chemical changes ever going on in all parts of the earth; and not only so, but it acts as a distributor, often bringing substances together which otherwise could never have come within the range of each other's chemical action.

41. **Influence of Heat.**—Alteration of temperature is another of the causes which modify the attractive force exerted between atoms. Both composition and decomposition are effected by the influence of heat. How this can be we will explain. Heat expands all bodies, or, in other words, spreads the molecules farther apart; but, as you

have already learned, it is necessary that the particles of different substances should be in immediate contact, or exceedingly near to each other, in order that they may exert their combining power. Now if any substance is heated so hot that the atoms of which it is composed are separated so widely that they pass beyond the range of their attraction, and new molecules form by a re-arrangement of the atoms, the body is said to be decomposed by heat.

42. **Influence of the Nascent State.**—When the molecules of a body are acted upon by any force which separates its constituent atoms, the latter momentarily possess unusual attractive force, and are said to be in the *nascent state*, or just born. The reason that a gas is so active in its nascent state is supposed to be that at the very instant of its production from some solid or liquid it is for that instant in a highly concentrated state, not yet having expanded to the dimensions which it has in the gaseous state. Many gases which will not show any affinity for each other under ordinary circumstances, if at the instant of their production, the moment of their birth, they are in immediate neighborhood of each other, unite at once. The particles of the two gases thus produced are, in their momentary concentrated state, so pressed in among each other that they must unite if they have any affinity at all. When they are expanded there is none of this pressure to bring the particles within the range of their attraction—in other words, they are removed too far apart to exert a chemical attraction upon each other. This being so, perhaps some one might think that if a mixture be made of two gases, and great pressure in some way be exerted upon it, these gases could be made to unite as they would do in their nascent state. But the difficulty would be that no artificial pressure can bring them into so concentrated a state as they are in at the moment that they are produced in some fluid or solid. The state of condensation in which gases are, as forming a part of solids or fluids, is far beyond any thing which mere pressure can produce. There are twenty-seven gallons of oxygen in a single pound of iron rust. Is there any pressure which man can produce in any way that can condense such a body of gas into so small a space?

43. **Catalysis—Dissociation.**—There are other circumstances which influence chemical attraction, among which should be mentioned what is termed *catalysis.* This word is derived from two Greek words, viz., *kata* "down," and *luein,* "to loosen," and is applied to the peculiar power ex-

erted by some substances which assist chemical action without themselves undergoing any chemical change. *Dissociation* is another term applied to a special kind of chemical change effected by heat alone. But a full discussion of these points is here out of place.

44. **Atomicity.**—After you have become familiar with the multitude of compounds formed by the union of the elementary bodies, it will appear that there is a large class of elements which invariably combine with each other in the proportion of one atom to one atom. Hydrogen, chlorine, bromine, iodine, sodium, potassium, and silver belong to this class; there are such bodies, for example, as HCl, AgI, KBr, NaCl, etc., in which the elements are combined in the simple ratio of one to one. Moreover, chemists are not able to make any such bodies as H_2Cl, or HCl_2, or $NaCl_2$, or K_2Br_3; hence it is supposed that this class of bodies are *monatomic*, and are said to possess only *one bond of affinity.*

There is a second class of elements which are prone to unite with *two* of these *monatomic* elements, and are hence called *diatomic*, and are said to have *two bonds* or *units of affinity.* Oxygen, sulphur, calcium, etc., belong to this class; thus water contains *two* atoms of H to *one* of O, and is written, as you know, H_2O. We have other examples in the following bodies, $CaCl_2$, H_2S, K_2O, Na_2O. These *diatomic* elements may also unite with two dissimilar *monatomic* elements, giving rise to such bodies as KHO, NaHS, etc.; in this case, however, hydrogen is generally one of the monatomic elements.

Besides these monatomic and diatomic elements, there are several other classes—the tri-, tetr-, pent-, and hex-atomic—which combine respectively with three, four, five, and six monatomic elements. A triatomic element may unite with one monatomic element and one diatomic; a tetratomic element may combine with two diatomic elements, or with one triatomic and one monatomic element, etc. This combining capacity, or *atom-fixing power*, is generally believed to point to a real difference of chemical power; it has nothing to do with the atomic weights, nor with the combination by volume.

This idea of atomicity is represented in symbols by a very simple method; a single stroke attached to the symbol, thus H' or $H-$, signifies that the element named has only one *bond of affinity*, or is monatomic. Two strokes connected with a symbol, thus O'', or $-O-$, or $O=$, represent a diatomic element; three, N''' or $\overset{\diagdown\;\diagup}{\underset{|}{N}}$, a triatomic; four, C^{iv} or $-\overset{|}{\underset{|}{C}}-$, a tetratomic, etc. You may, if you please, regard these strokes as so many arms stretched out to grasp some other element. Water is often represented thus, H–O–H, which is the same thing as H_2O, only it shows the relative *atomicity* of its constituent elements. The *atom-fixing power* of the elements is not a fixed quantity for each element; nitrogen, for instance, may be pentatomic or triatomic; sulphur may be hexatomic, tetratomic, or even diatomic, according to circumstances; the maximum is generally taken as the true atomicity of the element. This variation is ingeniously accounted for by supposing that in the lower powers the bonds are neutralized by self-saturation, or by combining with themselves; thus, if in pentatomic nitrogen, , two of the bonds unite, it may become triatomic,  The bonds are said to be *saturated* when joined to themselves or to the bonds of some other element.

It scarcely ever happens that an element possessing an *even* atomicity can assume an odd atomicity, nor can the reverse take place, consequently the elements are divided into two great classes—those of *even* atomicity, called *artiads*, and those of *odd* atomicity, called *perissads*. The following table embraces all the commonly occurring elements which are thus grouped. The symbols only are given, in order to familiarize you with them. This whole subject of atomicity is a theory which is as yet only in its infancy, and is so replete with exceptions to the rule that the longer it is studied the more unsatisfactory it becomes. We have only sketched its fundamental principles, and we do not propose to apply them in the body of this work, notwithstanding they have been of great advantage to the progress of theoretical chemistry.

In the following table the monatomic elements are called *monads;* the triatomic, *triads;* the diatomic, *dyads*, etc., in accordance with custom.

TABLE OF ATOMICITY.

PERISSADS.			ARTIADS.		
Monads.	Triads.	Pentads.	Dyads.	Tetrads.	Hexads.
H	Bo	N	O	C	Cr
Fl	Au	P	S	Si	Mn
Cl		As	Ca	Sn	Fe
Br		Sb	Sr	Al	Ni
I		Bi	Ba	Pt	Co
Li			Mg	Pb	
Na			Zn		
K			Cd		
Ag			Cu		
			Hg		

QUESTIONS.

37. Explain the difference between cohesion and adhesion. What is chemical attraction? Illustrate these forces.—38. What is said about the variety of chemical attractions? What element has the widest range of affinity? What about the compounds of oxygen with the metals? Under what circumstances do oxygen and nitrogen combine?—39. What advantages result to mankind from the various degrees of affinity?—40. How does solution affect chemical attraction? Give an example. How does water act on the earth?—41. How does heat modify the attractive force? —42. What is meant by the nascent state? Why are gases active in this condition?—43. Name two other circumstances which influence chemical attraction.—44. What are monatomic bodies? Give examples of compounds of monatomic elements. What other classes are named? How do these mono-, di-, tri-, and tetr-atomic elements combine? How is atomicity expressed in symbols? What is said of the variableness of this atom-fixing power? Explain the division into artiads and perissads. What is the atomicity of oxygen? what of phosphorus? what of hydrogen?

CHAPTER V.

OXYGEN AND OZONE.

45. **Composition of the Air.**—The air is composed chiefly of two ingredients, oxygen and nitrogen, which are elementary substances, gaseous in form. These are not united *chemically* in the air, but are only mingled together. The atmosphere is a mere mixture of gases, just as alcohol and water form a fluid mixture. We will now study oxygen at some length, and then take up nitrogen in the next chapter.

46. **Abundance and Importance of Oxygen.**—Oxygen is the most abundant of all substances. It forms nearly one half the whole bulk of material substances in our earth. It constitutes by weight nearly one fourth of the atmosphere, eight ninths of the waters of the earth, and about

one third of the earth's solid mass. It is one of the chief components, also, of all vegetable and animal substances. It enters into more combinations with other substances than any other element. There is but one element with which it does not combine. This is not true of any other of the sixty-four elements. Oxygen, therefore, may be said to be the most important substance in nature. This will be still more apparent when we come to consider its agency in the chemical operations every where going on, especially in those of living substances.

47. **One Way of Obtaining Oxygen.**—Oxygen can be readily obtained from many substances which have a great deal of it in them. The red oxide of mercury, formerly called red precipitate, is one of these. This is mercury united with considerable oxygen; its formula is HgO. By heating this oxide the oxygen can be made to leave the mercury. One way in which this can be done is shown in Fig. 3. We have here a glass vessel full of mercury, containing the mercuric acid at the top, standing in the mercury in the dish, B. The heat applied is that of the sun's rays concentrated by a burning-glass, C. The result is the decomposition of the red substance, the oxygen of which accumulates in the upper part of the glass vessel, pushing the mercury down before it.

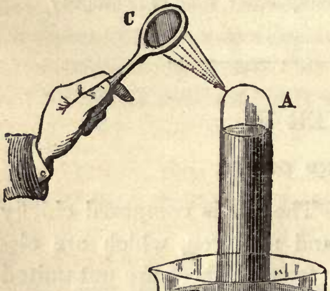


Fig. 3.

Expressed in symbols, the decomposition is very simple:

Mercuric Oxide.	Mercury.	Oxygen.
HgO	Hg	O

48. **Discovery of Oxygen.**—The above was the original ex-

periment by which Dr. Priestley, an English chemist, made the discovery of this gas a little more than a hundred years ago, on the 1st of August, 1774. It was discovered also by Scheele, a Swedish chemist, shortly after, he not having heard of the discovery by Priestley. The gas was called by Priestley *dephlogisticated* air, for reasons which we will explain to you. Very crude and fanciful notions prevailed at that time, and among others that of Stahl, a German chemist, who maintained that all combustible substances burn in consequence of an element in them which he called *phlogiston*. Now as this gas, while it makes other things burn brightly, does not burn itself, Priestley considered it as destitute of phlogiston, or dephlogisticated. Some years after, the investigation of the qualities of this gas having in the mean time been diligently prosecuted, Lavoisier, a French chemist, gave it the name which it has retained to this day, and which it probably always will retain—viz., oxygen. It is derived from two Greek words, *oxus*, acid, and *gennao*, I give rise to. His idea was that this gas is a component of all acids. This has since been found not to be true; but the name is nevertheless retained.

49. **Another Mode of Obtaining Oxygen.**—A more easy and convenient way of obtaining oxygen from oxide of mercury than that described in § 47 is represented in Fig. 4 (p. 52). Here the oxide is put into a retort, *a*, where it is heated by the flame of a spirit-lamp. You see also a receiver, *b*, from which a bent tube, *c*, passes under the water in the pneumatic trough, *g*, where its end is directly under the open mouth of a glass jar. The heat of the lamp decomposes the oxide, so that in place of this compound substance we have two elements, mercury and oxygen. But the mercury, as it separates from the oxygen, is, on account of the heat, in the form of vapor, and therefore passes on with the oxygen gas through the tube of the retort. By

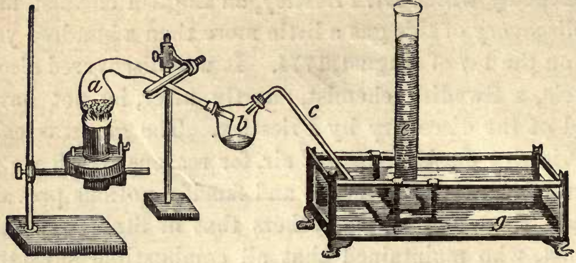


Fig. 4.

the time, however, that it arrives at the end of the tube it is so far cooled as to become liquid, and drops into the receiver, *b*. But the gas moves on through the tube, *c*, and goes up the glass jar, forcing the water in it down as fast as it collects.

50. **Difference between Gases and Vapors.**—You see in the above process what the difference is between a gas and a vapor. The mercury rises in vapor with the oxygen gas, and both are invisible as they pass mingled together through the tube of the retort. This is because the particles of the mercury are so much separated from each other by the action of heat, just as it is with water when it is converted into steam. But these particles are condensed or brought near together again, and appear in the liquid form in the receiver, *b*. Meanwhile the gas, though cooled equally with the mercury, retains its gaseous form, and passes on. You see that the vapor has its gaseous form dependent upon a certain range of temperature, but the gas retains it under all temperatures. No degree of cold (that is, diminution of heat) can condense the gas into a liquid form. The form of the gas, then, is not accidental and temporary, but *permanent*. The range of temperature in which vaporization can take place is different in different substances. Water can evaporate at all temperatures, while

mercury will not evaporate under 40°. The space above the mercury in a barometer or a thermometer is spoken of as a vacuum; but it is not strictly so, for there is some little of the vapor of mercury diffused through that space.

While it is proper, then, to speak of substances appearing, under certain circumstances, in the form of vapor as being gaseous or aeriform, they can not properly be called gases. This name belongs only to those substances which maintain this state under all circumstances; or perhaps we should say under all *ordinary* circumstances, for some of the gases under extraordinary circumstances have been made to take on another form, either solid or liquid.

51. **Obtaining Oxygen from Oxide of Manganese.** — The chemist does not now get his oxygen from mercuric oxide, for there are other compound substances that contain more of it, and furnish it more readily and abundantly. One of these is an oxide of a metal called manganese; there are several oxides of this metal containing different proportions of oxygen; the one used for the preparation of oxygen is called the *dioxide*, MnO_2. Manganese dioxide occurs native as a mineral, and when ground fine it is a convenient and cheap source of oxygen; it is not now so much used as formerly, for still better methods have been invented. In obtaining oxygen from it great heat is employed; it must therefore be heated in an iron retort, such as you see in Fig. 5, placed in a furnace. Only one third of the oxygen in the dioxide is driven off, leaving behind the red oxide of manganese. The dioxide is of a dark color, and is commonly called the black oxide.


Fig. 5.

52. **Preparation of Oxygen from Potassium Chlorate.**—The most common way of obtaining this gas is by heating a substance called potassium chlorate. This contains a large quantity of oxygen. In every hundred grammes of it there are thirty-nine grammes of this gas. This is more than four times as much as there is in the mercuric oxide, the substance from which Priestley obtained the oxygen for his experiments. Over a gallon and a half of oxygen can be obtained from an ounce of potassium chlorate. There is only a little more of this gas in this substance than in the dioxide of manganese; but the former gives up all its oxygen on being heated, while the latter, as we told you in § 51, gives up but a third part of what it contains. And, besides, the potassium chlorate needs to be heated but little compared with the manganese dioxide to evolve the gas. The heat of a spirit lamp or of a Bunsen burner is sufficient. Fig. 6 shows the method of generating and collecting the gas.

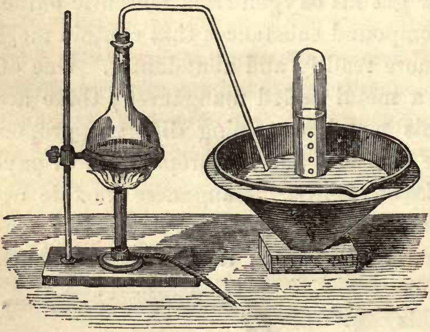


Fig. 6.

53. **Explanation of the Process.**—The potassium chlorate is composed of three elements—the two gases, oxygen and chlorine, and the metal potassium, in the proportion $KClO_3$. The oxygen is driven off by heat, and the chlorine remains united with the potassium, making what we call potassium chloride. Expressed in formulæ thus: $KClO_3$+heat $=KCl+O_3$. Of chlorine and potassium we shall speak particularly hereafter. There is some danger of explosion in obtaining oxygen from potassium chlorate alone, because

large quantities of the gas are apt to be set free suddenly. This danger is prevented by mixing with it an equal weight of manganese dioxide. What is singular is that the dioxide does not part with any of its oxygen, and yet it regulates and renders more easy the separation of the oxygen from the potassium chlorate. Less heat is required than when the chlorate is used alone, and the gas is driven off gradually and yet very readily.

54. **Other Methods of Preparing Oxygen.**—There are many other ways of preparing oxygen gas, and by some of them we obtain it indirectly from the atmosphere. One way in which this is done is (1) by passing air over a heated mixture of manganese dioxide and sodium hydrate, and then (2) heating the materials hotter while a current of steam is passing over them. In the first part of the operation sodium manganate is formed; this gives up its oxygen in the second part of the operation, thus reproducing the original materials, when the process is repeated. This method was invented by a Frenchman named Tessié du Motay, and has been tried on a very large scale.

Oxygen can also be prepared by decomposing sulphuric acid, by heating barium dioxide, and in other ways of less value. Oxygen gas is now a commercial article in great cities, being manufactured for use in the arts.

55. **Properties of Oxygen.**—Oxygen gas is heavier than that mixture of oxygen and other gases which we call air. If we take 1 as representing air, oxygen would be represented by 1.106. This is said to be the *specific gravity* of oxygen, air being the standard in reckoning the weight of all the different gases. Oxygen is, like the air, transparent, and without color, odor, or taste.

56. **Oxygen a Supporter of Combustion.**—It is this ingredient of the atmosphere which, to use common language, ordinarily makes things burn. If any thing that is burning

be introduced into a jar filled with oxygen, it will burn much more briskly and brilliantly than in the air. For the same reason, if a candle or taper be blown out, it will at once be rekindled if put into a jar of oxygen, though there be only a slight spark on the wick. This may be done many times in the same jar of oxygen. After a while this effect will not be produced, because the oxygen is used up; for every time the candle is introduced some of the oxygen unites with the wick and the tallow. It is this union that produces the phenomenon which we call combustion. A very convenient way of introducing a taper or a candle into jars filled with gas is represented in Fig. 7.

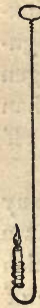


Fig. 7.

57. **Charcoal Burned in Oxygen.**—If a piece of charcoal be ignited in the air, it will exhibit only a dull red color; but the moment that it is introduced into oxygen gas it burns brilliantly, casting off sparks with great rapidity, as seen in Fig. 8. Charcoal made from bark is better for this experiment than that made from wood. In this case, as in that mentioned in § 56, the oxygen is used up by uniting with the burning substance. In doing this it forms with the charcoal or carbon carbonic anhydride, a gas which we shall speak of particularly in the next chapter. This union is very simple: $C+O_2=CO_2$.


Fig. 8.

58. **Phosphorus Burned in Oxygen.**—One of the most splendid experiments with oxygen is the burning of phosphorus in it. On introducing the ignited phosphorus into a vessel filled with oxygen, Fig. 9, thick white fumes arise, illuminated by a most intense brightness. In the combustion here the oxygen unites with the phosphorus to form phosphoric anhydride, the particles of which make the fumes that you see. In this case we have $P_2+O_5=P_2O_5$.


Fig. 9.

59. **Combustion of Steel in Oxygen.**—Some things which will not burn at all in common air will do so in oxygen gas. This is the case with even so hard a substance as steel. Take an iron wire, or, better, a steel watch-spring, which you can get at any jeweler's, melt a little sulphur and drop it on one end of the spring, ignite the sulphur, and introduce it into the oxygen in the manner represented in Fig. 10. The combustion will at once be communicated to the wire, and it will go on, throwing off sparks of intense brightness till most of the oxygen is united with the iron. The experiment will be very brilliant if the steel spring be coiled. The result of the combustion in this case is a solid, for the oxygen unites with the iron to form an oxide of iron. The sparks which fly from the red-hot iron struck by the blacksmith's hammer are the same, being formed by the union of the oxygen of the air with some of the iron. But there is this difference: The sparks emitted from the iron in the oxygen are much hotter, because the combustion is more brisk and perfect. Some of the iron falls in small burning globules, which are so intensely hot as to be imbedded in the glass, or they may even go through it if it be thin. We have spoken of iron as not burning at all in air. This is not strictly true, for every time that we strike fire with a steel and flint, or with the heel of the shoe upon the sidewalk, we set fire to a particle of steel. It is not only an exceedingly little fire, but it is also momentary. It would be continuous if the air were all oxygen, and the shoes on our feet would be constantly taking fire from this cause.

Fig. 10.

60. **Oxygen Essential to Life.**—As ordinary combustion can not go on without oxygen, so also is its presence essential to the continuance of life. It is the oxygen of the air that supports life in all breathing animals, and no other gas

can take its place in that respect. Cut off the supply of oxygen to our lungs for only a minute or two, and life is extinct. When death occurs by drowning, it is because oxygen is shut out from the lungs.

61. **Oxides.**—Among the most common chemical combinations are the oxides of metals. Most metals have such an affinity for oxygen that they readily unite with it and form oxides, some much more readily than others. Exposed to the air, they tarnish, that is, unite with oxygen. Gold, silver, mercury, and platinum do not oxidize in this way, and therefore are called the noble metals. Gold and platinum are so reluctant, as we may express it, to be united with oxygen, that when the chemist by certain processes forces them to a union with it, they very easily part with the oxygen and return to their metallic state. Such oxides are said to be *unstable* compounds. On the other hand, there are some metals which have so strong an affinity for oxygen that they are never found native, and can only be obtained by separating them from the oxygen with which they are combined. Such are the metals of which lime, potash, and soda are oxides.

62. **Different Degrees of Oxidation.**—While some of the metals have but a single oxide, most of them have two or more, made by having different amounts of oxygen united with the metal. Thus while there is but one oxide of zinc, lead has three, mercury two, copper three, etc. If there be two or more oxides of a metal, they are named thus: Monoxide, dioxide, trioxide, etc., the prefixes being derived from Greek words meaning one, two, three, etc. Thus the dioxide has twice as much oxygen as the monoxide, the trioxide three times as much, and so on, the relative amount of the metal being the same in all cases.

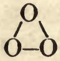
In some cases another system of nomenclature is employed, as mentioned in § 18. Thus we have nitrous oxide, nitric oxide, and nitric peroxide, according to the proportion of oxygen in them, as you will learn in the next chapter. A *peroxide* is an oxide having the highest amount of oxygen, or at least a higher amount than the *nitric* oxide in the series named. In the case of the compounds of oxygen with the metals, sometimes an oxide is discovered containing less oxygen than the monoxide, and this is called a *suboxide*, the prefix *sub* being the Latin for *under.* Some metals form compounds having one and a half times as much oxygen as the monoxide; or, what is the same thing, since we can have no half atoms, these compounds contain two atoms of metal to three of oxygen; they are then called *sesquioxides*, the prefix *sesqui* being the Latin for one and a half. Iron gives us an example of this, forming Fe_2O_3, which you see is a sesquioxide.

63. **Ozone.**—This is oxygen gas in a peculiar condition, distinguished from common oxygen by its pungent smell and its very active chemical properties. You may perceive the peculiar smell when an electrical machine is in action, owing to the partial conversion of the oxygen of the air into ozone. The easiest way of effecting this change is by means of phosphorus. Place a clean stick of phosphorus in a corked flask having a little water in the bottom, and let the flask stand half an hour. Remove the phosphorus with a pair of pincers, and notice the peculiar odor of the gas in the flask. The phosphorus very slowly oxidizes and induces the formation of a little ozone. Pure ozone has never been made—it is always mixed with much oxygen. Ozone when breathed irritates the lungs, and corrodes organic matter. It immediately oxidizes metals which ordinarily unite with oxygen at high temperatures only.

64. **Experiment.**—Boil as much starch as will cover the point of a penknife with about fifty cubic centimeters of

water, and add a very little potassium iodide. Now steep some slips of paper in the mucilage thus prepared, and you have a *test-paper* for ozone. Place a strip of this paper in the flask containing ozone prepared by phosphorus, and it will soon turn blue, owing to the action of the ozone. The explanation is this: Ozone first decomposes the potassium iodide, setting iodine free; now free iodine forms a blue substance with starch, called iodide of starch, and hence the color produced. Ordinary oxygen will not act thus. Traces of ozone are found in the atmosphere, particularly in the country, and it is tested for with this same iodine-starch paper.

Ozone has strong bleaching properties, and advantage has been taken of this to bleach sugar on a large scale, the ozone being formed by electricity.

65. **Nature of Ozone.**—Exactly how phosphorus or electricity act in converting oxygen into ozone is not understood by chemists. But it has apparently to do with the question of the arrangement of atoms, for the mere arrangement of atoms in the molecule of a substance has much to do with the production of the various qualities presented by different substances. Thus in oxygen we have two atoms in one molecule, arranged thus, O=O, the two lines indicating the supposed points of union; but in ozone we have three atoms of oxygen to a molecule, and arranged thus,  You will meet with other cases of *allotropism*, as this is called, where a fuller explanation will be attempted.

QUESTIONS.

45. Of what does air consist?—46. What is the most abundant of elements?—47. Describe one way of obtaining oxygen. Write the equation and explain its significance.—48. What makes this method of making ox-

ygen of interest?—49. Describe a more convenient way of obtaining oxygen from the same material.—50. How do gases and vapors differ? What is a permanent gas?—51. How is oxygen prepared from manganese dioxide?—52. How from potassium chlorate?—53. Explain the process. Why is there danger of explosion? How is explosion avoided? Write and explain the equation.—54. Name two other methods of making oxygen. Who invented a commercial process?—55. What are the properties of oxygen?—56. What is said of oxygen as a supporter of combustion?—57. What of burning charcoal in it? What becomes of the oxygen in this case?—58. What forms when phosphorus burns in oxygen?—59. How may steel be burned in oxygen? What is striking fire?—60. Why is oxygen essential to life?—61. What are oxides? Mention an unstable oxide.—62. What is said of metals uniting with oxygen in different ratios? What is a peroxide? What a suboxide? What a sesquioxide?—63. How may ozone be prepared?—64. How does ozone act on potassium-iodide-starch paper?—65. What are the properties of ozone? What is said of its nature?

CHAPTER VI.

NITROGEN AND ITS OXIDES.

66. **Abundance of Nitrogen and its Combinations.**—Nitrogen gas forms about four fifths of the atmosphere. It is one of the elements in all animal substances, constituting about one fifth of the flesh of animals when dried—that is, when freed from the water that is in it. It enters also into the composition of many of the vegetable substances that are designed for food for animals. It forms some important substances by uniting with oxygen and other elements, as nitric acid, ammonia, etc. It does not enter into any thing like the number of combinations that oxygen does. For example, while oxygen makes with the metals a multitude of substances called oxides, there are very few compounds of the metals with nitrogen.

66 *a*. **How Nitrogen can be Obtained.**—Nitrogen gas can

be readily obtained from common air in the mode represented in Fig. 11. Let a cork, with a cup-shaped piece of chalk on it for the reception of a bit of phosphorus, float in a pneumatic trough, *d*. After igniting the phosphorus, hold over it a glass jar, *a*, keeping the edge of its mouth immersed in the water. After a little time there is nothing in the jar but nitrogen gas nearly pure. The explanation is this: As the phosphorus burns, it unites with the oxygen of the air in the jar, thus making phosphoric anhydride, as phosphorus burned in pure oxygen does (§ 58). This rises in fumes, and is mingled with the nitrogen. We have then nitrogen and phosphoric anhydride in the jar. How do we get the nitrogen separate? Wait a little, and the fumes disappear, for the phosphoric anhydride dissolves readily in the water in the pneumatic trough, leaving the nitrogen alone in the jar. The nitrogen occupies less space by one fifth than the air in the jar did, for the oxygen that has disappeared was one-fifth part of the air. The cork, therefore, rises somewhat in the jar during the process, being pushed up by the water to take the place of the oxygen. The water now contains phosphoric acid.

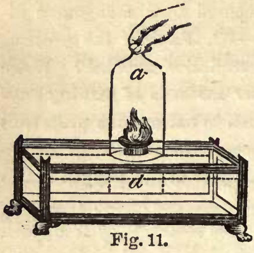


Fig. 11.

67. Properties of Nitrogen.—Nitrogen is lighter than air, its specific gravity being .972. Like oxygen, it is transparent, without color, taste, or smell. But it is very different from oxygen in some of its properties. Nothing will burn in it. The contrast between the two gases in this respect can be very prettily shown if you have two jars filled with them. If you let a lighted taper down into the jar of nitrogen, it will go out. If now you introduce it quickly into the jar of oxygen, it will light up again and burn brilliantly; and you can pass it back and forth from one jar to the other many times, producing the same results. The brilliancy of the lighting-up will diminish each time, because the combustion of the taper uses up the oxygen.

68. **Nitrogen in Respiration.**—As nitrogen can not support combustion, so it can not support life. If we put an animal—a mouse, for example—into a jar of nitrogen, it will die speedily. But nitrogen does not act as a poison. The air which animals take into their lungs is four fifths nitrogen, but it does them no harm. The reason that animals can not live in nitrogen alone is simply that they can not live without having some oxygen in the air which they breathe. Because this gas can not support life it is sometimes called *azote*, from two Greek words—*a*, privative, and *zoe*, life.

69. **Compounds of Nitrogen with Oxygen.**—Nitrogen forms five compounds with oxygen. Those which are of the most interest to us are nitric anhydride, which unites with water to form nitric acid (formerly called aqua fortis, the Latin for strong water), and nitrous oxide, the so-called laughing-gas.

The following table shows us the names and formulæ of these five oxides of nitrogen:

Names.	Formulæ.	Composition.
1. Nitrous oxide (or laughing-gas)……………	N_2O	28 parts N, 16 parts O.
2. Nitric oxide……………	N_2O_2 (or NO)*	28 " " 32 " "
3. Nitrous anhydride………	N_2O_3	28 " " 48 " "
4. Nitric peroxide…………	N_2O_4 (or NO_2)*	28 " " 64 " "
5. Nitric anhydride……….	N_2O_5	28 " " 80 " "

This table illustrates the regularity in proportions which prevails in all chemical combinations, explained in Chapter III.

In order to learn all about these oxides of nitrogen, you

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* For reasons which we can not explain here, the formulæ of these bodies are of necessity halved as indicated.

will understand them best by taking up nitric anhydride first, and then following the others in the order given above.

70. **Nitric Anhydride, N_2O_5.**—This body is a great curiosity even to a chemist; it is difficult to obtain, and hard to keep when prepared; and, since it has no good uses, you do not care to learn much about it. When, however, we have this substance united with water, we get the very important acid known as nitric acid. We will give you the reaction, although nitric acid is never prepared in this manner, as you will presently see:

$$N_2O_5+H_2O=2(HNO_3).$$

One molecule of nitric anhydride unites with one of water, forming two molecules of nitric acid.

71. **Preparation of Nitric Acid.**—Potassium nitrate, commonly called either nitre or saltpetre, and sodium nitrate, are the chief sources of nitric acid; they are natural products, but may also be made artificially, as you will learn hereafter. Nitrate of sodium, heated with sulphuric acid—also called oil of vitriol—gives us nitric acid and sodium sulphate:

Sodium nitrate.		Sulphuric acid.		Sodium sulphate.		Nitric acid.
$2NaNO_3$	$+$	H_2SO_4	$=$	Na_2SO_4	$+$	$2HNO_3$

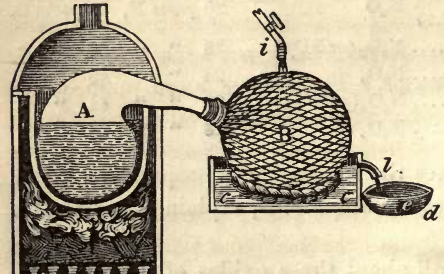

Fig. 12.

The process is represented in Fig. 12. In the retort, A, are the saltpetre and the sulphuric acid. The heat applied serves the double purpose of facilitating the chemical change, and of driving the nitric acid as it is generated over into the receiver, B, in the form of vapor. There it is condensed into the liquid form. To produce this condensation the receiver is kept cool by a stream of water flowing from the pipe, *i*, over its surface, a netting being spread over it to distribute the water evenly. As the water accumulates in the vessel, *c c*, in which the receiver rests, the waste runs off by the pipe, *l*.

72. **Properties of Nitric Acid.**—This is a nearly colorless fluid, intensely acid, and very corrosive. It stains the skin yellow the moment that it touches it, and if it continue to be applied, it eats the skin, as it is commonly expressed, or, in chemical language, decomposes it. It also attacks and dissolves most metals. These active properties result from the quantity of oxygen in nitric acid, and the readiness with which it parts with a portion of it. What we call the strength, then, of this substance is really its weakness—that is, the weakness with which it holds on to one of its ingredients. If it held on to its oxygen strongly, instead of parting with a portion of it readily, it would not produce such powerful effects upon other substances. We will proceed to illustrate this explanation of its power by its action on metals, and on certain combustible substances.

73. **Action of Nitric Acid on Metals.**—If you put a bit of copper (a copper cent will answer) in a saucer, and pour upon it some nitric acid, it will at once begin to dissolve the copper. But you do not really get a mere solution, as salt is dissolved in water. The copper acted upon by the nitric acid is no longer copper. It is chemically changed. What the change is we will explain. The acid immediately in contact with the copper lets go a portion of its oxygen, which unites at once with the copper, forming an oxide of copper. The acid that does this is of course no longer nitric acid, for it has lost a portion of one of its ingredients. It becomes nitric oxide, and passes off in fumes. Observe now what becomes of the oxide of copper that is formed. This

does not remain an oxide. It is immediately laid hold of by some of the acid, and they together make a substance called nitrate of copper and water. And so the process goes on, some of the particles of nitric acid constantly giving oxygen to the copper, and other particles as constantly seizing upon the oxide of copper thus formed, till the copper is all changed to nitrate of copper. This lengthy explanation is conveniently abridged in the following equations:

Copper.		Nitric acid.		Oxide of copper.		Nitric oxide.		Water.
$3Cu$	$+$	$2HNO_3$	$=$	$3CuO$	$+$	$2NO$	$+$	H_2O

Oxide of copper.		Nitric acid.		Nitrate of copper.		Water.
$3CuO$	$+$	$6HNO_3$	$=$	$3(Cu(NO_3)_2)$	$+$	$3H_2O$

The hydrogen of the acid takes to itself oxygen and forms water in each case. It is this action of nitric acid upon the oxides of metals which makes it so useful in cleansing the surface of instruments or vessels made of metals, as brass and copper, when they have become oxidized from exposure or any other cause. The acid dissolves the oxide, forming a salt with it, and thus makes the surface bright.

74. **Exceptions.**—Most of the metals are acted upon in the same way by nitric acid. The action upon tin and antimony is different from that which we have described in the case of copper. Only one step of the process is taken with these metals. The nitric acid merely parts with a portion of its oxygen, and forms oxides of these metals. No solution is made, but we have the oxides in the form of a white powder. Gold and platinum are not acted upon at all by this acid. The reason is that they are not oxidizable, and so the acid keeps all its oxygen to itself.

75. **Nitrates.**—These bodies are formed either by direct union of nitric acid with the oxides or by the action of the

acid upon the metals themselves. In the latter case the acid in immediate contact with the metal gives some of its oxygen to the metal forming an oxide, and the moment that this is done another portion of the acid seizes this oxide, forming with it the nitrate; and this double process goes on continually until the action stops. You see, then, that a part of the acid is decomposed in order to provide an oxide to unite with the other part. In this decomposition, the acid losing a portion of its oxygen, fumes of nitric oxide pass off.

We will study the nitrates of the metals in connection with the metals themselves.

76. **Combustion by Nitric Acid.**—As this acid so readily parts with some of its oxygen, it can set fire to certain substances on being applied to them. If you heat some powdered charcoal, on pouring nitric acid upon it combustion will at once take place. The cause is the rapid union of the charcoal with the oxygen, which it takes from the nitric acid. The reason that it is necessary to heat the charcoal is that the union would not be sufficiently rapid to produce a fire without the aid of heat. So, too, if you pour some of the acid upon warmed oil of turpentine, the oxygen which the turpentine takes from the acid sets it all ablaze. Some caution is required in trying this experiment. The test-tube containing the acid should be fastened to the end of a stick a yard long, so that the experimenter may be at some distance from the turpentine as he pours the acid upon it. Phosphorus, if thrown upon some nitric acid in a plate, will be set on fire, as seen in Fig. 13. The bits of phosphorus must be very small, or some harm will be done by the violence of the combustion. If the acid be rather weak, as that which is bought at the shops often


Fig. 13.

is, it may be necessary in this experiment to heat it before dropping the phosphorus upon it. In all these cases oxides of the bodies named are formed.

77. **Nitric Acid in the Atmosphere.**—Nitric acid can not be made by mixing together its ingredients, oxygen, hydrogen, and nitrogen. No degree of heat, however severe, will make them unite to form the acid. Accordingly they exist together in the air without uniting, except under extraordinary circumstances. If they could be made to unite readily, producing every now and then nitric acid in considerable amounts, the most destructive effects would result from the corrosive acid as it descended in showers upon the earth. As it is, there is only one agent that can cause them thus to unite, and that is electricity. Even this does it, as we may say, with difficulty. It is only when this agent acts with violence that the effect is produced. Nitric acid is, therefore, generated in the air only in small quantity, and it is carried down by the rain into the earth, where it answers a valuable purpose in vegetation, as you will see in another part of this book. Its formation then, small as the quantity is, is not a mere accident, but a provision of Providence for a special purpose of a marked character.

78. **Acids.**—Nitric acid being the first acid you have studied, we can now tell you about the class of bodies called acids. But first make a simple experiment. Purple cabbage, certain lichens, and other vegetables, when boiled with water, furnish blue infusions. Paper steeped in this strong blue solution, and dried, gives us a test-paper for acids which is very useful. The substance usually employed is called *litmus*, and the paper, prepared as above, *litmus paper*. Now this blue coloring matter is turned red by the action of even a very small quantity of acid. Dip some litmus paper in a very weak solution of acetic, sul-

phuric, nitric, or any other acid, and you find the blue paper will turn red. This is a characteristic property of acids. Another and important distinction is this: all acids contain *hydrogen*. *Nitric anhydride*, which has just been mentioned, contains no hydrogen, as its very name indicates; when, however, it comes in contact with water, a new body is formed containing hydrogen, and this is nitric acid. The hydrogen in acids may be replaced, as it is termed, by metals forming new bodies called salts, as you will further learn in § 80. All the non-metallic elements, except hydrogen and fluorine, unite with oxygen, forming *anhydrides*, which, dissolved in water, yield acids.

79. **Names given to Acids.**—Just as we have *ous* and *ic* compounds of oxygen, so we have *ous* and *ic* acids named in like manner from the proportion of oxygen in them (see § 62). Thus *nitric* anhydride gives us *nitric* acid, while *nitrous* anhydride gives us *nitrous* acid. The compounds of sulphur and oxygen are similar; *sulphurous* anhydride yields *sulphurous* acid, and *sulphuric* anhydride yields *sulphuric* acid. The prefix *hypo* is used to name certain acids having less oxygen than the *ic* or *ous* acid—as *hypophosphorus* acid.

When the acids combine with the metals with elimination of hydrogen, we have bodies whose names correspond in a certain way to the acids whence they are derived. The rule is as follows: Compounds of acids ending in *ic* are indicated by names ending in *ate*, and compounds of acids ending in *ous* are distinguished by names terminating in *ite*. More concisely stated: *ic* acids form *ates*, *ous* acids form *ites*. Examples are abundant: nitr*ic* acid forms nitr*ates*, nitr*ous* acid forms nitr*ites;* chlor*ic* acid forms chlor*ates*, chlor*ous* acid forms chlor*ites*. The termination *ite* must never be confounded with the ending *ide*, as sulphide, chloride, etc.; these bodies contain no oxygen.

Acids containing one atom of hydrogen are said to be *mono-basic;* when they contain two or three atoms of hydrogen, they are called *di-basic* or *tri-basic.* Thus nitric acid, HNO_3, is *mono-basic*, and sulphuric acid, H_2SO_4, is *di-basic.*

80. **Bases and Salts.**—You have seen that blue litmus is turned red by acids; now there is another class of bodies which turns reddened litmus to blue again. These bodies, chemically opposed to the acids, are called bases. They are either oxides or hydrates of the metals. Thus sodium oxide, Na_2O, and potassium hydrate, KHO, and calcium hydrate, CaH_2O_2, are bases. The soluble hydrates are called alkalies, and possess strong caustic properties. Now when the hydrogen of an acid is exchanged for a metal, or when the acids act upon these bases, a third class of bodies is produced, called salts. Thus the hydrogen in nitric acid may be replaced by silver, forming silver nitrate, which is a salt. When the hydrates or the oxides are acted upon by acids, water is formed at the same time with the salts, as shown in the two examples below:

Potassium hydrate, *A base.*		Nitric *Acid.*		Potassium nitrate, *A salt.*		Water.
KHO	+	HNO_3	=	KNO_3	+	H_2O

Calcium oxide, *A base.*		Nitric *Acid.*		Calcium nitrate, *A salt.*		Water.
CaO	+	$2HNO_3$	=	$Ca(NO_3)_2$	+	H_2O

Having in the second example taken a *dyad* metal and an acid containing only one atom of hydrogen, two molecules of the acid are necessary to complete the equation and form the salt.

When an acid acts upon a base to form a salt, a remarkable change in the properties of both the acid and the base takes place; the acid loses its corrosive, acid properties, and the base loses its alkaline and caustic nature, the resulting body being *neutral.* Neither reddened nor blue litmus are affected by *neutral* salts.

Some acids contain two or more atoms of hydrogen, which may be replaced successively by a metal; if only one atom of hydrogen is thus exchanged, an *acid salt* is formed; if both atoms of hydrogen are exchanged for two atoms of a monad or one atom of a *dyad* metal (see § 44), a neutral salt results. You will observe this in the study of sulphuric acid.

81. **Nitrous Oxide, or Laughing-Gas.**—This gas is the compound of oxygen and nitrogen, which has the smallest proportion of oxygen. It is obtained by heating ammonium nitrate in a retort or flask, *a*. Complete decomposition ensues; the gas is washed in the flask, *b*, and collected in the receiver, *c*. We obtain two substances entirely different from each other and from the substance from which they come, viz., water and the nitrous oxide gas:

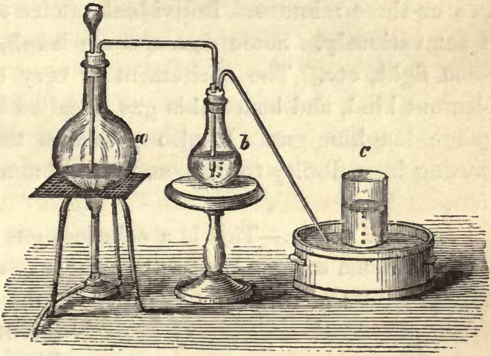

Fig. 14.

Ammonium nitrate.		Nitrous oxide.		Water.
NH_4NO_3	$=$	N_2O	$+$	$2H_2O$

The vapor of the water and the gas pass together into the second flask; but there the vapor is condensed into water, and the gas bubbles up into the glass jar set in the trough to receive it. Some caution is necessary in preparing this gas, or it may be impure, and therefore injurious to those who may inhale it. To avoid this the material must be pure, the heat must not be so great as to cause fumes to rise in the retort, and the gas should be passed through solutions of potassium hydrate and ferrous sulphate before collecting it in a receiver.

82. **Properties of Laughing-Gas.**—The nitrous oxide gas is as colorless and transparent as air, and has a sweetish taste. A lighted taper burns almost as brightly in it as in oxygen, and if there be but a spark on the wick, on introducing it into a jar of this gas it lights up instantly. When breathed, it occasions no irritation in the lungs, but produces a singular excitement, a delicious intoxication, which lasts but two or three minutes. Individuals under the influence of it act variously. Some dance, some laugh, some declaim, some fight, etc. The excitement is very commonly of a pleasant kind, and hence this gas is called in common language laughing-gas. It also possesses the property of causing insensibility to pain, and is now much used by dentists.

83. **Nitric Oxide.**—This is a colorless gas which has just twice as much oxygen in it as the nitr*ous* oxide. It can be obtained from nitric acid and copper in the apparatus represented in Fig. 15. Bits of copper and nitric acid, somewhat diluted, are introduced into a flask. The gas passes out through the tube, and may be collected in the usual way in jars in the pneumatic cistern. The first gas that passes over will be orange-colored, and we must not begin to collect till the gas is colorless. The object of

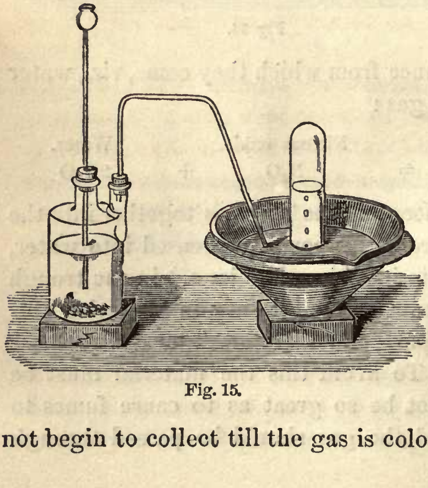

Fig. 15.

the funnel is to enable us to add more nitric acid as the action moderates.

$$\begin{array}{ccccccccc} \text{Copper.} & & \text{Nitric acid.} & & \text{Nitrate of copper.} & & \text{Nitric oxide.} & & \text{Water.} \\ 3Cu & + & 8HNO_3 & = & 3(Cu(NO_3)_2) & + & 2NO & + & 4H_2O \end{array}$$

Though this gas is colorless, the moment that it is exposed to the air it is changed into orange fumes. This is very prettily shown if a jarful of this gas be raised out of the water in the pneumatic trough. The air, entering the jar, diffuses an orange-red color in every part of it. The explanation is this: The oxygen of the air unites with the nitric oxide, converting it into a mixture of nitrous anhydride and nitric peroxide, $3(NO)+O_2=N_2O_3+NO_2$. You can now understand why the first gas that rises in the flask is colored. There is some air in the flask, and when the gas begins to rise it takes the oxygen from this air, and becomes nitrous anhydride. When this is driven off the nitric oxide will come along pure.

In making these experiments you must be very careful not to breathe the reddish fumes of nitrous anhydride mixed with nitric peroxide, for they irritate the lungs. Indeed, they smell so horribly we think you will not need to be warned.

84. **Explanation of a Former Experiment.**—You will see that in the above process the same materials are used as in the experiment given in § 73. Nitric oxide was formed in that experiment, as well as in this process, and yet reddish fumes arose from the copper and the acid. The nitric oxide at once united with the oxygen of the air, and so was changed into nitrous anhydride and nitric peroxide, as explained in § 83. In the process for obtaining the nitric oxide we prevent this change, as you see, by shutting out the air.

85. **Air and Nitric Oxide Contrasted.**—The two great ingredients of air are those which compose nitric oxide. And yet how entirely opposite these two substances are in their

qualities!—one being one of the blandest of all substances, flowing into the lungs without irritating in the least the delicate air-cells, while the other is powerfully acid, and dangerous to breathe. The chief reason of this difference is that the air is a mere mixture of oxygen and nitrogen, and therefore partaking of the properties of both of these gases, while nitric oxide is a compound, a new substance formed by the chemical union of the two gases. You have here illustrated in a striking manner the grand difference between mixtures and compounds, the mixture having properties intermediate between those of its ingredients, while the compound generally has properties differing widely from those of either of the substances of which it is composed.

86. **Nitrous Anhydride.**—This is a thin, mobile, blue liquid at a very low temperature, otherwise it is an orange-red gas. Dissolved in water, it combines with it and forms nitrous acid, which is of no great importance, though some of its compounds are useful in the arts; they are called *nitrites.*

87. **Nitrous Anhydride in Nitric Acid.**—It is the nitrous anhydride that gives the yellow color which nitric acid so commonly has. But how is this gas generated in the nitric acid? The explanation is easy. Nitric acid, we have told you, is very ready to part with a portion of its oxygen. Even exposure to light will make it do this; so that if we wish to preserve the acid pure, we must keep it in a dark place or in dark-colored bottles. As we commonly see it, a portion of it has become, by a loss of one fifth of its oxygen, nitrous anhydride, which, readily dissolving in the nitric acid, gives it a yellow color. Sometimes the oxygen which is disengaged in this decomposition of the nitric acid, together with some of the nitrous anhydride, forces out the stopper of the bottle.

88. **Nitric Peroxide.**—To obtain this substance in a liquid

form you can heat nitrate of lead in a glass retort and collect the deep red fumes in a tube surrounded by a freezing mixture. At a low temperature the fumes condense to a red liquid. The process is represented in Fig. 16. It also forms in the gaseous state by exposing nitric oxide to the oxygen of the air. This does not form an acid on dissolving in water.

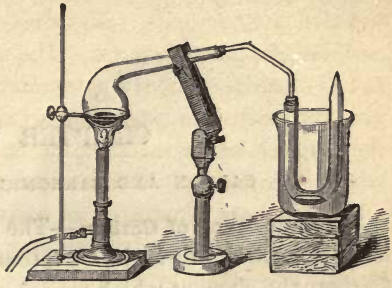

Fig. 16.

QUESTIONS.

66. Where does nitrogen occur in nature?—66 *a*. How can it be obtained? —67. What are the properties of nitrogen?—68. What are its relations to life?—69. How many and what are the compounds of nitrogen with oxygen? What are the proportions of these elements in laughing-gas? What in nitric oxide?—70. What is said of nitric anhydride? What does it form when dissolved in water?—71. Describe the preparation of nitric acid. —72. What are its properties?—73. Explain the action of nitric acid on metals.—74. What metal does not dissolve in nitric acid? Why?—75. What are nitrates?—76. Give an example of combustion produced by nitric acid. —77. What is said of the formation of nitric acid in the air?—78. What is the action of acids on blue vegetable solutions? How do anhydrides form acids?—79. Explain the method of naming acids. What does the prefix "hypo" mean? How are bodies derived from acids by replacement of hydrogen named?—80. What are bases? How do they act on reddened litmus? What is a salt? What do nitric acid and potassium hydrate form by combining? What is a neutral salt? What an acid salt?—81. How is nitrous oxide prepared?—82. What are its properties?—83. How is nitric oxide obtained?—84. What are the reddish fumes given off when copper is put into nitric acid?—85. What is said of the contrast between air and nitric oxide? What does this illustrate?—86 and 87. What is nitrous anhydride? How does it occur in nitric acid?—88. How is nitric peroxide obtained?

CHAPTER VII.

CARBON AND CARBONIC ANHYDRIDE.

89. **Abundance of Carbon.**—The two elements which we have described to you in Chapters V. and VI. are gaseous. Carbon, the element which we are now to consider, is a solid. This is present almost every where. It forms nearly one half of all the solid part of all vegetable and animal substances. The different varieties of coal are nearly pure carbon. This element is one of the ingredients of all limestones and marbles. All shells are composed in part of it. It is present every where in the air, united with oxygen to form a gas, carbonic anhydride, which we shall speak of particularly in the latter part of this chapter.

90. **Charcoal.**—One of the most common forms in which we see carbon is charcoal. Before hard coal was introduced into use it was the most common form; and it is for this reason that the word charcoal is often used as being synonymous with carbon. Charcoal is ordinarily made from wood; or, to speak more correctly, it is obtained from wood, for no new substance is formed, but there is merely a separation of the components of the wood. All the components except the carbon are driven off, for the most part. This is done by a smothered and imperfect combustion. The wood is piled together and covered over with turf. It is then set on fire from below, and suitable openings are kept in the covering to allow the proper degree of combustion. Figs. 17 and 18 (p. 77) illustrate the manner of piling the wood and conducting the operation. Some of the car-

bon is lost in this process, for it unites with the oxygen of the air that is admitted in the openings, forming a gas, and so passes out at the upper openings with the other matters that are driven off by the heat. About 40 per cent. of the wood is carbon, and the charcoal obtained is from 20 to 25 per cent., so that the loss of carbon is nearly, often quite, one half. The best charcoal is made by heating wood in tight iron vessels till all the vapors and gases are driven off. The process of making charcoal can be illustrated by holding a burning slip of wood in a test-glass, as represented in Fig. 19. The portion within the glass, not having a free access to air, is subjected to a partial smothered combustion, and therefore becomes charcoal.

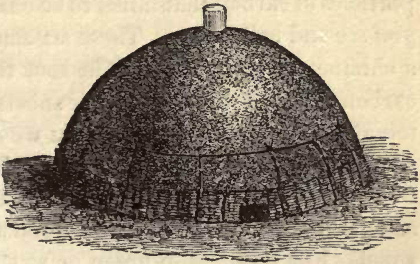

Fig. 17.

Fig. 18.

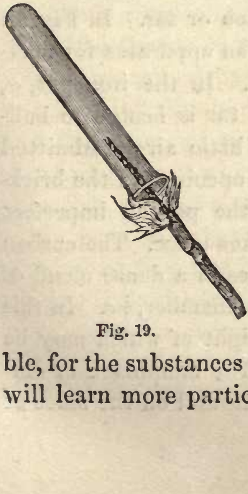

Fig. 19.

91. **Soot.**—In burning wood there is more or less smoke. This arises from the imperfection of the combustion, and is dense in proportion to that imperfection. If the combustion were perfect, there would be nothing visible, for the substances passing off in the air would be, as you will learn more particularly in another chapter, vapor and

gases only, and all that would be visible is the ashes. But, as it is, there pass upward in this body of vapor and gas solid particles of carbon that failed to be burned, and it is these that you see and call smoke. These accumulate to some extent in a chimney upon its sides. The soot thus formed is not pure carbon, for there are some other substances—creosote, etc.—mingled with it. The reason that we do not have smoke and soot from hard coal is that the combustion is more perfect than in the case of wood. So, too, there is more of smoke, and therefore soot, from green wood than there is from dry wood. For this reason green or wet wood is used in smoking meat. When a lamp smokes from having the wick too high, it is because the carbon of the oil is furnished in too large quantity for the oxygen that is in the air around the wick. Whatever this smoke touches has soot deposited upon it. When the combustion is perfect, all the carbon, as it rises in the heated wick, is made by the heat to unite with the oxygen of the air, and form carbonic anhydride, which passes upward unseen.

92. **Lampblack.**—This substance, so much used in making printing-ink, is a fine kind of soot made from pitch or tar. In Fig. 20 is represented an apparatus for making lampblack. In the iron pot, *a*, some pitch or tar is heated to boiling, and, as a little air is admitted through small openings in the brick-work around the pot, an imperfect combustion takes place. The carbon of the tar passes in a dense cloud of smoke into the chamber, *b c*. In this hangs a cone of coarse cloth, the height of which may be regulated, as you see, by a pulley. The lampblack or carbon is deposited in powder on the cone and on the sides of

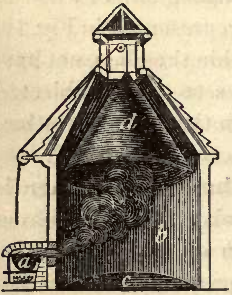

Fig. 20.

the chamber, which are lined with leather. There are two objects in having the cone—one to prevent the smoke from passing upward too rapidly, and the other to present a large surface for the deposition of the powder in addition to that of the walls of the chamber.

93. **Bone-Black.**—Bone or ivory black is a powdered charcoal prepared from bones. It is far from being pure charcoal, as you will see as we explain its preparation. A bone is composed of two parts mingled together, a mineral and an animal part. These can be obtained separate from each other, as has been fully shown in the "First Book of Physiology." It is the animal part alone that really furnishes charcoal; but in the preparation of bone-black both parts are used together. The bones are heated in iron vessels, and the heat, driving off all the volatile ingredients of the animal part, leaves the carbon mingled with the mineral portion—the phosphate of lime. The advantage of this form of charcoal is that the carbon is very minutely divided by being thus mingled with the mineral powder. Besides other uses soon to be noticed, bone-black is used in the manufacture of blacking, being mixed for this purpose with oil of vitriol and sirup.

94. **The Carbon in Animal Substances.**—As there is carbon in the animal part of bone, so it is in all animal substances. It exists in combination with other elements, and therefore does not appear as carbon. It is only by some chemical process which separates it from these combinations that it can be made manifest, and combustion is one of the processes that can do this. When animal skin or flesh is charred—that is, partially burned—the charcoal that appears is produced essentially in the same way that it is when made from wood. It is not really made, but it is separated by the heat from the substances with which it is combined, the heat for the most part driving these off into the

air. Whenever meat is overcooked in roasting, some of the outside exhibits this separation of carbon by chemical decomposition.

95. **Properties of Charcoal.**—Although charcoal is so combustible, it is in some respects a very unchangeable substance, resisting the action of a great variety of other substances upon it. Hence posts are often charred before being put into the ground. Grain has been found in the excavations of Herculaneum which was charred at the time of the destruction of that city, 1800 years ago, and yet the shape is perfectly preserved, so that you can distinguish between the different kinds of grain. While charcoal is itself so unchangeable, it preserves other substances from change. Hence meat and vegetables are packed in charcoal for long voyages, and the water is kept in casks which are charred on the inside. A ham was kept, by a friend of the author, packed in charcoal-dust eight years, and on being cut was found as fresh and sweet as when first put in. Charcoal is also a great purifier. Tainted meat can be made sweet by being covered with it. Foul and stagnant water can be deprived of its bad taste by being filtered through it. Charcoal is a great decolorizer. Ale and porter filtered through it are deprived of their color, and sugar-refiners decolorize their brown sirups by means of charcoal, and thus make white sugar. Animal charcoal, or bone-black, is the best for such purposes, although only one tenth of it is really charcoal, the other nine tenths being the mineral portion of bone. Other substances besides those which give color are often extracted by charcoal. Thus brandy is rendered pleasanter in taste and smell by being filtered through charcoal, because an acrid volatile oil, called fusel-oil, is extracted. So charcoal takes away from beer not only its color, but that which causes its bitter taste.

96. **Absorbing Power of Charcoal.**—Most, if not all, of the effects above mentioned are attributed to the absorbing power of charcoal. This power is very great. Charcoal will absorb of some gases from eighty to ninety times its own bulk. This constitutes a protection to substances which are covered with charcoal, for gases are the grand agents in decay. Absorbed by the charcoal, they are put out of the way; and not only so, but they constitute a part of the wall of defense together with the charcoal, filling up as they do all its spaces. Charcoal thus saturated with gases defends the substance that it covers from access of the air. When decay has already begun before the charcoal is applied in the work of purification, it absorbs all the gases that have been produced in the decay, and thus puts a stop to the process.

97. **Explanation.**—The question arises as to what gives this power of absorption to charcoal. It is generally supposed that it is owing to its great porosity. Charcoal is full of minute spaces, and is therefore intersected by numberless partitions. If these were spread out they would constitute a surface perhaps a thousand times larger than the external surface of the charcoal. As every point of this surface is a point of attraction, it is supposed to account for the enormous accumulation of gases in the spaces of the charcoal. But this accounts for it only in part. If it were the only cause of the absorption, there should not be such a great difference in absorbing different gases. Of some gases it absorbs nearly fifty times as much in bulk as it does of some others. When great quantities of gases are absorbed, there must be great condensation, and this would hardly come from mere common attraction. There must be some peculiar power in the charcoal to change in some way the condition of a gas of which it absorbs ninety times its own bulk. And, besides, it seems to show some sort of affinity

for certain substances in separating them from others, as, for example, in separating the coloring substance from ale, and also that which gives it its bitter taste.

98. **Coal.**—All the different varieties of coal—anthracite, bituminous, etc.—are carbon, more or less mixed with compounds of hydrogen and carbon called hydrocarbons. Anthracite burns without smoke, and when fully ignited without flame, for it is destitute of the volatile hydrocarbons that are present in bituminous coal. The reason of the difference is that these volatile substances have been driven off by heat in the formation of the anthracite. When the anthracite is burned the carbon all passes upward, united with the oxygen of the air, forming carbonic anhydride. The impurities combined with this carbon in the coal fall below, making the ashes. The bituminous coal is used in making illuminating gas. What is left after the volatile matters are driven off is a very impure charcoal called coke.

99. **Graphite.**—Graphite, or plumbago, sometimes called black-lead, contains not a particle of lead, but is crystallized carbon, having commonly a very little iron mingled with it. It is a grayish black substance having a metallic lustre. It is used for making the so-called lead-pencils, and for giving a polish to stoves and other iron articles. When powdered it is so soft and lubricating that it is added to grease for the prevention of friction in wheels and machinery. It is a very incombustible article, and therefore the coarser kinds are manufactured into crucibles, or melting-pots. There are famous mines at Cumberland, in England, and in Siberia, which furnish very fine graphite for pencils. It is quite a common mineral in this country, appearing in many localities. At Ticonderoga, in New York State, an extensive deposit occurs, most of which is worked up into crucibles and stove-polish.

100. **The Diamond.**—In the diamond we have pure carbon

crystallized, but differently from what it is in graphite. It is the hardest of all substances. It has not the least resemblance to coal, yet it can be burned up in oxygen, carbonic anhydride being the result, as in the burning of coal and other forms of carbon. It was discovered to be carbon in this way by Lavoisier, a French chemist. He threw the sun's rays, concentrated by a large lens, upon a diamond in a vessel of oxygen gas. It was consumed, and carbonic anhydride alone resulted, showing that the substance that had thus united with the oxygen was nothing but carbon. No one has ever yet been able to convert coal into diamonds. The difficulty seems to be that coal can neither be dissolved nor melted, for, in order to crystallize any substance, it must first be in a liquid state. It is indeed stated that a Frenchman, M. Despretz, has with a galvanic battery melted and crystallized carbon, and thus made diamonds; but they were so small as to be visible only with a microscope.

101. **Allotropism.**—You have learned that the elementary body carbon appears under three very different forms—diamond, graphite, and charcoal—varying in color, hardness, specific gravity, and other physical properties. We can not explain exactly how and why this is so, but we know that some other elements appear in two or more distinct forms, and the peculiarity is not confined to carbon. Bear in mind that, *chemically*, diamond, graphite, and charcoal are one and the same, but they differ in their physical aspects. Bodies having this power of taking different forms are said to be allotropic, and the phenomenon is called allotropism. These words are made up from two Greek words, *allos*, "other," and *tropos*, "way," because the body exists in some "other way." When we say that carbon exists in three allotropic forms, we do not explain any thing; we rather conceal our ignorance of the truth by employing a high-sounding word coined for that purpose.

102. Carbonic Anhydride.—Having given you an account of the element carbon, we will now notice a gas formed by the union of this element with oxygen, viz., carbonic anhydride.* This is formed whenever carbon is burned in oxygen, as in the experiment in § 57. So, also, when a diamond is burned in oxygen, this, being pure carbon, unites with the oxygen to form carbonic anhydride. This gas is one of the products of all ordinary combustion, the result of the union which takes place between the oxygen of the air and the carbon in the combustible substance. Thus the carbon of wood, oil, tallow, illuminating gas, etc., unites, in the act of burning, with the oxygen of the air, and forms this gas.

103. Common Mode of Obtaining Carbonic Anhydride.—Put into a flask, Fig. 21, some small bits of chalk or marble, and pour upon them some hydrochloric acid. The gas will bubble up, and, forcing out the air before it, will pass through

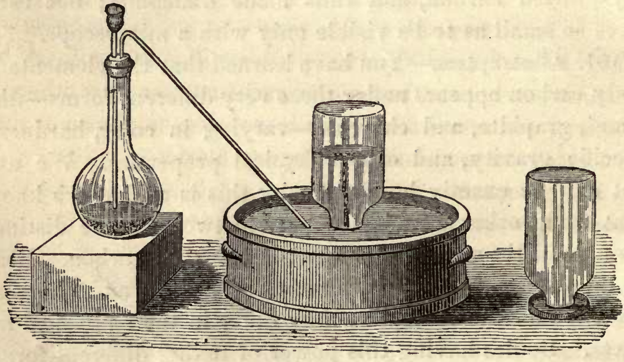

Fig. 21.

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* This gas used to be called carbonic acid, but chemists have decided that it is not a true acid because it contains no hydrogen, hence it is now known as carbonic anhydride.

the bent tube, and so can be collected in jars in the pneumatic cistern. The explanation is this: The chalk and marble are two forms of the same substance, calcium carbonate, which contains carbonic anhydride united to the oxide of calcium, commonly called lime. Now the hydrochloric acid decomposes the calcium carbonate, forming water, the gaseous carbonic anhydride, and a new body, calcium chloride, which remains dissolved in the water. We do not see the water formed, for it mixes with that in the flask; nor do we see the calcium chloride, for it is very soluble, and remains in the water; we can easily prove it is there, however, by evaporating the watery solution, when we will obtain a white solid mass. The carbonic anhydride set free is seen as it bubbles up through the water. Expressing this in symbols, we write thus:

$$\underset{\text{Marble.}}{CaCO_3} + \underset{\text{Hydrochloric acid.}}{2HCl} = \underset{\text{Calcium chloride.}}{CaCl_2} + \underset{\text{Water.}}{H_2O} + \underset{\text{Carbonic anhydride.}}{CO_2}$$

Sodium carbonate, potassium carbonate, or any other carbonate, will serve equally well; so, also, sulphuric or nitric acid may be used instead of hydrochloric.

104. Properties of Carbonic Anhydride.—This gas is, like air, transparent and without color. It has a slightly acid and agreeable taste. Its specific gravity is 1.527—that is, it is about one and a half times as heavy as air. Because it is so much heavier than air it can be collected by *displacement*, as it is termed. This is represented in Fig. 22. The gas produced in the flask passes over in the tube and


Fig. 22.

displaces the air in the jar, pushing it upward as water would oil. In order that it may do this quietly and effectually, the jar is so placed that the end of the tube is near the bottom. So, also, we can pour this heavy gas from one vessel into another, the same displacement of air taking place in this case. The comparative weights of air and this gas may be shown by the experiment represented in Fig. 23. An empty beaker—that is, a glass vessel full of air—is first balanced on a scale; then carbonic anhydride is poured into it, of course causing the beaker to go down.

Fig. 23.

105. Liquefaction and Solidification of Carbonic Anhydride.—By an apparatus which subjects carbonic anhydride to great pressure and cold this gas can be made fluid, and even solid. As a solid it is a very peculiar substance, of a white color, appearing much like dry snow. If held in the hand it will destroy the skin like red-hot iron. The enormous degree of pressure required to liquefy carbonic anhydride is shown by the fact that the apparatus once exploded in Paris, killing an assistant engaged in the experiment.

106. **Carbonic Anhydride not a Supporter of Combustion.**—A lighted taper introduced into a jar of this gas is extinguished as quickly as it would be if it were dipped into water. This is simply because oxygen is absolutely necessary to the continuance of the combustion. There is, it is true, a sufficient quantity of oxygen in the carbonic anhydride, but it is so thoroughly united with carbon that not a particle will quit it to unite with the carbon of the taper. A very pretty way of showing that this gas is not a supporter of combustion, and at the same time that it is heavier than air, is to pour it, as seen in Fig. 24, from one jar down into another in which there is a lighted taper. Notwithstanding that carbonic anhydride does not support ordinary combustion, a few substances having a great attraction for oxygen will burn in it. A piece of magnesium wire lighted and plunged into a jar of the gas burns brilliantly, taking the oxygen to itself and leaving the carbon, which appears as a black powder on the sides of the glass jar. The decomposition of the carbonic anhydride is thus expressed:

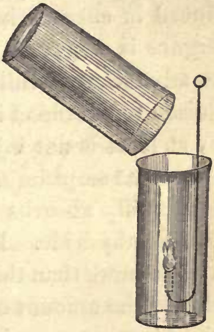

Fig. 24.

$$\underset{\text{Carbonic anhydride,}}{CO_2} + \underset{\text{Magnesium,}}{2Mg} = \underset{\text{Carbon,}}{C} + \underset{\text{Magnesium oxide,}}{2MgO.}$$

107. **Effects of Carbonic Anhydride when Respired.**—As it is with nitrogen (§ 68), so with this gas—no animal can live in it. But it destroys life not merely because, like nitrogen, it shuts out oxygen from the blood in the lungs, but it acts also as a positive poison. It produces an effect upon the system similar to that of some narcotics. Nitrogen is constantly taken into the lungs in large quantities without doing any harm, for about four fifths of the air is nitrogen; but if car-

bonic anhydride be present in the air to the amount of one tenth of the whole, its poisonous influence is very manifest. And even when it is present only in the small quantity of one or two per cent., bad effects show themselves on breathing such an air for some little time. This gas is always present in the atmosphere, but in so very small amount, as you will see in the next chapter, that it produces no effect as a poison.

108. **Carbonic Acid in the Stomach.**—While this gas is thus a poison in the lungs, it is far otherwise in the stomach. It produces an agreeable tonic effect there, as it is introduced in effervescing drinks. The chemistry of these two organs is different. The lungs can use oxygen chemically to advantage; while carbonic anhydride, which is a deadly poison to the blood in the lungs, is beneficial in the stomach, or at least is not injurious there.

109. **Absorption of Carbonic Anhydride by Liquids.**—Water readily absorbs or dissolves about its own bulk of carbonic anhydride. By means of pressure it can be forced to absorb more than this, the amount absorbed being in proportion to the amount of pressure. Thus "soda-water" is commonly only water into which a large quantity of carbonic anhydride has been forced, and the effervescence is owing to the escape of this gas on taking off the pressure. The waters of many natural springs have considerable of this gas, which, being generated under pressure in the earth, is therefore largely dissolved in the water, and, escaping from this pressure as the water issues forth, causes an effervescence. In beers and sparkling wines the carbonic anhydride is made by the fermentation of the liquid as it is confined. The bursting of bottles, which sometimes occurs, is produced by the generation of too large an amount of this gas, or by its undue expansion by exposure to heat.

110. **No True Carbonic Acid.**—Carbonic anhydride is one

of a class of bodies which unite with water to form acids. You have learned in § 70 that nitric anhydride combines with water, forming nitric acid; thus $N_2O_5+H_2O=2HNO_3$. But carbonic acid does not seem to have any definite existence; the solution of CO_2 in H_2O may be regarded as H_2CO_3, but the acid, if it exist at all, is decomposed at ordinary temperatures, and quickly by boiling. Although carbonic acid has a doubtful existence, the carbonates derived from it are a most important and numerous class of bodies. From these carbonates the stronger acids, hydrochloric and nitric, for example (or even acetic), do not drive out *carbonic acid*, but *carbonic anhydride*, and the reaction is accompanied by the formation of water.

111. **An Apparent Inconsistency.**—Notwithstanding the comparative weakness of carbonic acid, it adheres to its union with some substances in spite of the most intense heat. No degree of heat can drive off the carbonic acid from potassium or sodium carbonates. Why this is we know not, neither do we know why lime will take carbonic acid away from potash. It would seem from this that carbonic acid has a stronger attraction for calcium than for potassium, and yet, from the effect of heat upon carbonate of lime, we should make exactly the opposite inference. This is one of the apparent contradictions in affinity which we can not explain, though the object which the Creator had in making such differences is generally quite obvious.

112. **Carbonic Oxide.**—This is a gas which has but half as much oxygen in it as carbonic anhydride, its formula being CO. It is a transparent colorless gas, and burns with a beautiful blue flame, which you have often seen playing over the surface of an anthracite fire as it kindles. The explanation of its formation in this case is this: The closely packed coal does not get sufficient oxygen from the air to make carbonic anhydride, and so carbonic oxide is formed.

When, however, it emerges into the air, if the heat be sufficient to inflame it, it takes from the air an additional quantity of oxygen, and thus becomes carbonic anhydride. When the whole body of the coal has become thoroughly ignited, there is no more carbonic oxide formed, but only carbonic anhydride, and hence there is no longer any flame. When charcoal burns without a good supply of air, carbonic oxide is produced, mingled with carbonic anhydride. This gas is very poisonous, much more so than the carbonic anhydride. It is the mixture of the two gases that produces such injurious effects when charcoal is burned in a chafing-dish or an open furnace in a close room. We have known similar effects produced when a damper of an anthracite coal-stove was closed before the coal was well ignited, thus preventing the carbonic oxide as it rises from being fully converted into carbonic anhydride, and forcing some of both of these gases out into the room.

113. **Preparation of Carbonic Oxide.**—This gas is commonly obtained from oxalic acid, the acid which gives the sour taste to sorrel. This is composed of carbon, oxygen, and hydrogen, the same ingredients which we have in carbonic anhydride and carbonic oxide *plus* water, but in different proportions. The chemist by means of sulphuric acid splits up, as we may say, the oxalic acid into these two

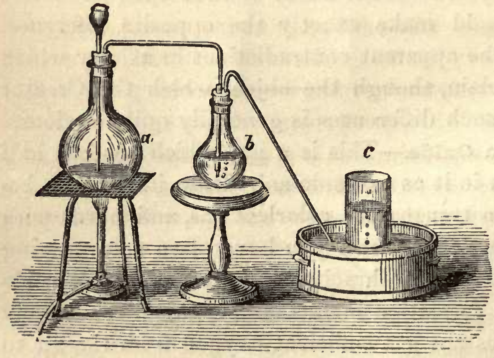

Fig. 25.

gases, and then, by taking away the carbonic anhydride, he has the carbonic oxide by itself. The way in which he does this is represented in Fig. 25 (p. 90). The oxalic acid and the sulphuric acid are put into the flask, *a*, and on the application of gentle heat the two gases, carbonic anhydride and carbonic oxide, are produced, and pass over through the tube into the bottle, *b*. Here there is a solution of potassium hydrate; and as the gases pass into it the carbonic anhydride unites with the potassium to form potassium carbonate, and the carbonic oxide goes on alone into the jar, *c*, where it is received for experiments.

114. **Experiment.** — If you take a jar of this gas, Fig. 26, and apply a lighted taper to its mouth, the gas will burn with a beautiful blue flame. You can make the flame very large by pouring water in, for this forces the gas out rapidly. As it burns it becomes carbonic anhydride by taking oxygen from the air.

Fig. 26.

Carbonic oxide.		Oxygen.	yield	Carbonic anhydride.
CO	$+$	O	$=$	CO_2

QUESTIONS.

89. In what forms does carbon occur in nature?—90. How is charcoal made? How illustrated?—91. What is soot? What is said of imperfect combustion? Why do lamps smoke when the wick is too high?—92. How is lampblack made?—93. What is bone-black? What does it contain besides charcoal? What are some of its uses?—94. What is said of the presence of carbon in animal substances? What is the chemical explanation of the charring of flesh and skin? What is said of overcooking meat?—95. What of the unchangeability of charcoal? What of its preservative power? What of its purifying and decolorizing powers? What other

effects does it produce?—96. What is said of its absorbing power?—97. How is this power to be explained?—98. What is the difference between anthracite and bituminous coal? What is coke?—99. What is said of black-lead?—100. What of the diamond?—101. What is meant by allotropism? Whence is the word derived?—102. State various cases in which carbonic anhydride forms?—103. Describe and explain the common mode of obtaining it? Write the equation given.—104. What are the properties of carbonic anhydride? How is it collected? Show it has weight.—105. What is said of converting gases into solids?—106. What effect does carbonic anhydride have on combustion? Illustrate this.—107. What effect on respiration? How does it differ from nitrogen in this respect?—108. How does carbonic anhydride act on the stomach?—109. What is "soda-water?"—110. Why is there no true carbonic acid?—111. State what is said of an apparent inconsistency.—112. What is the composition and nature of carbonic oxide? Where do we often see it burning? Explain its production and burning in this case.—113. How may it be prepared? Why will it burn when forced out of a jar by pouring in water? Is it poisonous?

CHAPTER VIII.

THE CHEMISTRY OF THE ATMOSPHERE.

115. **Ingredients of the Atmosphere.**—The air is a mixture of three gases—oxygen, nitrogen, and carbonic anhydride. The proportions of these ingredients are changed by circumstances, as you will soon see, and yet wherever the air is free the proportions are always the same. About one fifth of the air is oxygen, and the remaining four fifths nitrogen. The amount of carbonic acid is very small, there being only 4 volumes in every 10,000 volumes of air. These proportions are represented to the eye in Fig. 27, the largest square representing the nitrogen, the one at its side the oxygen, and the smallest the carbonic anhydride.

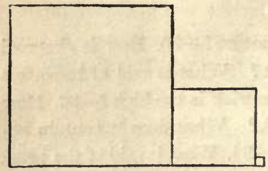

Fig. 27.

116. **Quantity of Carbonic Anhydride in the Atmosphere.**—As the air encircling the earth is from 45 to 50 miles in height, the quantity of carbonic acid, although proportionably small, is really in the whole very great. It has been estimated that there is seven tons' weight of this gas over every acre of the earth's surface.

117. **Chief Use of Nitrogen in the Air.**—Oxygen, you have seen, is a very active substance, supporting life and combustion every where. It is so active that it needs to be diluted in the air with four times its bulk of nitrogen gas. If it were not thus diluted the world would be one vast scene of continued conflagrations. Combustible substances would take fire five times as easily as now, and when once on fire it would be difficult to put them out. Iron would burn as readily as wood now does. So also the operations of life would be attended with five times the amount of heat that they now are, and the tendency in every animal would be to fever and inflammation. As oxygen is so stimulating, it has sometimes been used successfully in reviving persons who have been drowned or suffocated. In such cases, the more of this gas you can introduce into the lungs for a little while the better. It is easily introduced by a pipe from a bladder filled with it. The remedy, however, has seldom been used, because it is not at hand unless the accident occur near the laboratory of a chemist.

118. **Analysis of the Air.**—We will describe two modes of analyzing the air. The first is this: A certain volume of air is allowed to pass slowly through a tube containing potassium hydrate. This has a very strong attraction for one of the ingredients of the air, carbonic anhydride, and has none for either the oxygen or nitrogen. It takes, therefore, the carbonic anhydride, and the weight of the tube compared with its weight before the experiment shows how much there is of this ingredient in the volume of air employed. And now the air, thus deprived of its carbonic anhydride, is made to pass through a tube filled with red-hot copper-filings. The copper in this state attracts to itself the oxygen, but having no tendency

to unite with the nitrogen, this passes on. The weight of this tube compared with its weight before the experiment shows the amount of oxygen in the air. Then subtracting the sum of the weights of the oxygen and carbonic anhydride from the weight of the air examined, we have the weight of the nitrogen.

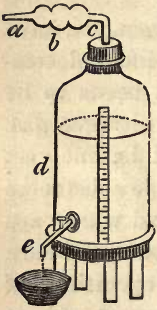

Fig. 28.

Another mode which ascertains the proportionate volumes of the gases as well as their weights is represented in Fig. 28. We have here a tube, *a b c*, with a very minute opening at *a*, a bulbous enlargement at *b*, and its larger orifice, *c*, made to fit air-tight in the top of the vessel, *d*. This vessel is filled with mercury, and is graduated, as you see. There is a cock at *e*, by which you can let the mercury run out in as small a stream as you please. Before fitting the tube, *a b c*, to the vessel, it is filled with loose cotton having bits of phosphorus scattered in it, which, by warming, is spread over the fibres of the cotton, and then the tube is accurately weighed. Fitting the tube to the vessel, the cock, *e*, is now slightly opened. As the mercury flows slowly out, air passes in at *a* to take its place, and in passing in it loses all of its oxygen, for the phosphorus which it finds every where in the cotton takes it, forming with it phosphorous anhydride, which remains in the cotton. We have therefore nitrogen alone in the vessel, *d*, to take the place of the mercury that runs out. When the volume of air employed is used up we close the stop-cock at *e*. We can ascertain the volume of the nitrogen by the graduation on the vessel, or more accurately by measuring the mercury which has run out, for this, of course, exactly equals in bulk the nitrogen that has taken its place. And from its volume we know its weight, because the specific gravity of the gas has been ascertained by chemists. Then we find the weight of the oxygen, by weighing the tube, and comparing its weight with that which it had before the experiment; and its volume is found from its specific gravity. In this process you see that no account is taken of the carbonic anhydride that is in the air. It is indeed so small in amount (§ 115) that it would make but little difference in the result. There is always moisture in air, and this must be got rid of in order to make the analysis accurate. This can be done by letting the air to be analyzed first pass through a tube containing some substance which has a great affinity for water, as the fused calcium chloride.

119. The Gases of the Air Obedient to Gravitation.—You learned in Part I., Chapter VI., that the atmosphere is held as a robe around the earth by the attraction of gravitation. Now it is with the gases as with solid and liquid substances—each is attracted to the earth in the proportion of its specific gravity, the heaviest always taking the lowest position—that is, getting the nearest to the earth. As mercury, therefore, gets below water, and water below oil, so carbonic anhydride tends to get below oxygen, and oxygen below nitrogen. See what would be the consequence if this tendency were allowed to be carried out unopposed. The carbonic anhydride would be accumulated beneath all the oxygen and nitrogen, filling up all the valleys, and lying along upon all the plains. And as this gas is a deadly poison, no animal could live except upon elevated places, hills, and mountains. But even there life would be short, and attended with suffering; for the nitrogen, being lighter than oxygen, would be above it, so that animals would breathe air that would be too stimulating, producing fevers and inflammations, and the extreme readiness with which every thing would burn would occasion constant trouble.

120. **Disposition of Gases to Mingle Together.**—The influence of gravitation upon the gases is counteracted to a great extent by a disposition which we find in gases to mingle with each other, and thus the disastrous consequences above alluded to are prevented. The following experiment beautifully exhibits this *diffusion*, as it is termed: Let a bottle (Fig. 29, p. 96) be filled with carbonic anhydride, having a long tube fitted into the cork. At the upper end of the tube place a bottle of hydrogen gas. As the carbonic anhydride is twenty-two times heavier than hydrogen, gravitation tends strongly to keep the carbonic anhydride in the lower bottle, the hydrogen of course remaining in the upper one. But observe what happens. If the apparatus be left to stand for an hour or two, it will be found that there is a

mixture of carbonic anhydride and hydrogen in both bottles. A part of the carbonic anhydride has gone up into the upper one, and a part of the hydrogen has come down into the lower. This is because, for some reason, there is a strong disposition in the two gases to mingle—strong enough to overcome the force of gravity which tends to keep them separate. And notice that in this case gravity must operate very strongly indeed, for hydrogen is the lightest of all substances, while carbonic anhydride is a very heavy gas. If, then, the disposition of gases to mingle overcomes so readily in this case the force of gravity, much more readily will it do so when we have carbonic anhydride with oxygen and nitrogen, as in the air, where the difference in specific gravity is so much less.

Fig. 29.

121. **An Analogy.**—There are some liquids which have a disposition to mingle together in the same way that gases do. Thus water mingles readily with alcohol, with the various acids, etc. Alcohol is lighter than water, as oxygen is lighter than carbonic anhydride, and therefore, in obedience to gravitation, the water inclines to keep below the alcohol, and would do so if the disposition to mingle were not stronger than the influence of gravity. In the case of oil and water there is no disposition to mingle, and therefore gravitation acts without any impediment, keeping the water under the lighter oil. Agitation promotes the mingling of both liquids and gases. Alcohol can be poured so quietly upon water that it will remain for some little time. This can be made obvious by having the alcohol colored. They will

mingle intimately in a little while, but will do so at once if shaken or stirred together. So it is with the gases. If in the experiment in § 120 we shake the apparatus, the two gases will not require an hour or two to mingle, as is the case when they are still, but will do so at once. So the constant motion of the atmosphere causes the gases that compose it to mingle together most perfectly, so that the carbonic anhydride, heavy as it is, though constantly produced in various ways, as you will soon see, at the bottom of the atmospheric sea that envelops the earth, is readily diffused throughout that sea though it be fifty miles high. This is not done merely by violent winds, but equally—nay, more—by the slighter motions which are every where and always going on in the air.

122. **Grotto del Cane.**—There are some localities where the carbonic anhydride does, however, lie along under the other gases of the atmosphere. Such a locality is the Grotto del Cane in Italy, so called because the layer of gas on the floor of the grotto is only high enough to destroy dogs that enter it—*cane* being the Italian for dog. There are two reasons for this accumulation of carbonic anhydride. One is, that the gas is produced at the locality in very great abundance from some chemical operations in the earth; that is, it is produced so rapidly that it is not all readily diffused. Another is, that the locality is so sheltered as to shut out in some good degree the common agitation of the air.

123. **Carbonic Anhydride in Wells.**—Sometimes this gas is generated in wells and deep pits. When this is the case, the diffusion must be slow, the air being confined, and so prevented from being agitated. The gas will therefore accumulate, being mingled with air toward the mouth of the well, but not so at the bottom. If a light then be lowered, it will burn more and more dimly as it goes down, and

at length will go out. It is prudent always to use this test before going down into a well or a pit. It is to be remembered that if the light merely burn dimly on coming near the bottom, there is danger, as you will understand by recalling what is said in § 107. There are various means resorted to for ridding wells of this gas. One is to lower into the well a pan of recently heated charcoal. This will absorb into its pores 35 times its own bulk of this gas. Another is to burn a bundle of straw held to one side in the well. The fire occasions an upward current in the gas, the air going down on the other side to take its place. Another expedient is to bail out the gas with a bucket. This can be done owing to its great specific gravity. The bucket comes up to the mouth of the well apparently empty, but actually full of the gas, as you might find by trying with a lighted candle.

124. **Fumes of Burning Charcoal.**—If charcoal be burned in a chafing-dish or open furnace in a close room, we have the production of carbonic anhydride under circumstances similar to those attending its production in a well. The air in the room is comparatively still, and it is shut in. Life has often been destroyed in this way. It is not carbonic anhydride alone that does this, for, as stated in § 112, there is produced with this more or less of a still more deadly poison—carbonic oxide. The grand remedy, when we find persons suffering from the fumes of burning charcoal, is to open all the doors and windows, so that these gases may be speedily diffused in the gases of the atmosphere, and the reviving pure air from without be introduced into the lungs of the sufferers.

125. **Carbonic Anhydride Discharged from the Lungs.**—Every time that we breathe *out* we add to the carbonic anhydride in the atmosphere around us. That this gas is thus discharged from the lungs can be proved by a very simple

experiment. All that you require for it is a tumbler of lime-water and a tube. If you breathe through the tube into the lime-water it will soon become milky; and if you let the tumbler remain for a little time a fine powder will settle on the bottom.* This is calcium carbonate, or chalk, formed by the union of the carbonic anhydride that came from your lungs with the calcium hydrate, or lime-water. The experiment can be made more striking by using the simple apparatus represented in Fig. 30. You can either draw in air through the tube A, and thus let the air that goes into your lungs come through the lime-water, or you can force the air out of your lungs through the lime-water by the tube B. If you draw air through the lime-water, it will take a very long time to make it milky, because there is so very little carbonic anhydride in the air that you breathe in, as you saw in § 115; but if you throw the air *from* your lungs into the lime-water by the tube B, it will require only a few breaths to make it decidedly milky. The experiment can be tried in still another form, as represented in Fig. 31. Here we have lime-water in both vessels. You

Fig. 30.

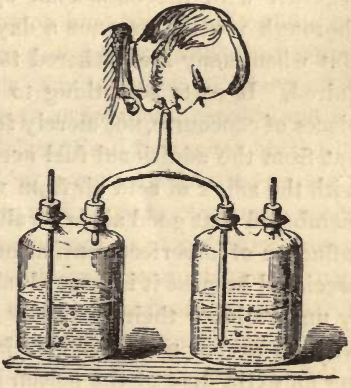

Fig. 31.

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* When a substance thus falls as a sediment in any chemical process, it is said to be *precipitated*, or is termed a *precipitate*.

see by the arrangement of the tubes that the air which is breathed *in* must come through the vessel at the left hand, while that which is breathed *out* must pass out through the other. In this latter, of course, will be seen the milky appearance. The reaction in these experiments is thus expressed:

$$\overset{\text{Lime-water,}}{CaH_2O_2} + \overset{\text{Carbonic anhydride,}}{CO_2} = \overset{\text{Calcium carbonate,}}{CaCO_3} + \overset{\text{Water,}}{H_2O}.$$

126. **Ventilation.**—The importance of free ventilation in our apartments, and especially in lecture-rooms, public halls, churches, etc., results from this production of carbonic anhydride in our respiration. Wherever breathing is going on there will be an accumulation of this gas, unless there be suitable facilities for its diffusion in the atmosphere. Where there are only a few persons in a room, the escape of this gas and the introduction of fresh air are effected sufficiently by means of the crevices here and there, together with the occasional opening of the doors, and a thorough ventilation once a day by opening the windows. But when many are gathered together, other means are required. It costs something to have good air in thronged places of concourse, not merely from the apparatus required, but from the additional fuel necessary to maintain warmth with the afflux of cold air from without. But it must be remembered that good air is a valuable commodity. The bad influence of imperfect ventilation upon the health is not appreciated because it is so gradual. Multitudes are constantly undermining their health by sleeping in small chambers with no proper means of ventilation, and occasionally taking an extra dose of the poison into their lungs in crowded assemblies. While the community are struck with horror at the sudden destruction of a few lives in such a case as that of the Black Hole of Calcutta, the slow and constant destruction of multitudes by the gradual introduction of

the same poison—the poison of human breaths—awakens but little attention. The bad effects of imperfect ventilation in places crowded with people do not depend alone on the carbonic anhydride which accumulates, but are due in large measure to a sort of effluvium which is given off from the surface of the bodies of human beings. The precise nature of this miasmatic emanation is not known, but it is shown to be largely organic by the fact that it is destroyed by passing through a flame. The importance of ventilation in rooms which are lighted by gas can not be too strongly insisted upon. When we come to study the chemistry of combustion, you will learn that carbonic anhydride and water are the chief products of the burning gas. In fact, it is calculated that even two candles of six to the pound produce as much carbonic anhydride per hour as would be generated by the respiration of a man of ordinary size.

127. **Sources of Carbonic Anhydride in the Atmosphere.**—Carbonic anhydride is constantly poured forth into the atmosphere chiefly from three sources. 1. All fires and lights produce it. 2. It is breathed out by all animals, from the greatest to the smallest. 3. It is one of the products of decay. The two first-named sources we have already noticed. The third will be particularly noticed in another part of this book. You will observe in regard to the first two that while carbonic anhydride is formed the oxygen of the air is at the same time diminished. Indeed, in ordinary combustion the carbonic anhydride is made by a union of the oxygen of the air with the carbon of the burning substance; and in respiration the lungs absorb oxygen from the air at the same time that they give out carbonic anhydride.

128. **Chemistry of Leaves.**—We have stated in § 115 that all free air is composed of the same proportions of oxygen and nitrogen and carbonic anhydride; and yet there are processes, as you saw in the last paragraph, which constantly

add to the carbonic anhydride, and take from the oxygen of the air. If there were nothing in opposition to these processes, there would of course be a gradual accumulation of carbonic anhydride and lessening of the oxygen, rendering the air very shortly incapable of maintaining life. But there is provided an effectual counteracting process, and the seat of it is in the leaves of plants and trees. Upon their outspread surfaces are countless pores which take in carbonic anhydride, and at the same time discharge oxygen into the air. Each of these pores is a real chemical laboratory, and the number of them in a single leaf is immense. "On a single square inch of the leaf of the common lilac," says Johnston, "as many as 120,000 have been counted; and the rapidity with which they act is so great that a thin current of air passing over the leaves of an actively growing plant is almost immediately deprived by them of the carbonic anhydride it contains." Here, then, we have a sort of chemical barter between lungs and fires on the one side, and leaves on the other. Lungs and fires give carbonic anhydride to the leaves, and take from them oxygen in return. In this operation leaves may be regarded as the lungs of plants, having a chemistry, however, which is opposite to that of the lungs of animals; and the carbon which is thus introduced into the plant by the leaves is just as necessary for its life and growth as the oxygen introduced into the animal by its lungs is necessary for its life and growth.

129. **Agency of the Sun.**—It is only under the influence of the sun's light that the chemistry of the leaves is carried on. At night all the little laboratories cease their labor, and then with the first gleams of the morning sun begin again to pour out the oxygen and take in the carbon. Professor Draper, of New York, has made an interesting discovery in regard to this influence of light. Of the several colors which combined make up common white light, as you

learned in Part I., Chapter XIV., he found that the yellow ray is that portion which is the peculiar stimulus of the chemistry of the leaves.

130. **Priestley's Experiment.**—This chemical action of the leaves was first demonstrated by Priestley, the discoverer of oxygen (§ 48). The experiment by which he demonstrated it is represented in Fig. 32. Some green leaves were placed in a bell-jar filled with water well charged with carbonic anhydride, and the bell-jar was then inverted, as you see, in a vessel of water. Placing the apparatus in the sun, he saw bubbles of gas arise continually from the surface of the leaves, and soon quite a quantity of this gas was collected in the upper part of the bell-jar, forcing of course a part of the water downward. This gas, on being tested, was found to be oxygen, and an examination of the water showed that the carbonic anhydride in it had disappeared. The conclusion was clear, then, that the leaves had absorbed carbonic anhydride, and at the same time had given out oxygen.

Fig. 32.

131. **Wonderful Balancing of the Chemistry of the Atmosphere.**—Free air, we have told you, is every where composed of its three ingredients in the same proportions. Climate makes no difference. A gallon of air taken from the torrid zone, where the rank vegetation is breathing out such quantities of carbonic anhydride, and taking in from the air so much of its oxygen, on being examined by the chemist, shows the same proportions of nitrogen, oxygen, and carbonic anhydride that a gallon of air does which has been taken from the icy regions of the North, where all vegeta-

tion is covered up in its wintry tomb. This is certainly very wonderful when we consider the constant changes which are going on in two of these ingredients, oxygen and carbonic anhydride. An exact balance is maintained by the Creator in the opposing chemical operations that we have noticed, under circumstances in which there would appear to be a liability to great and sudden variations. Leaves might give out more oxygen than would be used by lungs and fires, and then there would be an increase of the oxygen of the air, rendering every thing more combustible, and producing in animals fevers and inflammations. Or more carbonic anhydride might issue from lungs and fires and decaying matters than the leaves could absorb, and then carbonic anhydride would accumulate in the air, destroying life and extinguishing fires. But so accurately does the Creator adjust these opposite chemical operations, that production and consumption in the case of each substance exactly balance each other. World-wide are these operations, and they are carried on under circumstances which are not only various, but exceedingly variable; but an Almighty Power so controls them that the air, amid all its changes, preserves those proportions which exactly adapt it for the respiration of the myriads of animals, great and small, that swarm on the earth's surface.

132. **Nitrogen in the Chemistry of the Air.**—Although nitrogen constitutes four fifths of the atmosphere, it is not at all affected in most of the chemical changes which we have noticed in the preceding paragraphs. The oxygen and carbonic anhydride of the air are continually changing, but not so with the nitrogen. It goes into the lungs of the animal, and comes out unchanged, though the oxygen that went in with it is much lessened, and the carbonic anhydride is much increased. So also in combustion, however hot may be the fire, the nitrogen of the air comes out of it unchanged.

It goes into the fire with the oxygen, but parts company with that gas as it unites with the combustible substance. There is only one of the processes that we have mentioned, that of decay, which affects the quantity of nitrogen in the air, and this it does very slowly. Nitrogen, therefore, may be considered, in comparison with oxygen and carbonic anhydride, almost a fixed constituent of the air. So far as we know as yet, the only way in which the nitrogen of the air is lessened is by the occasional formation of nitric acid by electricity, the result of a union effected by this agent between some of the oxygen and nitrogen of the air in the presence of moisture. Only minute quantities of this powerful acid are produced in this way, and chemists have to use very delicate tests to detect it. It is useful in the promotion of vegetation, as you will see in another part of this book; and it is supposed that this is the purpose of its production, it being brought down by the rain as it falls, to soak with it into the earth. But comparatively little of the great bulk of the nitrogen can be used in this way, and this small diminution is met by a supply from the processes of decay.

133. **Air in Water.**—There is always more or less air in water. It is dissolved in it, for it is wholly hidden from view among the particles of the water, and does not appear in bubbles except in the act of escaping from its dissolved condition. This can be shown by a very pretty experiment. Place a vessel of water under the receiver of an air-pump, Fig. 33. You can see no air in it, and yet on exhausting the air from the receiver multitudes of small bubbles will arise, as represented. This is because the pressure is taken off from the surface of the water, and the air, therefore, which is dissolved in it, expands and escapes, its particles huddling together in bub-

Fig. 33.

bles as they pass upward. So, also, if water be boiled, the air that is dissolved in it escapes, being expanded by the heat, and rising with the steam.

134. **Composition of the Air that is in Water.**—The air that is dissolved in water is not of the same composition with the atmosphere. The ingredients are the same, but the proportions are different. There is a larger proportion of oxygen in the air that is in water. The reason is that oxygen is more soluble in water than nitrogen, and therefore water absorbs or dissolves more of the former from the air than it does of the latter. Here is a marked and obvious provision of Providence for the benefit of the inhabitants of the waters. As fishes and other animals that live in the water get so little air compared with animals that live out of the water, it is necessary that the air they breathe should have a larger proportion of that ingredient which is essential to the purposes of life.

135. **Experiment with Snow.**—What we have just stated furnishes the explanation of an experiment which was formerly a great puzzle to philosophers. The experiment is this: Let a glass bottle be filled with snow, and, corking it tightly, let the snow melt. You will, of course, have in the bottle water and the air which escaped from the snow as it melted. On examining this air it will be found to contain much less oxygen than common air does; and yet the air which was in the interstices of the snow was common air which became mingled with it as it fell. The question is, what has become of the missing oxygen. The answer is easy. A part of the air in the snow has been dissolved in the water; but since water dissolves a larger proportionate quantity of the oxygen of the air than of its nitrogen, the air which is not dissolved will contain a larger proportion of nitrogen.

136. **Oxygen Supplied to Fishes by Water-Plants.**—Fishes

are not wholly dependent upon the air for their oxygen. Plants that grow under water continually discharge oxygen from their leaves, just as is done from leaves in the air; and there is the same chemical commerce between animals and plants under water that there is in the air, though it is not so extensive. The fishes and other animals give carbonic anhydride to the plants, and take from them oxygen in return. The oxygen can often be seen gathered in globules on the surface of water-plants, waiting to be dissolved by the water. A suitable regard to this exchange between plants and animals under water suggests the presence of water-plants in an aquarium as a necessary part of the apparatus, they getting from the lungs of the animals carbon for their growth, and breathing back to them from the pores of their leaves oxygen in return.

137. **Water in the Air.**—As water dissolves air, so air dissolves water when the latter is in a gaseous state. There is always water in the atmosphere, even when it seems to be perfectly dry. It is invisible because it is in its vaporous form, and so its particles are intimately mingled with the gaseous particles of the air. This solution of water in air is like the solution of some solids in water. If alum, for example, be dissolved in water, it disappears, and so does the water dissolved in air. And as warm water will dissolve more alum than cold water, so will warm air dissolve more water than cold air. There is therefore more water in the air in summer than in winter. Sometimes there is as much as one gallon of water to every sixty gallons of the air. The analogy can be traced farther. If warm air be chilled in any way, it can not hold as much water in solution, and some of it, therefore, is separated from the air—that is, taken out from that intimate union which constitutes solution. This separated part of the water may appear as fog or cloud, or be deposited as dew or frost, or fall as rain,

snow, or hail. So, likewise, if you dissolve as much as possible of alum in hot water, and then let it cool, the water can not then hold as much alum in solution, and some of it will be separated and deposited.

138. **How the Air is Freed from Impurities.**—Impurities that rise in the air and become mingled with it become diffused widely, as the air is so continually in motion. If they were not thus diluted and dissipated they would do great harm to health, especially in cities. The falling rain is the chief means of ridding the air of them. Water is here, as every where, the grand purifier. The shower-bath which the air receives whenever it rains brings down most of these impurities, as it does the nitric acid formed by the lightning (§ 132), and mingles them with the earth, where they are used in vegetation.

139. **Proofs that the Air is a Mixture.**—You are now prepared to appreciate fully the proofs that air is a mixture. It was the prevalent doctrine, even for a long time after Priestley and Scheele had by their discoveries placed chemistry upon a rational basis, that air is a compound. This opinion was based chiefly upon the fact that the proportions of the ingredients are always the same in all free air. Then, besides, it was thought that if the air were merely a mixture of the gases composing it, they would be very prone to obey the influence of gravity, the oxygen taking its place under the nitrogen, and the carbonic anhydride under the oxygen. The disposition of gases to mingle together (§ 120) had not then been demonstrated and illustrated, or this ground of the doctrine would have been abandoned. At the present time all chemists regard the air as a mixture, and the proofs are briefly these: The ingredients of the air are separated from each other too easily to warrant the belief that it is a chemical compound. Then again, though the composition of all free air is always the same, the proportions of the ingredients

are varied under certain restricting circumstances. For example, the air in a close room where there are many persons has its oxygen lessened, and its carbonic anhydride increased, and still it is air—a mixture, but with the proportions of its ingredients altered. So, also, when air is dissolved in water, the proportions of its ingredients are not the same as before it was dissolved (§ 134). Then, again, the qualities of air are not wholly different from its constituents, as is the case with compounds (§ 85), but they are midway between those of oxygen and nitrogen. And, lastly, if we mingle these two gases in the same proportions that occur in air, the mixture has nearly all the properties of the atmosphere.

QUESTIONS.

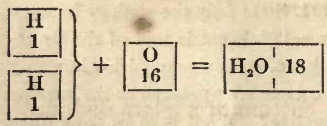
115. What are the ingredients of the atmosphere, and in what proportions?—116. How large is the total amount of carbonic anhydride in the air?—117. What is the chief use of nitrogen in the air? What would happen if all the air were oxygen?—118. Explain the two methods of analyzing the air. How is the moisture removed in the second operation?—119. What is said of the influence of gravitation on gases? What would result if there were nothing tending to counteract this?—120. Describe an experiment illustrating diffusion.—121. State fully the analogy between liquids and gases in regard to mingling.—122. What is said of the Grotto del Cane?—123. What of the accumulation of carbonic anhydride in wells? How can it be removed?—124. What two gases are produced by the burning of charcoal? Which is the most destructive? What is to be done when persons are suffering from the fumes of charcoal?—125. How can you show that carbonic anhydride is discharged from the lungs? What is a precipitate? Explain the experiments to illustrate this exhalation.—126. Why is the bad influence of poor ventilation not commonly appreciated? Are the bad effects of imperfect ventilation due to the carbonic anhydride solely?—127. What are the sources of carbonic anhydride in the air?—128. Describe the chemistry of the leaves.—129. What influence has the sun upon the chemistry of leaves?—130. State Priestley's experiment.—131. State in full what is said of the wonderful balancing power of the chemistry of the atmosphere.—132. How is nitrogen in contrast with the other ingredients

of the air in respiration? How in contrast with oxygen in combustion? How is the nitrogen of the air lessened? What is said of the nitric acid formed in the air?—133. How can you show that air is contained in water? —134. What is said of the composition of the air that is in the water?— 135. Describe the experiment with snow.—136. What is said of the chemical exchange between plants and animals in water?—137. What is said of the moisture in the air? Trace the analogy between this and the solution of solids in a liquid.—138. What is said of the diffusion of impurities in the air? How is it purified from them?—139. For what reasons was the air formerly thought to be a compound? What are the proofs that it is a mixture?

CHAPTER IX.

THE CHEMISTRY OF WATER.—HYDROGEN.

140. **Constituents of Water.**—Water, though a fluid, is composed of two gaseous elements. With the properties of one of these, oxygen, you have already become well acquainted. The other gas is hydrogen, so called because when chemically united with oxygen it produces water, the name being derived from two Greek words—*hudor*, water, and *gennao*, I form. In forming water, two volumes of hydrogen unite with one volume of oxygen, or two parts by weight of the former with sixteen parts by weight of the latter. All this is presented to the eye in the diagram, Fig. 34—the spaces representing the proportions of the two ingredients in bulk, and the figures their proportionate weights. You will notice that owing to the contraction which takes place, two volumes of water result



2 vols. + 1 vol. = 2 vols.

Oxygen	88.9	per cent.
Hydrogen	11.1	" "
Water	100.0	

Fig. 34.

from the combination of three volumes of the component gases.

141. **Decomposition of Water.**—Water may be decomposed—that is, resolved into the two gases of which it is made—in a variety of ways, both physical and chemical. We will first describe a method in which electricity is used, and then give you some chemical methods.

A current of electricity from a galvanic battery, generated as explained in Part I., decomposes water very readily. By employing the apparatus, Fig. 35, the gases may be collected separately. Through the bottom of a glass dish are introduced, water-tight, two platinum wires, *a c* and *a b*. Over each of these wires a tube, with its upper end closed, is placed. The tubes and the dish are filled with water, which is slightly acidulated in order to make it a better conductor. If now the wire *a c* be connected with the positive pole of a battery, and the wire *a b* with its negative pole, some of the water will be decomposed, and the resulting gases, oxygen and hydrogen, will collect in the tubes *e* and *f* respectively, driving the water down

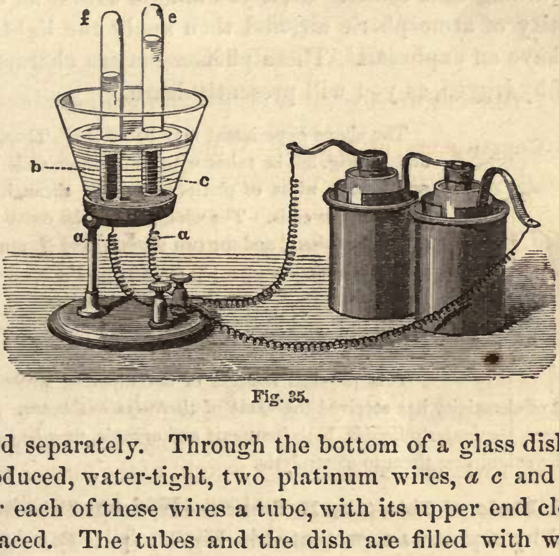


Fig. 35.

in them. You see that there is twice as much gas in *f*, the tube containing the hydrogen, as there is in *e*, the tube containing the oxygen; this confirms what we have just stated, viz., that two volumes of hydrogen unite with one volume of oxygen. If, when there is a sufficient amount of the gases collected, you cautiously remove the tube *e*, closing its mouth with your finger, and, turning it upside down, introduce into it a slip of wood with a spark on the end, the wood will burst into a flame—showing that the gas is oxygen. If now you remove *f*, and apply a light to its mouth, the gas will rush out, burning as it comes. Or, if you mingle with it an equal quantity of atmospheric air, and then apply the light, you will have an explosion. These phenomena are characteristic of hydrogen, as you will presently learn.

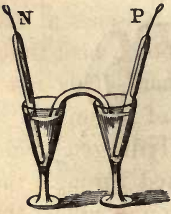


Fig. 36.

The above experiment may be varied. Thus, let P and N, Fig. 36, be tubes with their lower ends open, and having wires of platinum passing through their sealed upper ends. The wine-glasses, the curved tube connecting them, and the two tubes, P and N, are filled with acidulated water. On connecting P with the positive pole, and N with the negative, oxygen gas will collect in P and hydrogen in N, and as readily as they would if the tubes were in one vessel.

This physical method of decomposing water by a current of electricity has received the name of *electrolysis* of water. Many substances, particularly liquids, both inorganic and organic, may be decomposed by submitting them to electrolysis.

142. **Mode of Obtaining Hydrogen.**—Hydrogen can be obtained by a process represented in Fig. 37 (p. 113). A gun-barrel filled with clean iron turnings is placed across the fire in a furnace. Steam, or more properly water-gas, is made to pass through the barrel by means of a glass tube, which conducts from a flask where water is boiling by means of a gas-burner. The water-gas—that is, the water in the form of vapor—passing among the iron turnings, is decom-

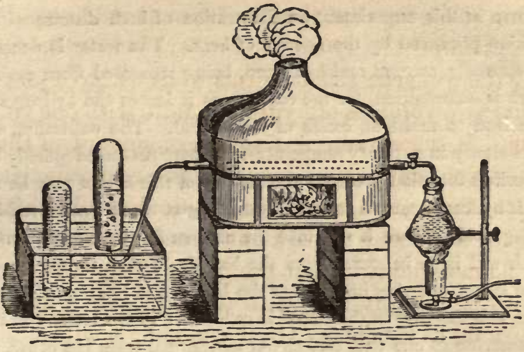


Fig. 37.

posed by reason of the attraction of oxygen and iron for each other. The oxygen of the water unites with the iron, forming an oxide of iron. This leaves the other constituent of water, hydrogen, to pass on alone. It issues at the other end of the barrel, and is conducted off by a bent tube, to be collected in jars in the usual manner. This reaction, expressed in the symbolic language of chemistry, is written thus: $4H_2O+Fe_3=Fe_3O_4+8H$. Hydrogen would not be formed if water were merely poured through the barrel. Neither would it if steam pass through, unless the iron turnings be heated to a high degree. You see, then, that a very great heat is required to make the iron decompose the water, or, in other words, to make the oxygen quit the hydrogen and unite with the iron. The object of having iron turnings in the barrel is to allow the steam to come in contact with a very extensive surface of iron. Bundles of knitting-needles are sometimes used, and, instead of a gun-barrel, a piece of iron gas-pipe. If the barrel were empty, but little of the steam would be decomposed. As it is, some steam may pass through unchanged; but if it does it is condensed in the water of the pneumatic trough, and does not pass on with the hydrogen into the receiving jar.

We have in this experiment an illustration of both decomposition and composition produced by the agency of heat. The water is decomposed, its two elements, oxygen and hydrogen, being separated from each other; and there is composition, for the oxygen, as it leaves the hydrogen, unites with the iron to make an oxide of that metal. The oxidation, which is produced slowly in ordinary temperatures, is here produced quickly by heat. It is a curious fact that precisely the reverse of this action may be made to occur. If hydrogen gas be passed through a gun-barrel heated red-hot, and containing oxide of iron, it will take the oxygen from the iron, forming water, which will issue in steam from the barrel. In the former experiment you have steam entering one end of the barrel and hydrogen issuing from the other, and the iron in the barrel is oxidized; in the latter you have hydrogen entering at one end, and steam discharged from the other, and the oxide of iron in the barrel is deoxidized.

143. A Better Method.—You can obtain hydrogen from water without having this great amount of heat applied, and therefore with a less cumbrous apparatus, as seen in Fig. 38. Some bits of zinc or of iron are put in water in a bottle, and sulphuric acid is poured in through the funnel tube. An effervescence at once appears, occasioned by the gas as it is produced from the water; and you must be careful not to pour in too much, lest the heat generated by mixing the strong acid with the water crack the glass bottle,

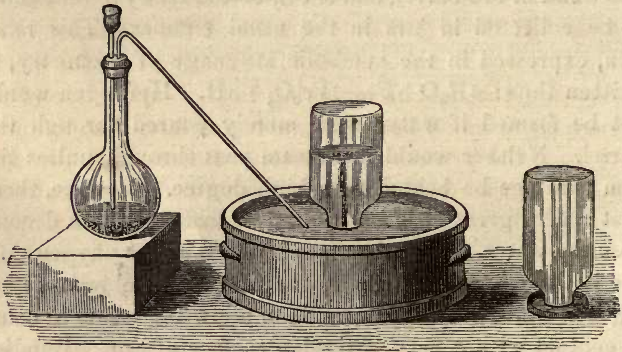


Fig. 38.

and lest effervescence be violent. When the effervescence slackens, more of the acid can be added. The gas passes out through the tube, which, like the funnel tube, is fitted in the cork, and is received in the jar standing in the pneumatic trough. The first portion of the gas must be allowed to escape, as it has the air which is in the flask and tube mingled with it, constituting an explosive mixture. The explanation of the process is this: The acid makes the oxygen of the water unite with the metal to form an oxide, and so the hydrogen is set free and rises in effervescence. This union does, indeed, take place when there is no acid present, but it is very slow; while the acid causes a rapid union, and therefore sets free at once a large amount of hydrogen. But this is not all. The acid not only turns the metal into an oxide, but it unites with that oxide, making with it a substance called zinc sulphate, which dissolves in the water. Observe the effect of this on the production of the gas. If the acid merely occasioned the formation of an oxide, this would make an insoluble coating over the metal, preventing the acid from acting farther upon it, and so, though there would be considerable gas formed at the first, very soon the process would stop. But as it is, the acid takes away the oxide as fast as it is formed, so that a fresh surface of the metal is constantly present for it to act upon. Sometimes a different sort of explanation is given; and the hydrogen is considered to come from the acid rather than from the water; the zinc replaces the hydrogen of the sulphuric acid, forming zinc sulphate, and the hydrogen is set free. This way of regarding the matter is shown in the following equation:

$$\underset{\text{Zinc.}}{Zn} + \underset{\text{Sulphuric acid.}}{H_2SO_4} = \underset{\text{Zinc sulphate.}}{ZnSO_4} + \underset{\text{Hydrogen.}}{H_2}$$

144. Forming Water by Uniting Oxygen and Hydrogen.—As the oxygen and hydrogen that constitute water may be separated from each other, as just described, so, on the other hand, water may be formed by uniting these gases. But they will not unite by merely being mixed together. Some force must be brought to bear on them to effect their union. Heat will do it when sufficient to produce combustion. Accordingly, when combustion takes place where there is hydrogen, the oxygen unites with the hydrogen, forming water; and this occurs very generally in most cases of what we call combustion, as you will see in the next chapter. Electricity, also, will do it. If a charge of electricity be passed through a mixture of the two gases, they will unite, and water will be formed.

To show this experiment an apparatus called a *Eudiometer* is employed. It consists of a strong glass vessel containing two platinum wires soldered into the glass and nearly touching at their points. The glass vessel is filled with two volumes of hydrogen and one volume of oxygen, and closed tightly with a well-fitting stopper. An electric spark is then passed between the wires, so that as it jumps from one end of a wire through the mixed gases to the other wire, the gases are intensely heated and unite with explosive violence. If the eudiometer is cooled and opened under water, water will rush in to fill the space left by the condensation of the gases. If, however, the eudiometer is placed in a vessel heated by steam to 100° C., the water-gas will be found to occupy two thirds of the volume of the mixed gases, provided they were measured at the same temperature and pressure. This confirms the statement already made that two volumes of hydrogen combine with one volume of oxygen to form two volumes of water-gas. (See § 34.)

$$\begin{array}{c}\boxed{\mathrm{H}}\\ \boxed{\mathrm{H}}\end{array} + \boxed{\mathrm{O}} = \boxed{\mathrm{H}_2 \,\vert\, \mathrm{O}} \quad \text{or } \mathrm{H}_2+\mathrm{O} = \mathrm{H}_2\mathrm{O}.$$

145. Specific Gravity of Hydrogen.—In Fig. 39 is represented the weight or gravity of hydrogen as compared with the gravity of some other substances. Platinum is the heaviest of all substances; hydrogen, on the other hand, is the lightest substance known. In the figure are represented equal quantities, by weight, of these two substances, as well as of water and air. Air is about fourteen and a half times as heavy as hydrogen, water more than eleven thousand times, and platinum nearly a quarter of a million times. Here is a tabular statement of the relative gravities of these substances:

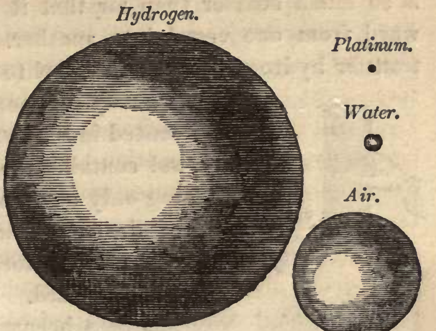


Fig. 39.

Hydrogen......................	1		
Air..............................	14.4	1	
Water..........................	11163	773	1
Platinum......................	239921	16626	21.5

In the first column, taking hydrogen as 1, the proportionate weights of the other substances are given. In the second column we call air 1, and in the third water.

146. **Hydrogen and Carbonic Anhydride Contrasted.**—Carbonic anhydride is twenty-two times as heavy as hydrogen. It is so much heavier than air that you can set a jar of it down with its mouth open, and the gas will remain in it for some time. Its weight tends to keep it in the jar, and it will only gradually escape by its disposition to mingle with other gases, as noticed in § 120. But if you set down a jar of hydrogen in this way, it rises out of the jar at once, precisely as oil would rise out of a jar plunged into water with its mouth upward. In order to keep the hydrogen in the jar it must be held with its mouth downward. We can follow the contrast farther. Carbonic anhydride

is so much heavier than air that it can be poured downward from one vessel into another. But if you wish to transfer hydrogen from one vessel to another, you must, as we may say, pour it upward, as represented in Fig. 40. Here the lower vessel contains the hydrogen. This being only one fourteenth of the weight of air, goes quickly upward into the upper vessel, forcing the air that is in it downward. You can not see the gas pass, because it is invisible; but a similar phenomenon can be made visible by emptying a vessel of oil into another under water. Here the lighter oil passes upward into the upper vessel, forcing the water down out of it, just as the hydrogen does to the air.

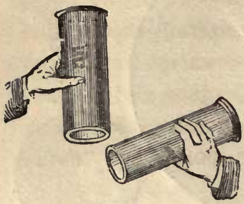


Fig. 40.

147. **Ballooning.**—Hydrogen gas has been much used in balloons. Montgolfier, a Frenchman, who was the first to make an ascent with a balloon, inflated it with heated air. This was in 1783, thirteen years after the discovery of hydrogen by Cavendish. Hydrogen is much better than heated air for inflation on two accounts—first, because it is so much lighter; and, secondly, because it retains its lightness, while the heated air becomes heavy by being cooled as the balloon is on its passage. Hydrogen was used in ballooning the same year that Montgolfier made his ascent, and yet Montgolfier balloons continued to be used to some extent even as late as 1812. Even so late as 1847, strange as it may seem, an ascent was made with one of these balloons by a Frenchman, Godard, who fell into the Seine, but was saved from drowning. At the present time gas balloons alone are used, and illuminating gas, a mixture of hydrocarbons, is employed for inflation, as this, though heavier than pure hydrogen, is sufficiently light, and can always be readily obtained from neighboring gas-pipes. Ascending

in balloons is exceedingly dangerous. We have seen a list of the most famous aeronauts, and of the whole forty-one there were fourteen killed, and various injuries were received by many of the others. Plainly, then, an ascent ought never to be made for mere show, and the only useful purpose that ballooning has yet subserved is for observation in time of war. During the war of 1871 between France and Prussia, both armies made use of balloons to a considerable extent. The people shut up in Paris sent out balloons nearly every day.

148. **Combustibility of Hydrogen.**—While oxygen is the grand supporter of combustion, hydrogen itself burns. The flame is very pale, and attended with so little light as to be almost invisible on a bright day. In Fig. 41 you have represented hydrogen burning from what has been called the "philosopher's candle." The materials for the production of hydrogen gas, noticed in § 143, are placed in the bottle, which has a tube fastened into the cork. Here, too, carelessness may occasion an explosion. The air must be expelled from the bottle before the "candle" is lighted.

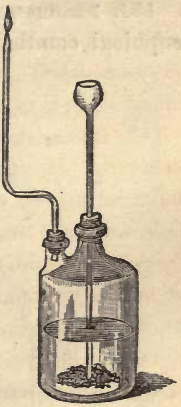


Fig. 41.

149. **Hydrogen Bubbles.**—The lightness and combustibility of hydrogen may both be very prettily exhibited by having a tobacco-pipe, *b*, Fig. 42, attached to the stop-cock, *a*, of an India-rubber gas-bag filled with hydrogen. If the pipe be introduced into soap-suds while the stop-cock is opened and the bag is pressed upon, soap-bubbles will rise in the air, which, on being touched with a light, quickly burn with a slight explosion, occasioning a popping sound.

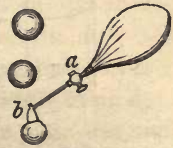


Fig. 42.

150. Hydrogen not a Supporter of Combustion.—Though hydrogen burns, it does not support combustion. This may be shown by the following experiment: Let there be introduced into the bell-jar, *a*, Fig. 43, filled with hydrogen, a lighted taper. It will set the hydrogen on fire at the mouth of the bell-jar, but will itself go out as soon as it is immersed in the gas. If you take it immediately out, it will be relighted as it passes through the burning hydrogen at the mouth of the glass jar, and the putting out and relighting may be repeated several times in succession.

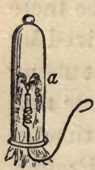


Fig. 43.

151. Production of Musical Sounds.—If you let a "philosophical candle" burn in a tube, as seen in Fig. 44, musical sounds will be heard, which will be varied in their note by the size of the tube, and by raising or lowering it. The sound is owing to the vibration of the air confined in the tube, caused by the burning of the hydrogen. This experiment is not peculiar to hydrogen, but may be made with a small jet of coal gas. In the first-named form it is sometimes called "*Harmonica chemica.*"

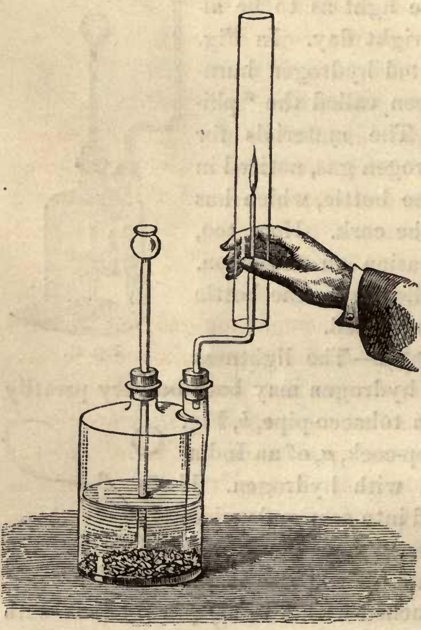


Fig. 44.

152. **Breathing Hydrogen.**—This gas can not be breathed alone for any time, simply because life can not be continued without oxygen. But oxygen and hydrogen can be breathed together with impunity, showing that hydrogen does not act as a poison when introduced into the lungs. It is in this respect like nitrogen, and unlike carbonic anhydride. Of course it can be breathed with air, though not in so large proportion as with pure oxygen.

153. **Sounds in Hydrogen.**—If a bell be rung in a jar of hydrogen gas the sound can be scarcely heard, because the gas is so very rare a medium. It is for the same reason that sounds are so faint in the attenuated air on the tops of very high mountains. So, also, if one speaks immediately after breathing in a mixture of hydrogen with oxygen or air, his voice has a small, squeaking sound. If the common speaking toy be made to utter its voice in a jar of hydrogen, as represented in Fig. 45, the sound is very laughable.

Fig. 45.

154. **Illuminating Gas.**—In the common gas that we burn we have a mixture of hydrocarbons, or compounds of hydrogen with carbon. There are two forms of this combination, or rather two distinct compounds. They are marsh gas and olefiant gas, sometimes called the light and the heavy carburetted hydrogen. There is exactly twice as much carbon in the latter as in the former—one being CH_4, and the latter C_2H_4. The light carburetted hydrogen is the *fire-damp* of coal-mines, which by its explosions destroyed so many lives before Sir Humphrey Davy invented his safety-lamp (Part I.). It is also one of the products when

vegetable matter decays under water, and hence its name, *marsh* gas. You can very easily secure some of this gas from the mud of a pond in the way shown in Fig. 46. A bottle filled with water is held inverted in the pond with a funnel in its mouth, and the mud is disturbed underneath with a stick. When the bottle becomes filled with gas, close it with a cork before removing it from the water. There are two gases together in the bottle—carburetted hydrogen and carbonic anhydride. In order to get rid of the latter you must introduce something which will combine with it, and not with the carburetted hydrogen. It is done in this way: Pour a little water into the bottle, and then introduce a piece of quicklime or of potassium hydrate, and, quickly returning the cork, shake the bottle a few minutes. The carbonic anhydride is thus made to unite with the calcium or potassium, forming a carbonate. Remove now the cork from the bottle, with its mouth under water. Some of the water will go up into the bottle, to take the place of the carbonic anhydride which has disappeared. If now you apply a lighted match to the mouth of the bottle, the gas will take fire and burn with a blue flame. By pouring water,

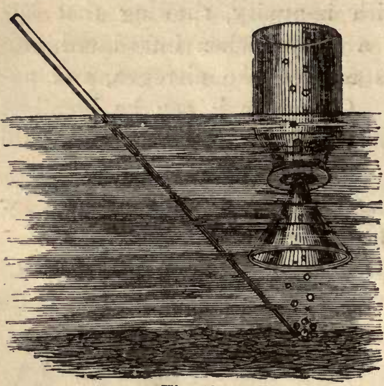


Fig. 46.


Fig. 47.

Fig. 47, at the same time into the bottle you expel the gas, and thus keep up a brisk burning till the gas is all consumed. In the common illuminating gas we have a mixture of olefiant and marsh gas. The brightness of the flame is owing to the greater quantity of carbon which is in the former, as will be noticed more particularly in the next chapter.

155. **Hydrogen Peroxide,** H_2O_2.—Water was for a long time supposed to be the only compound of oxygen and hydrogen. It is really the only compound existing in nature; but another can be produced by a chemical process that has exactly twice as much oxygen in it as water. It is called hydrogen peroxide, water being considered as an oxide. This substance has very peculiar qualities, differing greatly from those of water. It is a sirupy, colorless, transparent liquid, having a slight odor, and a very nauseous and astringent taste. The quality in which it differs most from water is that no degree of cold can freeze it. The contact of carbon will decompose it instantly, often with an explosion and a flash of light. Heat also decomposes it, producing an effervescence. This singular compound seems to have no tendency to combine with any other substance, and as yet has not been found to be of any value, but a mere chemical curiosity.

156. **Nature of Hydrogen.**—It is a common supposition among chemists that hydrogen is a metal having two oxides, water and hydrogen peroxide. At first thought it seems impossible that this is true of the lightest substance in the world. Metals we are accustomed to think of as being heavy and solid. But, as you will see in a future chapter, there are some metals sufficiently light to float on water. Besides, we have one metal, mercury, that is a liquid, and why should there not as well be a gaseous metal? And, farther, the metal mercury is in a state of invisible vapor in the space over the metal in every thermometer and barometer. If a metal, then, can thus be gaseous under certain circumstances, what difficulty is there in conceiving one to be so under all ordinary circumstances? Moreover, a compound of the very rare metal palladium with hydrogen has

been made, which acts much like a true alloy, and confirms the view that hydrogen is a metal.

157. **How Compounds and Mixtures Differ.**—We have already stated the proofs that air is a mixture. Having now become acquainted with the composition of water, you readily see, in regard to air and water, the two grand distinctions between compounds and mixtures. 1. A chemical compound differs wholly in its character from either of its constituents, while a mixture does not. Water is entirely unlike either the oxygen or the hydrogen that compose it; but air is in many respects like the oxygen and nitrogen, which are its chief ingredients, having a mixture, as we may say, of the qualities of the two gases. So, also, is the difference strikingly illustrated by contrasting air with nitric oxide, as has been shown in § 85. 2. A compound always contains precisely the same proportions of its elements; but in a mixture the proportions may be made to vary more or less. Thus water always contains the same proportions of oxygen and hydrogen; but you can take away a part of the oxygen of the air and increase its carbonic anhydride (§ 126), and it will be air still, though not good and healthful.

158. **Water as a Chemical Agent.**—Though water is a very mild substance, and not powerful like the acids, it has a great deal to do with the chemical operations every where going on, as you will see as we proceed with the investigation of other subjects. It is the common solvent of the world, dissolving, as you have already seen, gases, as well as liquids and solids. It unites, as you will learn in § 159, chemically with many substances, being incorporated intimately with them as water. Some solids can not exist in a crystalline form without having a certain amount of water in them, and this is said to be their water of crystallization. Then in the vegetable kingdom water is decomposed to a consid-

erable extent, and its elements are used in the formation of almost every variety of vegetable substance.

159. **Water of Crystallization.**—In the crystals of many substances there is considerable water. This is the case with crystals of sulphate of lime, commonly called plaster of Paris. A little over one fifth by weight of these crystals is water. They are perfectly dry, because the water is combined with the substance making a part of the solid. The water is in this case really solidified without freezing. Not only is it a part of the crystals, but they could not be formed without it. Drive out the water by heat, and the crystals fall to pieces, and you have the plaster of Paris in powder. This water, thus essential to the existence of the crystals of this substance, is called its water of crystallization. Burned alum is alum deprived of this water by heat, and therefore its crystalline arrangement is lost. The amount of water required for crystallization varies in different substances. The crystals of Epsom salts, so familiar to you, are fully half water. You may perhaps have noticed that sometimes some of the crystals of this salt have changed into a white powder. This is because some of the water of crystallization has escaped into the air. Any crystalline substance which is apt to have this occur is said to *effloresce.* When a substance has a tendency to absorb water from the air and run to liquid, it is said to *deliquesce.* Do not confound these terms.

Water of crystallization is usually written separately in formulæ, because it seems to be less closely connected with the body than are the atoms composing it. Thus crystallized gypsum is $CaSO_4+2H_2O$, and anhydrous gypsum is simply $CaSO_4$. Epsom salts is $MgSO_4+7H_2O$.

160. **Ammonia.**—Hydrogen and nitrogen united in the proportion of three atoms of the former to one of the latter form a colorless, alkaline, pungent gas called ammonia. Its formula is therefore NH_3. It is one of the products of the decomposition of both animal and vegetable substances. You therefore perceive its pungent smell in the stable; and it is also emitted from guano, the bird-manure which has for many years been imported into this country from certain islands. Ammonia is obtained for the purposes of commerce as a secondary product in the distillation of coal. The nitrogen of the coal unites with the hydrogen to form ammo-

nia, which distills over and condenses in the water used to wash the coal gas. It can also be obtained by distilling animal substances, especially bones. It received the name hartshorn from having been formerly obtained by the distillation of the horns of harts and deer. The name ammonia comes from sal ammoniac; and this was so called because it was first manufactured near the temple of Jupiter Ammon by the distillation of camels' manure.

161. **The Production of Ammonia Explained.**—If you introduce into a vessel the two gases of which ammonia is composed, you can not in any way make them unite to form this substance. You may heat them to any degree, and they will not unite chemically, but will only be mixed together. But if you let these gases be together at the moment that they are produced, they will unite and form ammonia. We will give you an illustration. If you heat some potassium hydrate and iron filings together in a flask, hydrogen will be produced; and if you heat iron filings and potassium nitrate in another flask, nitrogen will be produced there. Now if you conduct these two gases from these flasks by tubes into another vessel, you will have only a mixture of them; but if you put all the materials into one flask, nitrogen is liberated from the potassium nitrate, and hydrogen from the potassium hydrate just as before, and the two gases, being in each other's company at the moment they are produced, unite and form ammonia. The chemist, therefore, says that they must be in their *nascent state* in order to unite, as explained in § 42. Ammonia is formed in the decomposition of animal and vegetable substances, because the two gases nitrogen and hydrogen are evolved simultaneously, and are present in their nascent state.

162. **Preparation of Ammonia.**—Ammonia is never actually prepared by heating the substances named above,

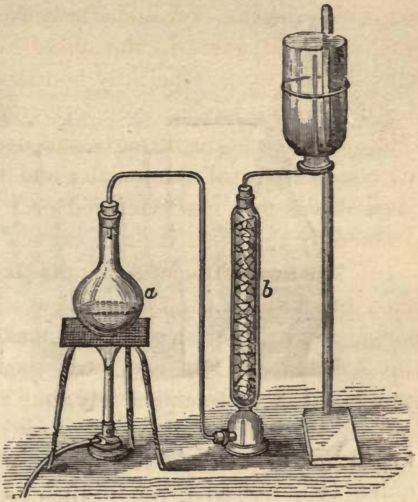


Fig. 48.

but is obtained for the chemist's use by heating sal ammoniac (or ammonium chloride) with lime. The materials may be mixed in a glass flask, and a gentle heat suffices. The gas is lighter than air, and may be collected by *upward* displacement, as represented in Fig. 48. The reaction is as follows:

$$\overset{\text{Ammonium chloride.}}{2(H_4NCl)} + \overset{\text{Lime.}}{CaO} = \overset{\text{Calcium chloride.}}{CaCl_2} + \overset{\text{Water.}}{H_2O} + \overset{\text{Ammonia.}}{2(H_3N)}$$

Ammonium salts will be studied farther on.

163. **Water of Ammonia.**—Water eagerly absorbs ammonia, and can dissolve nearly five hundred times its bulk of this gas. The gas, in thus uniting with the water, becomes greatly condensed, for it occupies a space nearly five hundred times as small as it did before it was dissolved. We say nearly, for the water is somewhat increased in bulk by dissolving the ammonia, the specific gravity of the solution being .870 compared with water reckoned as 1. This solution is prepared in the apparatus represented in Fig. 49 (p. 128). The ammonia is generated in the first flask, and enters the water contained in the three-necked bottles (called Woulfe-bottles), saturating them successively. The pungent odor of this water of ammonia when in its full strength is exceedingly strong. If it be applied to the skin, its irri-

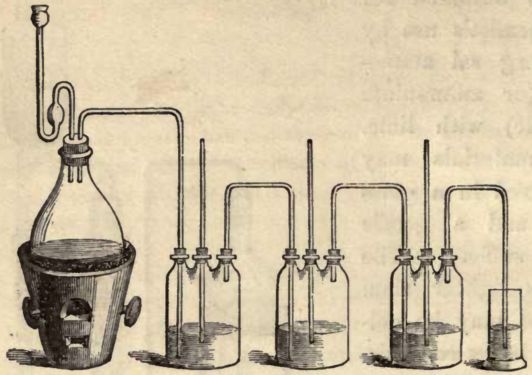


Fig. 49.

tation will even blister. When given as a medicine it requires to be considerably diluted. If an overdose be taken by accident, the best antidote is one which is always at hand—viz., vinegar, which forms with the ammonia a salt that is harmless. The water of ammonia with sweet-oil forms a soapy liniment—the volatile liniment so much used as an external application. The disposition of this solution to form soapy compounds with fatty substances makes it very effectual in removing grease spots from woolen clothes.

Both the gas ammonia and the solution react strongly alkaline, turning reddened litmus paper blue.

164. **Cyanogen,** CN.—Carbon and nitrogen unite to form a colorless gas of a penetrating odor much like that of hydrocyanic acid, its compound with hydrogen. It forms cyanides with the metals, as chlorine, iodine, etc., form chlorides, iodides, etc. Because of this and its formation of an acid with hydrogen it is classed with these elements. Yet it is not an element, but a compound, the constituents of which are carbon and nitrogen. A body which is compound, and yet acts in some respects like an element, is called a *rad-*

ical; you will see that radicals play a very important part in organic chemistry.

165. **How Cyanogen is Obtained.**—Though you can make carbon and oxygen unite, forming carbonic anhydride, and oxygen and hydrogen, forming water, you can not make carbon and nitrogen unite to form cyanogen. This substance can be obtained only in an indirect manner. A cyanide of some metal is first formed, and then the cyanogen is obtained from this. We will state the process by which one of the cyanides, the cyanide of potassium, is formed. Potassium carbonate is strongly heated with some refuse animal matter, as leather, horn, or dried blood. The animal matter furnishes the elements of cyanogen, carbon and nitrogen, which in their nascent state unite to form cyanogen, and this, seizing the potassium of the potassium carbonate, forms cyanide of potassium. But the carbonic acid and oxygen of the potassium carbonate are not yet accounted for. How are they disposed of? They, together with a portion of the carbon evolved from the animal matter, form carbonic oxide gas, which passes off. The cyanide is left mingled with some refuse, from which it is separated by alcohol, which dissolves only the cyanide.

166. **Prussic or Hydrocyanic Acid.**—This acid is composed of two gases, hydrogen and cyanogen, and hence its proper chemical name is hydrocyanic acid. In its pure, undiluted state it is the most deadly of poisons: a drop or two put upon the tongue of a dog causes instant death. It is a colorless, limpid fluid, having a peculiar and powerful odor, like that of peach blossoms and bitter almonds. The odor from these is caused, indeed, by a very minute quantity of this acid. And so, also, the flavor of distilled waters of the cherry, laurel, and bitter almonds, etc., comes from this acid very largely diluted. Indeed, this is an organic acid, produced in certain vegetables by means of the processes alluded to in the second division of this work. The chemist does not obtain this acid by extracting it from the vegetable substances in which it exists in so diluted a state; but he heats certain cyanides with sulphuric acid in a distilling apparatus, and collects the acid in a cool receiver. This is a dangerous experiment, and we will not describe it further.

QUESTIONS.

140. What are the constituents of water? What proportion of each by weight and by volume?—141. Describe a physical method of decomposing

water. What is electrolysis ?—142. Explain the process of obtaining hydrogen by decomposing water by means of red-hot iron. What reaction takes place? How does this experiment illustrate decomposition and composition? —143. Give in full the best method of preparing hydrogen gas. Give the explanation of the chemical reaction.—144. Under what circumstances will oxygen and hydrogen unite? How is a eudiometer used?—145. How does the specific gravity of hydrogen compare with that of other substances? Explain the table.—146. Give the contrast between hydrogen and carbonic anhydride. How is hydrogen transferred from one jar to another?—147. What is said of ballooning? When should balloons be used?—148. What is hydrogen in relation to combustion? Explain the "philosopher's candle." What caution is needed to prevent explosion?—149. Describe the experiment represented in Fig. 42.—150. How may it be shown that hydrogen is not a supporter of combustion?—151. Describe and explain the effects produced by burning hydrogen in glass tubes.—152. What is said of breathing hydrogen?—153. What of sounds produced in this gas?—154. What is the composition of illuminating gas? What is the *fire-damp* of coal-mines? What is marsh gas? Describe the mode of collecting it represented in Fig. 46. How is it freed from the carbonic anhydride that is mingled with it? Describe the experiment represented in Fig. 47. To what is the brightness of illuminating gas owing?—155. What is said of hydrogen peroxide?—156. State in full what is said of the nature of hydrogen?—157. State and illustrate the differences between compounds and mixtures.—158. What is said of the extent of the chemical agency of water? Mention some of the ways in which this agency is exerted.—159. What is meant by water of crystallization? Give examples. What is efflorescence? What deliquescence? How is water of crystallization usually expressed in formulæ?—160. What is ammonia? Where does it occur? Whence its name? —161. Explain its production.—162. Describe the preparation of ammonia. Write the equation.—163. What is said of the solution of ammonia in water?—164. What is cyanogen? What is meant by a radical?—165. How is cyanogen obtained?—166. What are the properties of hydrocyanic acid?

CHAPTER X.

COMBUSTION.

167. Importance of the Subject.—The interest attending the subject of combustion is very great, because the chemical processes involved in it produce such varied and extensive effects in the world. We are dependent upon combustion in many ways for our comfort and enjoyment, and even for the continuance of life. The preparation of our food is effected in part by combustion. We guard by it against the influence of cold. Nay more, it is by a real combustion, though without flame, that the heat of our bodies is maintained, as we shall show you in a part of this chapter. Combustion gives us our light in the darkness of night. It is very busy in many of the arts, especially in preparing the metals for the various uses to which we appropriate them. In these latter days it has been put extensively to a new use, in propelling steamers on the water, and locomotives on the iron roads that thread the land. It is by combustion, also, that the missiles of war are hurled. The grandest scenes of destruction witnessed in the earth come from combustion—conflagrations of towns and cities, and forests and prairies; explosions of masses of combustible material, and, above all, the bursting forth of the immense and lofty volcanoes. Combustion, then, is one of the principal things with which man has to do, and therefore a thorough knowledge of it is not only interesting, but of practical importance. As the old proverb has it, fire is a good servant, but a bad master; and we trust that you will see as we proceed that an acquaintance with the chemical processes which it involves helps us to keep it in our service, and to prevent it from gaining the mastery. We have had considerable to say incidentally about combustion in the previous chapters, but the subject demands a full and systematic consideration.

168. **Early Ideas of Combustion.**—Fire was regarded by the ancients as an element; this view prevailed largely during the Middle Ages also, but gave way about the year 1700 to the idea that all combustible substances contain a certain principle called *Phlogiston*, which escapes when they burn. This theory, promulgated by Stahl, a celebrated German physician, was accepted for nearly a century, but was eventually abandoned when the discoveries of Priestley, of Lavoisier, and others made chemistry a rational science.

169. **Chemistry of Common Combustion.**—In the combustion which we commonly witness there occurs a chemical union between oxygen, on the one hand, and carbon and hydrogen on the other. The oxygen, in uniting with the carbon, forms carbonic anhydride, which is diffused as gas in the air. In uniting with the hydrogen it forms water in the shape of vapor, which passes upward in company with the carbonic anhydride. That this is the chemistry of ordinary combustion you will see as we proceed to consider its different modes and circumstances.

170. **Burning Gas.**—In the burning of hydrogen gas we have only the union of this gas with oxygen, forming water. That this is the product can be proved by holding a glass bell-jar over a burning jet of hydrogen gas, Fig. 50 (p. 133). It will soon become bedewed all over the inside with moisture, and if the experiment be continued drops of liquid will at length trickle down, which, if caught in a vessel and examined, can be proved to be water. The metal sodium, as you will hereafter learn, burns on touching water; so

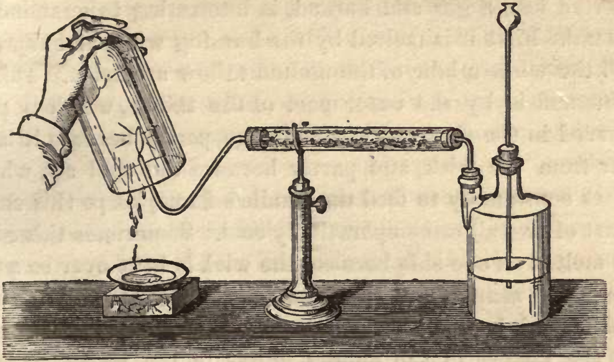


Fig. 50.

a little piece of this metal may be thrown into the bell-jar to show that water has formed on its sides. In the flame of burning coal gas we have both the unions mentioned in § 169, producing water and carbonic anhydride. The coal gas consists of a mixture of several hydrocarbons, or bodies consisting of hydrogen and carbon chemically combined. Both of these in burning unite with the oxygen of the air. In doing this, however, the carbon and hydrogen become separated from each other. The hydrogen, being more combustible than the carbon—that is, more ready to unite with oxygen—burns first, and the little separated particles of carbon burn in the flame of the hydrogen, giving to it its brightness. The little bright flashes that you see continually shooting up in a gas-light are occasioned by the burning of these minute particles of carbon.

171. **Chemistry of a Candle.**—The same thing substantially occurs in the combustion of a common candle. The flame here is burning gas, and consists of nearly the same gases as those which issue from a gas-burner. The tallow is composed of carbon and hydrogen. The process, or rather series of processes, by which this solid compound is con-

verted into a gas and burned, is interesting to examine in detail. First it is melted by the burning wick, and there is all the while a lake of the melted tallow around it. This is hemmed in by the outer part of the tallow, which is preserved in the shape of a raised edge, partly because it is so far from the wick, and partly because the cool air, which rises continually to feed the candle's flame, keeps this outer part of the tallow comparatively cool. Sometimes this edge is melted on one side because the wick is bent over so as to be quite near it, and then the tallow runs down from the lake which is about the wick. The next step in the process is the raising of the melted tallow in the wick. This is done by capillary attraction, which is explained in Part I., Chapter VI. Then the tallow is vaporized by the heat, and lastly it is burned—that is, it unites with the oxygen of the air, forming carbonic anhydride and water, precisely as is done in the burning of illuminating gas. That water is formed you can prove in the same way that it was proved of the burning of hydrogen gas in the experiment presented in Fig. 50. That carbonic anhydride is formed can be proved by an experiment shown in Fig. 51. A small funnel is suspended over a candle, and is connected by a tube with a bottle containing lime-water. Another tube passes from this bottle to the mouth of the experimenter. You see that the tubes are so arranged that by the suction of the mouth the gas from the candle can be made to pass

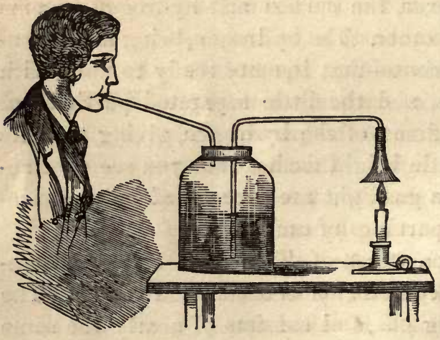


Fig. 51.

into the lime-water. There it will form a milky cloud, which on settling is found to be calcium carbonate or chalk, proving that the gas produced by the burning of the candle is carbonic anhydride. It is just as we prove carbonic anhydride to be discharged from the lungs, as described in § 125.

172. **Structure of the Candle's Flame.**—The flame of a candle is quite a complex affair. You can see that it is not simply one thing, for some of it is dark, and that which is bright is not all equally so. It is really a shell of burning gas, containing within it a body of gas that is not on fire. The shell itself is not one thing, as you will see when we describe Fig. 52, which is a sort of map of the whole. At 3 we have the gas that is not yet on fire. This is the melted tallow which has come up the wick, and is now vaporized by the heat. Around this interior dark cone is a very bright envelope, at 2 in the figure, formed by active combustion of the hydrocarbons, and containing the little red-hot particles of carbon which, sparkling brightly, give to this part of the flame its strong light. Then at 1, the outer part of the shell, the fine carbon is finishing its burning by uniting thoroughly with the oxygen of the air to form carbonic anhydride. This outside portion of the shell is called the mantle, and this is the hottest part of the flame. Observe why the gas at 3 is not on fire. It is shut in by the shell of flame around it from the oxygen of the air, and there can

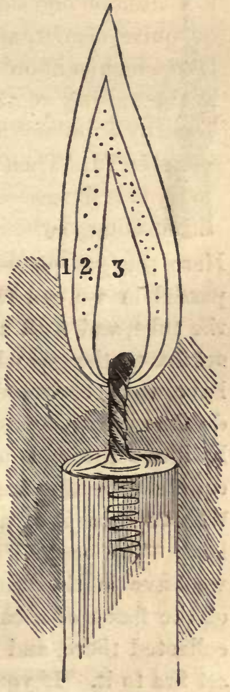


Fig. 52.

be no burning without oxygen. But as the gas is continually forming, and pressing upward and outward, some of it passes all the time into 2, where it mingles with the oxygen and takes fire. While the form of each of the parts of the flame remains the same, the matter in them is continually changing.

173. **Experiments.**—What we have said of the flame of a candle can be verified by many very interesting experiments. If we place one end of a small tube in the dark part of the flame, Fig. 53, some of the unburned gas will pass through the tube, and may be lighted at the other end. This experiment may be tried in another form, as represented in Fig. 54. Here the gas passes into a flask. After considerable has passed in we can take out the tube, and with a match set fire to the gas which we have thus collected. We do the same thing essentially if we throw a piece of candle into the flask, and then vaporize it by a strong heat. The same gas that we have in the dark part of the flame of a candle is collected there, and we can set fire to it. If you put a small slip of wood directly across the flame of a candle, just above the wick, so that the middle of it will be in the dark part, and hold it there a few seconds, on taking it out

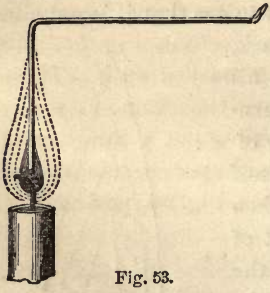


Fig. 53.

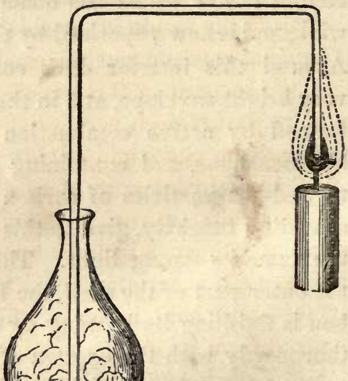


Fig. 54.

you will find that the middle is not burned at all, while it is charred where the outer portions of the flame touched it. So, also, it is possible to thrust a match so quickly into the dark part of the flame that the phosphorus on its end will not take fire, while the wood that is in the outer part of the flame burns readily. For the same reason a piece of white paper pressed down on the flame, nearly to the wick, for an instant, Fig. 55, will have a black ring marked on it. These experiments prove that flame is really hollow. If you blow out a candle, and present a lighted taper to the smoke at the distance of two or three inches, Fig. 56, you can see a train of fire go along the smoke till it reaches the candle and lights it. This train of fire is the burning of the gas that you blow from the inside of the shell of flame as you put out the candle. To succeed in this experiment you must do it very quietly, and at the same time quickly.

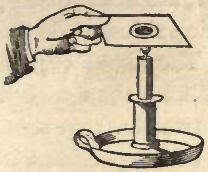


Fig. 55.

174. Experiment with Metals.—If you take a slip of some metal, as copper, which is tarnished—that is, oxidized on its surface—and hold it across the flame, the tarnish will be removed from its middle portion, while it will be increased each side of this where the metal is in contact with the very outer part of the flame. The explanation is this: In this outer faint blue part of the flame there is plenty of oxygen from the surrounding air, and some of this unites with the metal, increasing the oxide or tarnish. But in the inner

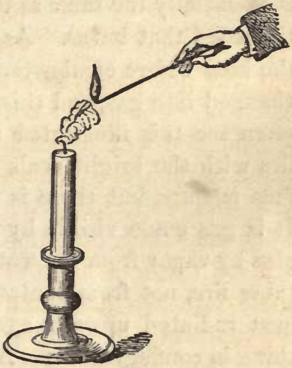


Fig. 56.

part, where the uninflamed gas is, there is no oxygen, and the heated hydrogen and carbon are ready to unite with oxygen, and so take it from the surface of the metal. Then, too, in the bright part of the flame there is not a free access of oxygen, and therefore the oxygen combined with the metal is taken and used in the burning. The portions of the flame, then, marked 2 and 3 in Fig. 52, are deoxidizing; that is, they take oxygen, *de*, from metallic oxides, while the outer portion of the flame is oxidizing. The above experiment is more satisfactory with a spirit-lamp than with a candle, because in that there can be no trouble from soot. A tarnished copper cent will answer for this experiment if held with a pair of pincers horizontally in the flame.

175. **Combustion of Wood.**—The flame of burning wood is essentially the same as that of the candle. It is not really the wood that burns. As the tallow is turned into gas by the heat before combustion occurs, so a part of the wood is changed into gas, and this, burning, makes the flame. You often see this illustrated in the kindling of wood. As it lies with the bright coals beneath it, at first its under surface smokes, but there is no flame. What is this smoke? It is gas made visible by particles of carbon, and perhaps also by vapor from the water in the wood. Soon this smoke takes fire, not from contact with the coals, but from their heat radiated upward against it. We often see the same thing in conflagrations. A wooden building, perhaps across the street from the one that is on fire, begins to scorch and smoke, and soon bursts into a flame. In these instances you have clear illustrations of the fact that the formation of gas and its combustion are two distinct processes. As another example, we often see jets of gas blowing out from some crevice in the wood, and set on fire by the heat. The gas is generated in the wood by the heat, and comes out of the crevice as from a gas-burner. If you hear the sound of

such a blowing forth of gas, and see no flame, you can at once produce a flame by applying a burning match to the crevice, just as you do by applying it to the opened orifice of a common gas-burner.

176. **Nature of Flame.**—To understand the cause of flame we must remember that it is produced by burning gases only; solid bodies, heated ever so intensely, emit light and may burn, but they can not make flame if they are incapable of being converted into vapor. Thus a piece of iron or silver may be heated hot enough to give out light, but can not burn with a flame. So with carbon, which burns without flame when alone.

In the examples mentioned the flame is caused by the combustion of the gaseous hydrocarbons.

177. **Combustion of Coal.**—In the combustion of anthracite coal when fully ignited there is no flame, for it contains no hydrogen, but is nearly pure carbon. Its combustion is like that of wood-coals, or charcoal. The reason that anthracite contains no hydrogen is that in its formation all volatile matters were driven off by heat. There is a blue flame given off by anthracite coal when it is kindling, and especially when a hot fire is freshly fed with coal, arising from the generation of carbonic oxide, noticed in § 112; but when the coal is fairly ignited it burns without flame. Bituminous coal, on the other hand, burns with a flame because it contains hydrogen as well as carbon.

178. **Manufacture of Gas.**—If you place some shavings in a test-tube, Fig. 57, with a cork in its mouth having a tube fixed into it, and apply heat, illuminating gas will pass out through the tube, and you can


Fig. 57.

light it. The same effect will be produced if you use bituminous coal, or oil, or tallow. The explanation is this: The heat sets free the hydrogen and the carbon in the form of carburetted hydrogen, just as it does in the case of the candle. The gas that we burn in our houses is made from coal substantially in the way indicated in the above experiment. It is made in large iron retorts. It has many impurities mingled with it, which are removed by certain chemical processes before the gas is distributed in the pipes. Gas which is made from oil is purer, and gives a stronger light, than that which is made from coal.

179. **Results of Combustion.**—The results of combustion are of two kinds—those which pass off in the form of gas or vapor, and those which are deposited in a solid form. When a gas burns, the results are all aeriform. The vapor, however, that is formed by the burning of hydrogen may be condensed into a liquid form, or even be made solid in the form of snow, hail, or ice. The results of the combustion of some solids are wholly aeriform, as, for example, in the case of the candle, whether it be tallow, wax, or stearine. The results in the case of some solids, on the other hand, are wholly solid. When a metal, as iron, burns, not a particle of it passes off as gas, but it all falls as a solid oxide. When wood or coal burns, the results are both aeriform and solid, the latter being in the form of ashes. The ashes of different substances vary much both in character and in quantity. When wood is burned, out of every 100 pounds about 2 are ashes, while 98 pounds fly off into the air by uniting with oxygen to form carbonic anhydride and water. Of what ashes are composed we shall speak particularly in another place.

180. **Expedients for Increasing Combustion.**—When any thing is burning, the greater the supply of oxygen the more brisk and perfect will be the combustion. If we blow

a fire, we bring more air, and therefore more oxygen, to it. The coals therefore brighten, the combustion being made more active, and this increasing the heat, the wood burns more briskly, or, if not burning at all, soon bursts into a flame. It is chiefly for the same reason that when a building takes fire there is great danger that the fire will extend to other buildings. So, also, whatever increases the draught of a chimney makes the fire more brisk. On this account the chimneys of foundries and other factories, in which a very hot fire is needed, are made very tall. For the same reason the tall chimneys of lamps cause them to give a very bright light. If you should take the chimney from a lamp that is burning brightly, leaving the wick at the same height, there would be a great smoke, because the oxygen would not come to the wick with sufficient rapidity to unite with all the carbon and hydrogen that go up from it. A flat wick gives a brighter light than a round one, because it presents a larger surface to the oxygen of the air. Still more light is given if a flat wick have a circular arrangement, the air being admitted inside as well as outside of the circle. This is the construction of the well-known Argand burner.

181. **Bunsen's Burner.**—By increasing the supply of oxygen to a flame we increase its luminosity; but if we mix the combustible gases with oxygen before igniting them, the resulting flame gives scarcely any light at all. This will not seem so strange if you understand that the particles of carbon are completely burned up in the mixed gases. Such a flame is not only smokeless, but deposits no soot on cold surfaces placed in it, and consequently is a very clean flame to cook or heat with. Many forms of stoves and lamps have been contrived which produce this colorless and very hot flame; the one commonly used in chemical laboratories is called Bunsen's Burner, after the great

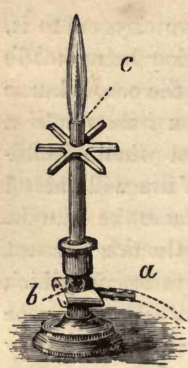


Fig. 58.

German chemist who invented it. Coal gas enters at *a*, Fig. 58, and air enters at *b;* they mix in the tube before they issue at *c*, and on applying a light at this orifice we have a very clean hot flame. By stopping up the hole, *b*, with your fingers you can cut off the supply of air, and consequently of oxygen, and the flame will instantly change its appearance, burning with the usual partially smoky yellow light of ordinary coal gas. Removing your fingers, oxygen enters, a perfect combustion of the carbon particles takes place, and the flame is colorless again.

In all chemical laboratories where gas is to be had, these burners, and stoves constructed on the same principle, are in constant use, being clean, cheap, and needing no attention. After a Bunsen burner has been long in use it sometimes burns badly, the gas igniting at the base of the tube, *c*, and burning within it with an illuminating flame. This is because there is too much air in proportion to the gas, and by cleaning the little hole in the jet at the base of the tube, *c*, more gas may be admitted and the evil remedied.

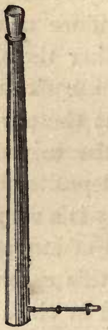


Fig. 59.

182. **Blowpipe.**—The oxidizing and deoxidizing flames referred to in § 174 are obtained with greater distinctness by using the little instrument called a blow-pipe. This consists of a short tube, generally of metal, either curved at one end or made of two pieces, one fitting into the other at right angles. By applying to a flame the end which terminates in a jet with a very small hole, and then blowing through the other end with the mouth, the flame is materially altered

in appearance. Its size is diminished, while its length is increased, and its brightness almost entirely destroyed, owing to the more perfect combustion of the carbon within it. The three cones named in § 172 are still seen, the inner one is of a blue color, the middle one is partly luminous, and the outer one is again paler. The middle cone is called the deoxidizing or reducing flame, and has the effect of reducing metallic oxides brought under its influence. This is owing to the fact that it contains an excess of combustible matter, and is ready to take oxygen from the metals. The outermost cone, called the oxidizing flame, has the opposite effect, for the supply of oxygen is here abundant, and any substance eager to take it up is oxidized. The hottest part of the flame is a little beyond the end of the middle cone.

In skillful hands either the reducing or the oxidizing flame may be made to predominate, and advantage is taken of this by the operator according as he may desire to reduce or oxidize any substance. This little instrument is of great service to the chemist and mineralogist to assist them in ascertaining the nature of mineral substances. The material to be examined is supported on charcoal, or in platinum-pointed pincers, and heated in the blow-pipe flame; by the changes which take place in its appearance the chemist is able to determine its constituents with considerable accuracy.

183. **Improper Management at Fires.** — The principles above indicated are often disregarded in attempts to put out fires. The more we can keep the air from having free access to a fire, the more readily shall we put it out. If a fire, then, be on the inside of a building, there should be no more openings made into it than are absolutely necessary to enable us to throw water upon the fire. Especially should we avoid making any openings which will allow a current of air to pass through the part that is burning. If,

at the same time that doors and windows are opened below, windows are opened or broken in above, as is often the case, the air sweeps up and through with great force, feeding rapidly the fire with oxygen.

184. **Blowing out a Candle.**—The fact that a puff of breath or a gust of wind puts out a candle seems at first thought inconsistent with what we have stated, for really more oxygen is thus carried to the candle than it gets when the air is still. It is easy to see, however, that there is no inconsistency. There is a certain amount of heat required to keep up the combustion, and the air, therefore, may be made to come so rapidly to the light as to take away sufficient heat to stop the combustion. The more rapidly the air comes to the light, the more oxygen, it is true, is brought to it; but this is not adequate to compensate for the loss of heat. You have undoubtedly noticed that it is easier to avoid having a lamp or candle go out in carrying it up stairs than in carrying it down. The reason is that the flame is blown in the first case, if you hold the candle inclined a little forward, directly down upon the wick, increasing therefore the fire and the heat, while in the other case the flame is blown away from the wick. For the same reason, in carrying a lighted taper or stick, you point it forward. You see now what is the chemistry of a lantern, as we may express it. The air is admitted freely that the light may have a good supply of oxygen, but the orifices are so small that no gusts of wind can reach the light and reduce its heat below the burning point.

185. **Putting out Fires.**—Water is the common means of putting out fires, and this acts in two ways. First, it shuts out the oxygen of the air from the combustible substance, acting as a covering to it, thin indeed, but yet effectual; and, secondly, it takes away some of the heat, and therefore lessens the combustion. Of course, the colder the water is,

the more serviceable it is in this respect. But even hot water is of some service in this way; for it is not as hot as the fire is. The fire converts it into steam, and thus parts with a great deal of heat, which is rendered latent as the steam forms, as noticed in Part I., Chapter XIII. And then, for the purpose of shutting out the oxygen, hot water answers as well as cold. Some other means are often resorted to for extinguishing fires, all of them acting by excluding the air. For example, we put an extinguisher over a candle to put it out. So, also, if a person's clothes take fire, and no water be at hand, we wrap some clothing or other article quickly and closely around him. Such expedients, in common language, are said to smother the fire, but in scientific language to prevent the oxygen of the air from coming in contact with the combustible substance.

186. **Fire Under Water.**—If we put a very combustible substance under water, we can make it burn there by giving it a good supply of oxygen. In Fig. 60 we have an experiment of this kind represented. A bit of phosphorus, *b*, is put in a glass of hot water, and a stream of oxygen gas is directed upon it through the tube, *a*. A brilliant combustion occurs. It is necessary that the water should be hot to make the phosphorus burn, or, in other words, unite with the oxygen.

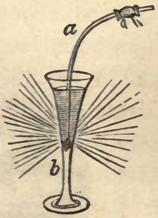


Fig. 60.

187. **Fire Extinguishers.**—Since carbonic anhydride is not a supporter of combustion, it may be used for extinguishing fires. It is usually employed in solution in water under pressure, and various contrivances have been made for generating the gas quickly when needed, and throwing a stream of it mixed with water in any direction desired. The "plain soda-water" sold in apothecary shops would serve just as well, for it is really the same thing. The pure dry gas has

also been used as a fire extinguisher. For example, a Mr. Gurney, in the case of a fire which had been burning for a long time in a coal-mine in Scotland, contrived to generate a large quantity of carbonic anhydride, so that it should flow to the spot where the fire was raging, and thus extinguished it. Here water could not be made to reach the fire, but the gas went to it without any difficulty.

188. **Oxyhydrogen Blow-pipe.**—When a jet of hydrogen gas is lighted, and a jet of oxygen is made to mingle with it, the union of the two gases produces the greatest heat known, with the exception of that which is produced by the galvanic battery. The sole product of this energetic combustion is water, the grand extinguisher of combustion. In Fig. 61 is represented an extemporaneous contrivance for burning these gases. The oxygen is contained in the bag, which has a weight upon it to press the gas out through the pipe. At the same time hydrogen gas is coming up from the bottle below through another pipe. Here you have the essentials of the blow-pipe invented by Dr. Hare, of Phila-

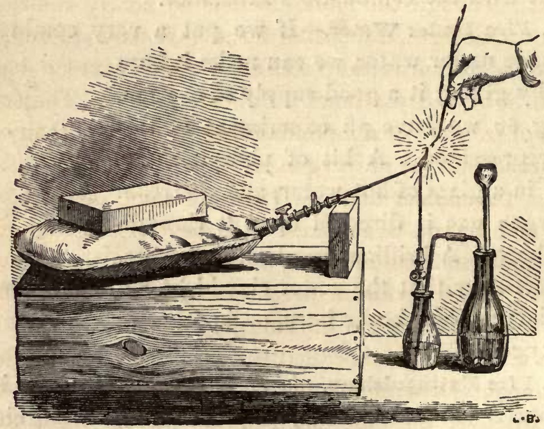


Fig. 61.

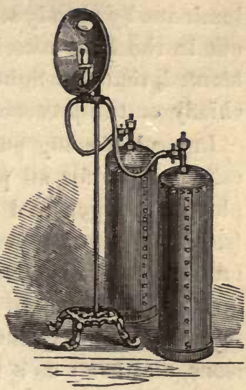


Fig. 62.

delphia. The common arrangement of this instrument is, however, represented in Fig. 62. In one reservoir is the oxygen, and in the other the hydrogen; flexible tubes lead to a common jet, where the gases issue and are set on fire. The flame, notwithstanding its heat, has very little brightness. It melts almost all substances, even the most refractory, dissipating many of them in vapor. Platinum, which can not be melted in the hottest furnace, readily melts here. Most of the metals are oxidized as they burn in this flame. Though the flame itself is so nearly colorless and destitute of light, a dazzling light, variously colored, is produced as it burns the metals. Copper gives a beautiful green light, and platinum a delicate white. The scintillations of iron are of a more dazzling brightness than when it is burned in a jar of oxygen, as noticed in § 59.

189. **Drummond Light.**—There are some of the earths, as lime and magnesia, that resist the heat of the oxyhydrogen blow-pipe, and one of these, lime, placed in the flame, gives a light which rivals in brightness the noonday sun. An arrangement having a burning jet of the two gases thrown upon a ball of lime is called the Drummond Light, because Lieutenant Drummond, of the English navy, if he did not first discover the fact that such an intense light could be thus produced, was at least the first to discover and recommend its use for most of the purposes to which it is now applied. The light can be seen at such great distances that it is exceedingly useful for signaling. In one case the light was seen at the distance of 70 miles. That a flame which gives so little light of itself should be made so intensely

luminous by merely striking against a solid substance, without in the least altering it, confirms what we have before learned, that the light-giving power of flame is dependent chiefly on the presence of incandescent solids.

Instead of using pure oxygen and pure hydrogen, an excellent light for all practical purposes is obtained by employing oxygen and coal gas. Strong metallic cylinders (see Fig. 62, p. 147) containing these gases under pressure are now sold in the large cities to any one wanting a bright light or intense heat. This light, also called the oxycalcium light, is very frequently seen in theatres, torchlight processions, and even as a means of advertising. The stereopticon used in illustrating public lectures is simply a magic-lantern provided with a calcium light.

190. **Cause of Explosions.**—So long as the two gases hydrogen and oxygen are kept separate before burning them no explosion takes place; but if oxygen and hydrogen be mingled together and then fire be applied there is a violent action, and a report proportioned to the amount of the gases. The combustion is alike in both cases, oxygen and hydrogen uniting to form water, and the explosion is due to the sudden expansion of the gases caused by the intense heat generated by their chemical union. The noise is produced by the sudden collision of the instantaneously expanded vapor with the air surrounding the vessel containing it.

191. **Experiments.**—Some interesting experiments can be tried illustrative of the explosive combustion of gases. If into a strong brass vessel, *a*, Fig. 63, we introduce a mixture of oxygen and hydrogen, and, having pushed the cork, *c*, in tightly, pass electricity by the ball and wire at *b*, an explosion will occur. The cork will be violently driven out by the expansive force of the heated vapor produced. Such

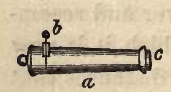


Fig. 63.

an apparatus is called a "hydrogen pistol," but it ought really to be called an "oxyhydrogen pistol," for only a mixture of these gases explodes. The two gases can be mingled in a bag, and by the aid of a common tobacco-pipe, as seen in Fig. 64, soap-bubbles can be formed, which on flying upward can be exploded by touching them with a light. To obtain good soap-bubbles mix a little glycerine with the soap-water before using. In such experiments we use in bulk twice as much hydrogen as oxygen, for it is in this proportion that these gases unite to form water (§ 140). Common air is often used in place of oxygen, and answers the purpose because it contains this gas. When this is used we introduce about equal bulks of the air and the gas. In all such experiments great care should be exercised. For example, in the bubble experiment we should be careful not to bring the light near the pipe of the gas-bag, else the whole might be exploded at once.

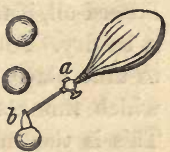


Fig. 64.

192. **Spontaneous Combustion.**—We mean by spontaneous combustion the taking fire of any substances without the application of heat to them. We will give you some examples, and explain them. If you place a bit of phosphorus of the size of a pea upon blotting-paper, and sprinkle over it some soot or powdered charcoal, it after a while melts and bursts into a flame. This is owing to the large absorption of oxygen gas by the carbon, as noticed in § 96. Much oxygen is thus introduced to the phosphorus, for which it has a strong affinity; and a union is therefore readily effected between them, which union is combustion. Heat is generated by the absorption of the gas; and as carbon is a non-conductor, the heat is retained, and is sufficient to start the combustion of the phosphorus. Indeed, where there is a large amount of powdered charcoal heaped to-

gether, the heat thus developed and retained may be sufficient to set fire to it. Gunpowder factories have sometimes exploded from this cause. For the same reason spontaneous combustion may occur in a mixture of lamp-black and linseed-oil, if the lamp-black be in excess, or if a portion of it be dry. Any substances in which chemical action is apt to take place, if heaped together so as to shut in the heat which this action produces, may take fire spontaneously. This is the case with oiled cotton and rags if there be in them any drying oil, or even with damp goods packed together. Damp hay may take fire for the same reason. More often, in this case, the combustion is imperfect, and the hay is turned black—that is, charred or changed into charcoal, just as wood is in the coal-pit. Spontaneous combustion of the human body, often referred to by ignorant people, is a fiction.

193. **Combustion without Oxygen.**—We have seen that ordinary combustion is the union of a substance with oxygen, accompanied by the development of light and heat. The presence of oxygen, however, is not indispensable to combustion, for we have many examples of chemical combination taking place, with such intensity as to generate light and heat, where oxygen is absent. Thus carbon will burn when heated in the vapor of sulphur, and a yellowish green gas called chlorine supports the combustion of metals and even of a candle. But of this we will learn more farther on.

194. **Requisites for Combustion.**—The variations in the readiness with which ordinary combustion goes on depend chiefly on three things: 1. The comparative affinity of the substance for oxygen. 2. The amount of oxygen supplied. 3. The temperature to which the combustible body is raised. Thus in the case of phosphorus, the slight heat caused by friction is sufficient to make it take fire. Wood, on the oth-

er hand, requires a much higher temperature to ignite it. Friction will do it, but it must be brisk and long continued. By increasing the quantity of oxygen present combustion will take place with less heat than is ordinarily required. This is the cause of spontaneous combustion in many cases, as noticed in § 192. In the brisk and continued burning of iron or steel in oxygen gas, § 59, we see the influence of an abundance of oxygen about the iron, in contrast with the mere spark that flies off in striking fire in the air, which is only one-fifth part oxygen.

195. **Ordinary Oxidation a Slow Combustion.**—As carbon and hydrogen in burning unite with oxygen, forming carbonic anhydride and water, so do the metals, forming oxides. It is indeed this union which is the combustion. It follows, then, that the gradual oxidation of the metals, the rusting of iron, copper, zinc, etc., is a combustion—a slow fire. And it undoubtedly produces as much heat in the aggregate as rapid oxidation does, though the process is so very slow that the heat at any one moment is so little as to be imperceptible.

196. **Sun-Bleaching is Combustion.**—The old mode of bleaching by exposure to the sun, *grass-bleaching* as it is termed, is an example of oxidation—that is, combustion. By the influence of the sun's light the oxygen of the air is made to unite with the coloring matter of the cloth, and so this is burned up, the product passing off in the air, just as the products of ordinary combustion do. If the cloth be exposed too long, some of the substance itself is burned up, lessening the strength of the cloth, or rotting it, as it is commonly expressed. The reason that the coloring matter is affected before the substance is that it is more combustible, or, in other words, more readily oxidized.

197. **Animal Heat.**—The heat of the body is maintained by a real combustion, though without light. To produce

this heat the same chemical unions take place as in the burning of a common candle. We have told you something already about the introduction of oxygen into the body in breathing. It enters the blood in the lungs, and courses about in search of carbon and hydrogen. It finds these every where, and unites with them, forming with the carbon carbonic anhydride, and with the hydrogen water, as in the case of the candle. In effecting this union heat is produced, and thus the body is kept warm.

198. **The Lungs not the Body's Furnace.**—It was for a long time supposed that the chemical combinations producing the heat occurred in the lungs, and that the heat generated there was carried with the blood all over the body. But there were some facts observed that were inconsistent with this doctrine. If it were the true doctrine, the lungs should be hotter than any other organ in the body, just as a furnace is always hotter than the apartments to which the heat from it is carried. But it was found that the lungs were no warmer than other organs, and that therefore they were not the furnace of the body. Then, again, it was observed that the heat of different parts of the body is often temporarily increased. Thus when an inflammation occurs there is more heat than usual. So, also, blushing will make the face to burn. In such cases the increased heat is of course produced where it manifests itself, and not in the lungs. It was therefore found, on further investigation, that the animal heat is produced in all parts of the body, every little vessel being a chemical laboratory for this as well as other purposes.

199. **Temperature of the Body.**—The heat of the body is maintained quite uniformly at 98°.* You observe that this

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* The temperatures named in this section are given in Fahrenheit degrees. See Appendix.

is much above the ordinary temperature of the atmosphere, so that our bodies are almost always giving out considerable heat to the air around us. This is very obvious where there are many persons gathered together. A room that is just comfortably warm with but few in it, becomes uncomfortably so very soon when it is crowded full of company. It is very seldom that the air around us is as hot as our bodies, and therefore very seldom that we are not giving off heat. We are most comfortable when the air around us is at about 70° (Fahrenheit), and as this is 28° below the heat of our bodies, we may say that we are comfortable only when we are giving off considerable heat to the air. As this heat is given off from the surface, the outer parts of the body are not as warm as the inner. And as heat is constantly lost, so it is constantly made. The myriads of furnaces are at work all the time, night and day. The fires within us never go out while life continues.

200. **Sources of the Fuel.**—The fuel used in producing animal heat is carbon and hydrogen, as already intimated. There are two sources from which these come: 1. The waste of the body. In the wear and tear of the animal machine there are particles every where that have ceased to be useful. They must be got rid of to make way for other particles to be deposited in their place. How is this done? The oxygen that enters the lungs in breathing does it. This goes in the blood to these useless particles, and burns up, that is, unites with their carbon and hydrogen. This makes heat just where the particles are, and the products of the combustion, the carbonic anhydride and water, are carried off in the blood that sweeps along in the veins. What becomes of them we will soon tell you. 2. A part of our food furnishes fuel to feed the fires within us, the starchy, sugary, and fatty articles. We shall speak particularly of this subject in another part of this book, and so will not dwell

upon it here. Occasionally the fat which is deposited in various parts of the body is used as fuel, the oxygen in the blood seeking it out, and uniting with its constituents, carbon and hydrogen. This is done in sickness, when the accumulated fat disappears, and also in the hibernation of many animals, as will be noticed farther on.

201. **Amount of Fuel Consumed.**—Some calculations have been made in regard to the amount of fuel consumed in keeping up animal heat. This is more easily done in regard to carbon than hydrogen. A full-grown man requires about 100 kilogrammes of charcoal to keep him warm through the year. A horse needs about five times as much—500 kilogrammes.

202. **The Windpipe the Smoke-pipe of the Body.**—We have told you that in the combustion that is every where going on in the body carbonic anhydride and water are formed, and pass into the blood in the veins. Observe how they are disposed of. They are for the most part carried in the blood to the lungs,* where they are discharged through the windpipe into the air. The water comes out in the form of vapor mingled with the carbonic anhydride, just as the two rise together from the flame of a candle. As these products of combustion are discharged from the body by the windpipe, this may be termed the body's smoke-pipe. It acts thus as we breathe *out*, but when we breathe *in* it serves to introduce to all the little heat-laboratories of the body oxygen, the supporter of their combustion.

203. **Influence of Exercise on Animal Heat.**—When the body is in a state of activity the heat is increased, or, in other words, the fires within us burn more briskly. This is

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* For a particular description of the manner in which this is done we refer to either Hooker's "Human Physiology" or his "First Book in Physiology."

because the circulation is quickened, and with it the breathing, and so more of the oxygen is introduced into the blood, and thus to the carbon and hydrogen. The same effect is produced in this way upon the combustion of the body as upon an ordinary fire by blowing it. It is simply increasing one of the three requisites for combustion mentioned in § 194.

204. **Cold-blooded Animals.**—Reptiles and fishes are cold-blooded animals—that is, they have nearly the same temperature with the medium in which they live. The fires in them are not at all brisk, and they use little oxygen in comparison with warm-blooded animals. They have need of but little, for they live a comparatively sluggish life, as you may fully realize in relation to reptiles if you observe the difference in activity between a bird and a frog or toad. It may appear to you that this is not true of fishes, as their motions are often very quick. But it must be remembered that it requires but little exertion really for them to move with rapidity, because they live in a medium of a specific gravity so near their own. For further illustration of this point we refer you to Chapter XX. of Hooker's "Natural History."

205. **Hibernation.**—Animals are said to hibernate who go into a torpid state in the winter. The degree of torpidity varies much in different animals. In cold-blooded animals respiration and circulation may cease altogether, and the operations of life may be as thoroughly suspended as in a seed that is kept from heat and moisture. They may be preserved in this state for a long time. Frogs and serpents have been kept in ice for years without any signs of life, and then have been revived by exposure to a warm atmosphere. While animals are in such a state, the machinery of life being stopped, there is no wear and tear, and therefore no waste to be got rid of. As there is nothing to burn, no oxygen is needed. In hibernating warm-blooded animals the torpidity is not so thorough, and in proportion to the movements of life there is waste, and therefore need of oxygen to burn it. Hence there is occasional respiration. In such cases of imperfect torpidity the fat which has been acquired in summer is burned up for the purpose of maintaining the requisite warmth, and such animals therefore come out in the spring from their hiding-places in quite a lean condition.

206. **The Chief Elements.**—The four elements with which you have become so familiar in the previous chapters—

viz., oxygen, nitrogen, carbon, and hydrogen—are the chief elements concerned in the formation of the earth. Especially is this true of organic substances, both vegetable and animal. In some of these, it is true, there are lime, phosphorus, sulphur, iron, etc.; but these are generally in small quantities, while the great bulk of them is made up of combinations of the four grand elements which we have mentioned. Then of substances not living, the earth's envelope of air, fifty miles thick, is a mixture mostly of two of these elements, oxygen and nitrogen, and all the water is composed of oxygen and hydrogen. And to come to the solid crust of the earth, carbon is seen in the enormous quantities of coal treasured up in the bowels of the earth for the use of man; carbon and oxygen united with a metal form the limestone rocks and ranges of mountains; oxygen is a large constituent of the granite and other hard rocks; and of the compound mixture under our feet which we call earth the four grand elements form a very large proportion.

207. **Chemical Changes in Air and Water.**—These elements are continually the subjects of chemical changes. You have already seen how that mixture of gases, the air, is constantly changing by means of the chemical operations going on in the lungs of animals, in the leaves of vegetables, in combustion, in the various arts of man, and in the decay of animal and vegetable substances. Though, therefore, the atmosphere which envelops the earth is to-day composed of oxygen, nitrogen, and carbonic anhydride, in precisely the same proportions as that which enveloped it when our first parents were in the Garden of Eden, yet it is not the same air, but its elements have from that time to this been going through many changes, entering into the composition now of liquids, now of solids, and now of gaseous substances. The elements of water are also continually changing, though perhaps not to such an extent as those of air. In § 9, Part I.,

we spoke of the exceeding movability of water. As it courses about much of it becomes resolved into its elementary gases, oxygen and hydrogen, to engage in the formation of other substances, gaseous, liquid, and solid; and just as constantly new water is forming to take the place of that which is thus resolved. Especially do such changes in water take place when it enters living substances. The constituents of water form a part of all vegetable and animal substances, and it is, therefore, decomposed continually to furnish these in the growth that is every where going on.

QUESTIONS.

167. Mention some of the various effects of combustion.—168. What was Stahl's theory of phlogiston? How long did his theory prevail?—169. What takes place in ordinary combustion?—170. Explain the experiment represented in Fig. 50. State what takes place in the burning of illuminating gas.—171. State the processes involved in the burning of a common candle. How can you prove that water is formed in the burning of a candle? How that carbonic anhydride is formed?—172. Describe the structure of a candle's flame as mapped in Fig. 52, and the processes involved in the burning.—173. State the experiments shown in Figs. 53 and 54. Give the experiment with the slip of wood. That with the match. State the experiment represented in Fig. 55.—174. That represented in Fig. 56. State and explain the experiment with a slip of copper.—175. Illustrate the fact that in the combustion of wood the formation of gas and its combustion are two distinct processes.—176. What is the cause of flame?—177. What is said of the burning of anthracite? What of the difference between anthracite and bituminous coal?—178. What of the making of gas?—179. Mention cases of combustion in which the results are aeriform; cases in which they are solid; and cases in which they are partly solid and partly aeriform. What proportion is there of solid when wood is burned?—180. How may combustion be increased? What is said of the chimneys and wicks of lamps?—181. Describe the gas-lamp known as Bunsen's Burner. What are its advantages?—182. Describe a blow-pipe. What is said about oxidizing and reducing flames? How is a blow-pipe useful to chemists?—183. What is said of improper management at fires?—184. What of blowing out a candle? Explain the expedients resorted to for preventing lights from going

out as we carry them about.—185. In what two ways does water act in putting out fires? Explain other means of putting out fires.—186. How can a fire be made under water?—187. What is said about fire extinguishers? Explain the extinguishing of a fire in a Scotch coal-mine.—188. What is the oxyhydrogen blow-pipe? What is its use?—189. What is the Drummond Light? What the oxycalcium light? When are they used?—190. Explain the cause of explosions. What causes the noise?—191. Describe the hydrogen pistol, and the experiment with soap-bubbles?—192. What is spontaneous combustion? State and explain the experiment with phosphorus and charcoal. Give various examples of spontaneous combustion. —193. Is oxygen indispensable to combustion?—194. What are the requisites for ordinary combustion? Give examples illustrating the variation of these in different cases.—195. What is said of ordinary oxidation?—196. What of sun-bleaching?—197. How is animal heat the result of combustion?—198. What facts show that animal heat is not made in the lungs? Where is it made?—199. What is the temperature of the body? What is said about the body's giving out heat?—200. What is the fuel of the fire in the body? What is said of the sources of the fuel? What of the uses sometimes made of the fat of the body?—201. What of the amount of the fuel used?—202. How is the windpipe the smoke-pipe of the body?—203. Show how exercise influences animal heat.—204. What is said of cold-blooded animals?—205. What is said of hibernating cold-blooded animals? What of hibernating warm-blooded animals?—206. What is said of the four chief elements?—207. What is the nature of the changes in air and water?

CHAPTER XI.

CHLORINE, BROMINE, IODINE, AND FLUORINE.

208. **A Natural Group.**—Having now studied somewhat at length the most important and widely distributed elementary bodies—oxygen, nitrogen, carbon, and hydrogen—together with many of the compounds which they form, we will now take up the remaining elements one by one, and, for convenience' sake, will begin with the non-metals not yet described. Four of these non-metals—chlorine, bromine, iodine, and fluorine—resemble each other, chemically speak-

ing, to a remarkable degree, and are said to form a natural group; the most important member of this group is chlorine.

209. **Occurrence of Chlorine.**—All common salt is made up of this element and a metal called sodium. Afterward, when you have learned the remarkable properties of the constituents of salt, how one is a suffocating yellow gas, and the other a very light, soft metal which burns on water, it will seem rather strange that a union of these two bodies, both of them so corrosive and dangerous, should produce such a mild, healthful substance as common salt. And yet this is only another example of the marvelous change which elements experience when united, each one losing its identity, and the compound having the properties of neither of them. Chlorine forms more than one half of common salt; so that, as salt is abundant in sea-water and in salt-mines, and is also present to some extent in the soil and in animals and vegetables, chlorine is one of the elements that exists in large quantities in the earth.

210. **Preparation of Chlorine.** — Chlorine is never found free in nature; we can make it from common salt. Mix some common salt, or chloride of sodium, with manganese dioxide, put the mixture into a flask fitted with a tube, as in Fig. 65, and then add some sulphuric acid somewhat diluted. Now

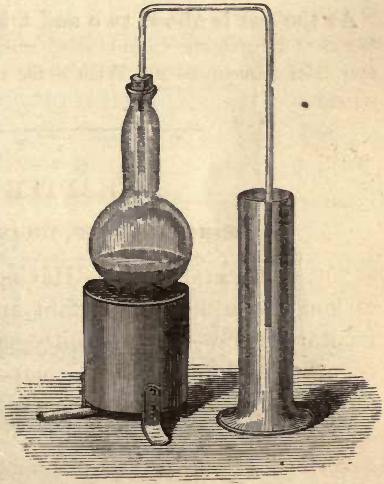

Fig. 65.

heat the contents of the flask, and yellowish-green vapors of chlorine will arise and pass over into the jar arranged to collect it.

The reaction which takes place is somewhat complex, but you will understand it by studying this equation:

$$\overset{\text{Manganese dioxide.}}{MnO_2} + \overset{\text{Sodium chloride.}}{2NaCl} + \overset{\text{Sulphuric acid.}}{3H_2SO_4} = \overset{\text{Manganous sulphate.}}{MnSO_4} + \overset{\text{Hydro-sodium sulphate.}}{2(NaHSO_4)} + \overset{\text{Water.}}{2H_2O} + \overset{\text{Chlorine.}}{Cl_2}$$

The manganese dioxide is necessary to furnish oxygen to unite with the hydrogen of the sulphuric acid, forming water. What happens when we omit the addition of manganese dioxide you will see very soon.

211. **Another Way of Obtaining Chlorine.**—Chlorine gas may also be obtained by heating hydrochloric acid with manganese dioxide. The heat required is not high—placing the flask in a bowl of hot water is sufficient. If the gas stops coming over, add more hydrochloric acid, for this is the source of the chlorine.

As the gas is about two and a half times as heavy as air, it can be collected in a jar, as represented in Fig. 66, the lighter air being driven out to give place to it. The explanation of the chemical change in the flask is this: There is a large amount of oxygen in the oxide of manganese, which is therefore loosely attached to the metal, and ready

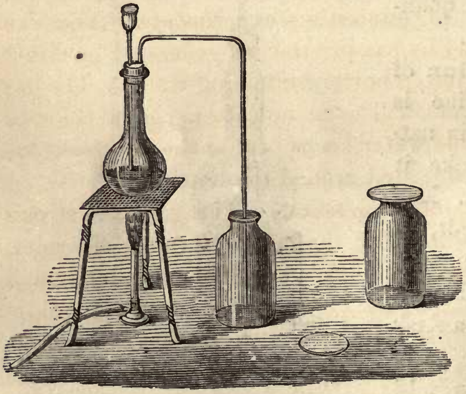

Fig. 66.

to leave it at the slightest invitation. The hydrogen of the hydrochloric acid, therefore, at once strikes up a union with this oxygen, and the chlorine of the acid being therefore forsaken by the hydrogen, a part of it unites with the manganese to form a chloride of that metal, and a part of it escapes and passes out through the tube.

Manganese dioxide.		Hydrochloric acid.		Manganese chloride.		Water.		Chlorine.
MnO_2	$+$	$4HCl$	$=$	$MnCl_2$	$+$	$2H_2O$	$+$	Cl_2

212. **Breathing Chlorine.**—This gas can not be breathed with safety unless very largely diluted with air. If breathed when but little diluted, it occasions violent coughing and a suffocating effect. Great care, therefore, is requisite in preparing it and in experimenting with it. The very small quantity that is in the air where bleaching is carried on, or where it is disengaged from chloride of lime for disinfecting purposes, though decidedly appreciable to the sense of smell, occasions no embarrassment in the respiration.

213. **Chlorine Water.**—Water will dissolve twice its bulk of chlorine. This solution, called chlorine water, may be used in a variety of interesting experiments. You can make it very readily by passing the gas generated by either method described into a bottle containing water. The gas will be absorbed, and will communicate a yellow color to the water. Chlorine water keeps best in the dark, so some black paper may be pasted around the bottle.

214. **Action of Chlorine on Metals.**—This gas has a strong disposition to combine with the metals, forming chlorides. If you put some pure gold-leaf into chlorine water it will soon disappear, because the chlorine forms with the gold a chloride, which is dissolved in the water as fast as it forms. In some cases so eager are the chlorine and the metal to unite that the violence of the action occasions the phenomenon of combustion. Thus if antimony in fine powder be

dropped into a vessel of chlorine gas, it will fall in a shower of fire, and the vessel will be filled with a white smoke which is made up of small particles of chloride of antimony. (Fig. 67.) If a fine brass wire, with a little bit of tinsel fastened to its end, be introduced into a vessel of chlorine gas, the wire will burn briskly, the tinsel of course taking fire first and kindling the wire, as shavings do wood. In this combustion the zinc and copper, of which brass is composed, unite with chlorine to form chlorides of zinc and copper.


Fig. 67.

215. **Attraction for Hydrogen.**—Fill a jar with chlorine water, and invert it in a vessel of water. If this be kept in the dark no change will occur; but if it be exposed to the sun for a few days there will collect a colorless gas in the upper part of the jar, and the water will be found to have lost its chlorine and to have become sour. This is because the chlorine in the solution has decomposed some of the water by taking to itself its hydrogen to form hydrochloric acid, while the other constituent of the water, oxygen, has collected in the upper part of the jar. That this gas is oxygen can be readily proved by setting the jar upright and introducing into it a taper which is merely in a glow, and not in a flame. It will burst into a bright flame at once.

$$\underset{\text{Water.}}{H_2O} + \underset{\text{Chlorine.}}{Cl_2} = \underset{\text{Hydrochloric acid.}}{2HCl} + \underset{\text{Oxygen.}}{O}$$

216. **Bleaching.**—The powerful attraction between chlorine and hydrogen, and the consequent decomposition of water, furnish us the explanation of chlorine bleaching. The

first step in the process is the decomposition of water, and hence the necessity for having the substance to be bleached moist. If a colored rag be introduced into chlorine gas dry, the chlorine will have no effect upon it; but if it be moistened, it will lose its color. The explanation of bleaching is this: The chlorine, taking the hydrogen of the water, sets free oxygen, and this in its nascent state (§ 42) has special chemical power, and attacks the coloring matter, destroying it, or burning it up, as we may say, for the union of oxygen with other elements is, as you have seen, essentially a combustion. It is oxygen, then, that really does the bleaching here, just as in the case of sun-bleaching (§ 196). But the question arises, Why does the oxygen burn up the coloring matter, and not the cloth itself? This is from a principle which is well established in chemistry, viz., that the more ingredients there are in a compound the more easily it is decomposed. While the vegetable tissue or substance is composed of three elements, carbon, oxygen, and hydrogen, the coloring matter is composed of these with nitrogen in addition, and therefore is more readily demolished by the oxygen than the cloth is.

217. **Carrying the Bleaching too Far.**—But sometimes the cloth is somewhat burned in the process—that is, some of the tissue is destroyed by the released oxygen, and the cloth consequently weakened. This is done whenever, after the chlorine has released sufficient oxygen to destroy the coloring matter, it continues to release more. The point, then, to be aimed at by the bleacher is to set free only just enough oxygen by means of the chlorine to oxidize the coloring matter, and not the substance. There is the same danger that the process may be carried too far in the common sun-bleaching, or grass-bleaching, as it is usually called.

218. **Comparison with Grass-Bleaching.**—The old mode

of bleaching was very tedious and uncertain, but chlorine bleaching is both an expeditious and certain process. Professor Pepper, an English author, thus remarks on the benefits which the discovery of this process has conferred upon English manufacturers: "All our linen used formerly to be sent to Holland, where they had acquired great dexterity in the ancient mode of bleaching, viz., by exposure of the fabric to atmospheric air, or the action of the damps and dews, assisted greatly by the agency of light. Some idea may be formed of the present value of chlorine when it is stated that the linen goods were retained by the Dutch bleachers for nine months; and if the spring and summer happened to be favorable, the operation was well conducted; on the other hand, if cold and wet, the goods might be more or less injured by continual exposure to unfavorable atmospheric changes. At the present time as much bleaching can be done in nine weeks as might formerly have been conducted in the same number of months; and the whole of the process of chlorine bleaching is carried on independent of external atmospheric caprices; while the money paid for the process no longer passes to Holland, but remains in the hands of our own diligent bleachers and manufacturers." Quite as great is the usefulness of chlorine bleaching in the art of paper-making in the preparation of its material. A most valuable present, then, did the Swedish chemist Scheele make to the arts when he discovered chlorine and its application in bleaching.

219. **Difference between Chlorine Bleaching and Sulphur Bleaching.**—In chlorine bleaching the coloring matter is actually destroyed—burned up—that is, its elements are dispersed in new combinations. But in sulphur bleaching, as you will learn, the coloring matter remains. It is only changed, not dispersed, and therefore it can be restored as before by certain chemical actions. Chlorine bleaching is inapplicable to straw, because for some reason it imparts a brown tinge to the material. Therefore for straw goods sulphur bleaching continues to be used.

220. **Chlorine a Disinfectant.**—Chlorine not only decomposes colors, but also, and probably for the same reason, the volatile compounds which are formed in decay, and which are so disagreeable to the smell and injurious to the health. It may be used, therefore, for purifying all morbid matters and infected atmospheres, and even for arresting decay. Musty casks may be cleansed by washing them first with chlorine water, and then with milk of lime. Mouldy cellars, in which milk readily turns sour, can be purified by fumigating them with chlorine gas, or washing them with chlorine water or a solution of chloride of lime.

221. **Combustion in Chlorine.**—It was formerly supposed that oxygen is the sole supporter of combustion, but we have an example to the contrary in chlorine. You have already seen in § 214 that certain metals spontaneously burn in this gas. In the burning of ordinary substances in chlorine the flame comes from the union of chlorine and hydrogen, no union with the carbon, so commonly attending combustion, taking place in this case. Thus, if a candle be let down into a jar of this gas, Fig. 68, it burns as it enters with a dull red flame, but a dense cloud of smoke arises, and the light is soon extinguished. The explanation is this: The hydrogen of the tallow unites with the chlorine, giving a flame; and the carbon, being separated from the hydrogen, flies off in minute particles, and soon extinguishes the flame. The results of the combustion are hydrochloric acid and lamp-black, the former coming from the union of the hydrogen of the candle and the chlorine, and the latter from the carbon of the candle, which can find nothing in the jar to unite with, and so takes this form, some of it being deposited in a dark film upon the sides of the jar. If you moisten a slip of paper with oil

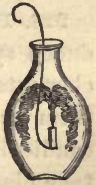
Fig. 68.


Fig. 69.

of turpentine, which is composed of carbon and hydrogen, and put it into a jar of chlorine, it will burn spontaneously (Fig. 69, p. 165), the hydrogen making the flame, and the released carbon producing a cloud of heavy smoke.

222. **Hydrochloric Acid**, HCl.—We have already had so much to do with this acid that you know its composition and nature. We have hitherto always used a solution of gaseous hydrochloric acid in water without further explanation. Hydrochloric acid, then, is a colorless gas, with acid properties, pungent odor, and very soluble in water; in fact, water is capable of taking up 500 times its bulk of this gas. Commercially this solution is called muriatic acid—a name a hundred years old. Hydrochloric acid dissolves many metals, forming chlorides. It is of great value in the arts.

223. **Production of Hydrochloric Acid.**—It can be produced synthetically, *i. e.*, by the direct combination of its elements, and it is curious that light is the agent that makes them combine. If equal quantities in bulk be mixed by candle-light, and be kept in the dark, no combination will take place, but the two gases will remain simply mixed together. If now the jar containing the gases be exposed to the direct rays of the sun, the union will be so sudden as to cause an explosion. Sometimes this result occurs by exposure to the diffuse light of the sun, but commonly the direct rays are required. Of course in this very dangerous experiment the jar should be inclosed in a wire screen to guard against injury.

224. **Common Mode of Preparation.**—Hydrochloric acid is commonly prepared by mixing together common salt and dilute sulphuric acid, and applying heat to the mixture. The chemical reaction is as follows:

Sodium chloride.		Sulphuric acid.		Hydro-sodium sulphate.		Hydrochloric acid gas.
$NaCl$	$+$	H_2SO_4	$=$	$NaHSO_4$	$+$	HCl

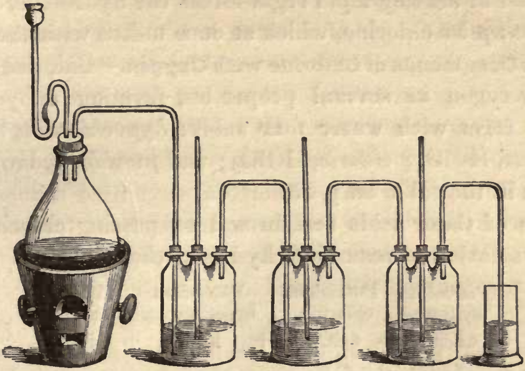

Fig. 70.

You see the chlorine of the sodium chloride unites with part of the hydrogen of the sulphuric acid, forming hydrochloric acid; and the sodium takes the place of the hydrogen which left the acid, forming an acid salt—hydrosodium sulphate. Now you see what would have taken place had we omitted the manganese dioxide in the preparation of chlorine in § 211. Compare the two equations.

225. **Aqua Regia.**—This is a mixture of nitric and hydrochloric acids in the proportion of one part of the former to three of the latter. Neither of these acids alone will dissolve gold or platinum, but this mixture of them will do it; and as gold is considered the king of metals, the liquid that can dissolve it has been styled *aqua regia*, or royal water. But we do not have in this case, in reality, a mere physical solution of gold. It is something more. A chemical change takes place by which a union is effected between the gold and the chlorine of the hydrochloric acid, making chloride of gold, and it is this salt of gold which is dissolved, and not gold itself. The explanation is this: While gold put into hydrochloric acid can not take its chlorine, the nitric acid which

is added in making aqua regia forces the hydrochloric acid to give up its chlorine, which at once unites with the gold.

226. **Compounds of Chlorine with Oxygen.**—Chlorine unites with oxygen in several properties, forming anhydrides. These form with water four acids: *hypochlorous*, $HClO$; *chlorous*, $HClO_2$; *chloric*, $HClO_3$; and *perchloric*, $HClO_4$, as shown in the table on p. 35.

Two of these acids are formed on passing chlorine gas into a solution of potassium hydrate; thus:

Chlorine.		Potassium hydrate.		Potassium chloride.		Potassium hypochlorite.		Potassium chlorate.		Water.
Cl_8	+	$8KHO$	=	$6KCl$	+	$KClO$	+	$KClO_3$	+	$4H_2O$

You see that part of the oxygen of the potassium hydrate oxidizes the chlorine and combines with the potassium. According to the strength of the potassium solution you obtain more of the hypochlorite or of the chlorate, the weaker solution giving more of the former. Hypochlorous acid is a powerful bleaching agent; combined with calcium it makes the so-called chloride of lime, of which you will learn more later. Potassium chlorate, you remember, was used in the preparation of oxygen gas. It is also used in medicine to a limited extent. The anhydrides corresponding to the first three acids named are unstable gases; all have a red or yellow color and a pungent odor. We will not describe them further, but will notice the preparation of one of them—hypochlorous anhydride. It is best prepared by the action of chlorine upon dry mercuric oxide:

Mercuric oxide.		Chlorine.		Hypochlorous anhydride.		Mercuric chloride.
$2HgO$	+	Cl_4	=	Cl_2O	+	$HgCl_2$

227. **Other Compounds of Chlorine.**—Chlorine also forms compounds with carbon and with nitrogen, but they are far too rare and uninteresting to describe here. Chloride of nitrogen is one of the most dangerously explosive substances known, and must never be prepared by students "*for fun.*" So we will not tell you how to make it.

228. **Iodine.**—While chlorine is a constituent of the salt of the sea, iodine is found in many of the sea's products, as sea-weed, sponge, etc., in combination with sodium and other metals. It is commonly obtained by making a lye from the ashes of sea-weeds, called kelp, and separating the iodine from this lye by a chemical process. The lye is evaporated till all the sodium carbonate and other salts in it are crystallized, and the remaining liquor, after being treated with sulphuric acid, is heated gently with manganese dioxide in a leaden retort, *a b c*, Fig. 71, the iodine passing out in vapor, and being condensed in the successive receivers, *d*. The action of the manganese dioxide is the same as in the corresponding method of preparing chlorine. After the discovery of iodine, in 1811, by M. Courtois, of Paris, the preparation of kelp became quite a large business on the coast of Scotland. Iodine is chiefly used in the arts in the process of dyeing and in the making of photographic pictures. It is also used in medicine.

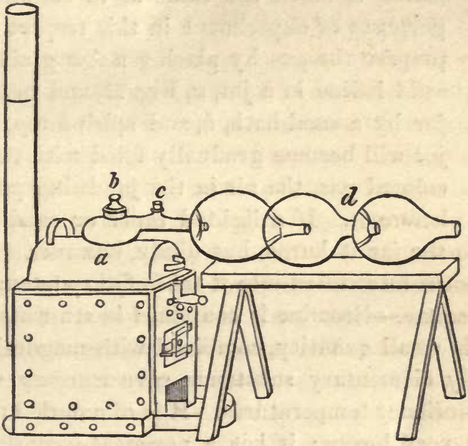

Fig. 71.

229. **Properties.**—Iodine is a solid substance of a deep-blue color, with a somewhat metallic lustre. By the application of heat it may be made to rise in a beautiful violet vapor or gas. This gives it its name, which comes from a Greek word meaning violet-colored. The vapor of iodine is nearly nine times as heavy as air, and is one of the heaviest of the gases. Iodine is not very soluble in water, but is quite soluble in alcohol, and forms with it a tincture much used in medicine.

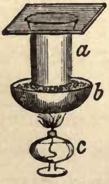

Fig. 72.

230. **Iodine a Supporter of Combustion.**—Combustion in iodine is much the same as in chlorine. For purposes of experiment in this respect you can prepare the gas by placing a few grains of the solid iodine in a jar, *a*, Fig. 72, and heating the jar by a sand-bath, *b*, and spirit-lamp, *c*. The jar will become gradually filled with the violet-colored gas, the air in the jar being pushed up before it. If a lighted taper or candle be let down into the jar it burns, but dimly, however. A piece of phosphorus introduced into it takes fire spontaneously.

231. **Bromine.**—Bromine is contained in sea-water, where it exists in small quantity, combined with magnesium. It is the only elementary substance, save mercury, which is liquid at ordinary temperatures. It is of a dark brown-red color, and very heavy; it has a powerful, irritating odor, whence it receives its name, *bromos* being the Greek word for bad odor. It is a corrosive and deadly poison. It is used in medicine and in photography, chiefly as sodium bromide. Iodine and bromine form hydrogen compounds and oxygen compounds almost exactly the same as chlorine. These three elements are always found associated, and seem to be members of the same family.

232. **Fluorine.**—This element has never been prepared in a free state, and is known to chemists only in combination.

It occurs rather abundantly in nature, combined with calcium chiefly. The beautiful mineral fluor-spar is calcium fluoride. The hydrogen compound of fluorine is of great importance to the chemist and in the arts, owing to its valuable property of dissolving silica and attacking glass. This hydrofluoric acid, as it is called, HFl, is a colorless, acid gas, soluble in water. You can make a pretty experiment with it, but be careful not to breathe the fumes. Take a small leaden dish, and put into it some powdered fluor-spar, calcium fluoride. Next take a watch-glass, warm it gently, and make beeswax to flow evenly over the convex surface. Now write a word, or scratch any thing you please with a pin on this wax-covered glass, removing the wax only where you wish lines to be eaten into the glass. Pour some strong sulphuric acid into the leaden dish containing the calcium fluoride, heat gently, and, as soon as you see white fumes, cover the dish with the wax-covered glass. The gaseous hydrofluoric acid will eat away the glass where not covered by the wax. Remove the glass after some minutes, scrape off the wax, wash the rest off with benzol, and you will have an etched surface exposed. Paraffin may be used instead of wax.

QUESTIONS.

208. What four bodies form a natural group?—209. Where and how does chlorine occur in nature? Is it abundant?—210. Describe and explain a method of obtaining chlorine from common salt.—211. From hydrochloric acid.—212. What is said about breathing chlorine?—213. What about chlorine water?—214. State what action chlorine has on some metals.—215. Show its attraction for hydrogen by describing the experiment named.—216. How is advantage taken of this attraction in bleaching? What really does the work?—217. What happens if the chlorine be in too great excess?—218. What advantages has this method over grass-bleaching? Who discovered chlorine?—219. Explain the difference between chlorine bleaching and sulphur bleaching.—220. How is chlorine used as a

disinfectant?—221. Describe a case of combustion in chlorine. Why does a candle smoke so badly in chlorine? How does oil of turpentine act in chlorine gas?—222. What is hydrochloric acid, and what are its properties? What is its commercial name?—223. Show how this acid can be obtained synthetically.—224. Describe the common mode of preparing hydrochloric acid. What will be formed if you add manganese dioxide to the materials employed?—225. What is aqua regia? Whence comes its name?—226. What is said of the oxygen compounds of chlorine? What bodies form when chlorine gas is passed into a solution of potassium hydrate?—228. What is said of iodine?—229. What of its properties?—230. How does it support combustion?—231. What is noticeable about bromine?—232. Of what use is fluorine itself? Explain a method of etching glass.

CHAPTER XII.

SULPHUR.

233. **Occurrence of Sulphur.**—Sulphur is a very abundant substance in nature. In the combinations of sulphur with copper, lead, silver, and many other metals, forming sulphides, we have their most important ores. Much of the sulphur which is used is obtained from a sulphide of iron, or iron pyrites. Large beds of native sulphur are often found, especially in volcanic localities. Combined with oxygen as sulphuric acid, it exists in great amount in the sulphates, the most abundant of which is the sulphate of lime, called gypsum or plaster of Paris. It enters also in small proportion into the composition of both vegetable and animal substances, being in considerable quantity in some of them, as in beans, pease, horseradish, onions, etc., in the vegetable world, and in eggs, hair, horns, hoofs, etc., in the animal.

234. **Forms of Sulphur.**—Sulphur is disposed to take a crystalline arrangement, and always does to a greater or less degree. Even when cast in roll there is some crystallization, imperfect and irregular, so that when it is held in

the warm hand the expansion occasioned by the heat causes a separation and friction of the crystals, and consequently a crackling sound. So, also, when the roll is broken the surface presents a glistening appearance, because of the multitude of surfaces of crystals. Even in the flowers of sulphur, though apparently a fine powder, there is really the crystalline state, as may be seen by examining the powder with a microscope. When a fair opportunity is given to the particles of sulphur to arrange themselves without disturbance, crystals are formed of considerable size and of great beauty. In the fissures and cavities of the beds of sulphur in volcanic countries there are collections of crystals of the shape seen in Fig. 73. It is curious that the crystals are of a different shape if they are formed artificially. Melt some sulphur in a crucible, then, letting it stand till a crust forms over the surface, quickly break the crust, and pour out all the sulphur that is yet liquid. On breaking the crucible afterward you will find the cavity of the sulphur covered with fine crystals in the form of lengthened pillars, as represented in Fig. 74. Sulphur is said, therefore, on account of its taking these two crystalline forms, to be *dimorphous*, from the Greek *dis*, twice, and *morphe*, form.

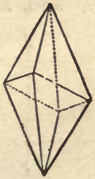

Fig. 73.

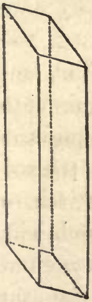

Fig. 74.

235. **Amorphous Sulphur.** — Twist a wire around the mouth of a test-tube, Fig. 75, so that you can conveniently hold it, and, filling the tube with flowers of sulphur, hold it over a Bunsen burner. The sulphur as it melts but half fills the tube. At first it is thin like water, but on heating it more it becomes brown and thick. If now you heat it a little farther it becomes fluid again,

Fig. 75.

and then on being poured into water it becomes a soft waxy mass, which slowly hardens. This sulphur, not being at all crystalline, is said to be *amorphous*, from the Greek *a*, without, and *morphe*, form. When in its waxy state it is used for copying coins and medals, the copy becoming hard in a few hours.

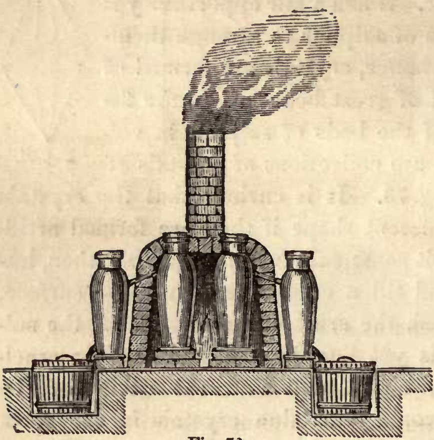

Fig. 76.

236. Flowers of Sulphur.—The two common forms of sulphur in commerce are the roll sulphur and the flowers of sulphur. The roll sulphur is obtained by distillation in the manner shown in Fig. 76, or by simply melting the crude sulphur, and as the impurities sink in the liquid the sulphur is poured into moulds, where it is left to cool. The apparatus for making the flowers of sulphur is represented in Fig. 77 (p. 175). The crude sulphur is melted in the iron pot, *a*, whence it flows into the retort, *c*; here it is heated to boiling by the fire, *d*, and the vapors pass into the large chamber, *e e e*. After a while the sulphur vapor cools and condenses on the sides of the chamber in the form of very small crystals, so minute as to appear like a powder. When a sufficient quantity of the flowers is thus formed they are removed by the door at *p*. Some melted sulphur accumulates at the bottom, and is drawn off into moulds and cooled. This constitutes roll sulphur. If the mixture of sulphur vapor and air should inflame, the consequent explosion will

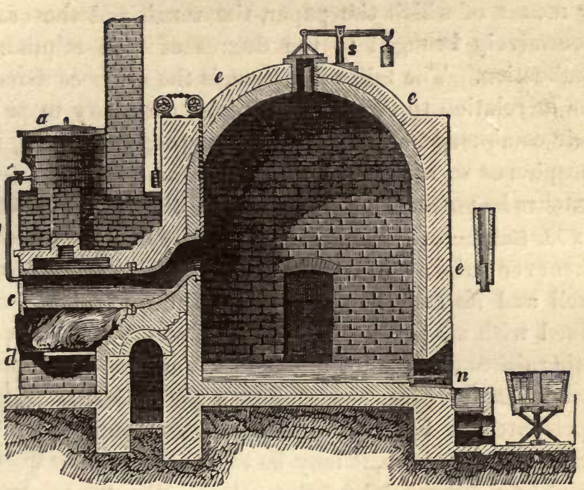

Fig. 77.

do no harm, for it opens at once the valve, *s*, and the gases escape. This process of raising a solid in vapor, and then condensing it in the form of a powder, is called *sublimation.*

237. **Properties of Sulphur.**—Sulphur is familiar to you as a brittle yellow solid. It is insoluble in water and alcohol. It takes fire readily, or, in other words, its attraction for oxygen is such that it requires but little heat comparatively to render its union with oxygen sufficiently rapid to occasion the phenomena of combustion. For this reason it has been much used for kindling purposes. By means of it other substances that unite less readily with oxygen may be heated to the degree of temperature requisite to set them on fire. The kindling of a coal fire in the times of the old-fashioned tinder-box illustrates well the different degrees of combustibility in various substances. The iron spark cast off by the blow of the flint sets fire to the finely divided charcoal of the tinder; this kindles the sulphur on the match,

by means of which the paper, the wood, and the coal are successively brought to the degree of heat requisite for combustion. The following, then, is the order of these articles in relation to the degree of heat necessary to produce their combustion—tinder, sulphur, paper, wood, coal. If the phosphorus so much used at the present day in the lucifer-matches be put in this list, its place will be at the head of it.

238. **Sulphurous Anhydride,** SO_2.—This gas is produced whenever sulphur is burned. You are familiar with its smell and its suffocating power. The gas unmixed with air can not be breathed at all. It extinguishes at once a lighted taper, as may be seen when it is introduced into a jar of it, as represented in Fig. 78. For this reason, when a chimney takes fire, it may be extinguished by sprinkling some sulphur upon the coals. The sulphurous anhydride, rising, drives out all the air, and, thus preventing the burning soot from being supplied with oxygen, puts out the fire. The fact that the gas is very heavy helps to produce this result, for while it fills the chimney it is not disposed to pass rapidly upward.

Fig. 78.

239. **Preparation of Sulphurous Anhydride.**—This gas, though easily obtained on a large scale by burning sulphur, is usually prepared in the chemist's laboratory by heating copper with concentrated sulphuric acid. The reaction is as follows:

Sulphuric acid.		Copper.		Copper sulphate.		Sulphurous anhydride.		Water.
$2H_2SO_4$	+	Cu	=	$CuSO_4$	+	SO_2	+	$2H_2O$

The sulphuric acid is decomposed, some of it furnishing SO_2 and O_2 to form water with H_4, while some of it forms copper sulphate with the metal.

Charcoal can be used in place of copper, the reaction being different:

Carbon.		Sulphuric acid.		Sulphurous anhydride.		Carbonic anhydride.		Water.
C	+	$2H_2SO_4$	=	$2SO_2$	+	CO_2	+	$2H_2O$

You see that more sulphurous anhydride is obtained by this method from the same amount of sulphuric acid, but it is mixed with carbonic anhydride, which is not wanted in many experiments.

Sulphurous anhydride is very eagerly absorbed by water, which takes up 40 volumes. This solution is an unstable acid, like carbonic acid:

Sulphurous anhydride.		Water.		Sulphurous acid.
SO_2	$+$	H_2O	$=$	H_2SO_3

Yet many salts are formed by replacement of the hydrogen in this acid; such salts are called *sulphites*, "ous" acids making "ites," as you learned in § 79.

240. **Bleaching Properties of Sulphurous Anhydride.**—It is the sulphurous anhydride which is the bleaching agent when straw goods are placed in a chamber in which sulphur is burned. The gas unites chemically with the oxygen of the coloring matter, and turns it white. The bleaching power of this acid may be very prettily illustrated by holding a red rose or peony over a burning stick of sulphur. The coloring matter is not destroyed in bleaching, but there is a chemical union between it and the acid; and it is a union that can be broken up either gradually by the action of light and air, as is manifested in the return of color after a time to the bleached articles, or quickly by the action of some powerful agent, as sulphuric acid. We will give a single illustration of the latter. If you pour a solution of sulphurous anhydride in water into an infusion of logwood shavings, the infusion loses its dark color; but if you pour into it a little sulphuric acid, the color will be at once restored.

241. **Sulphuric Anhydride,** SO_3.—This body, which may be considered as sulphuric acid less the elements of water, is a glistening white solid. It can not be kept unless it be shut in from the air in glass tubes hermetically sealed. On exposure to the air it fumes violently, and soon becomes fluid by attracting the moisture of the air. If it be thrown

into water it hisses like red-hot iron, and forms sulphuric acid:

Sulphuric anhydride.		Water.		Sulphuric acid.
SO_3	+	H_2O	=	H_2SO_4

This anhydride dissolved in common sulphuric acid forms the so-called Nordhausen or fuming sulphuric acid, generally obtained by distilling ferrous sulphate (sulphate of iron):

Ferrous sulphate.		Ferric oxide.		Sulphuric anhydride.		Sulphurous anhydride.
$2(FeSO_4)$	=	Fe_2O_3	+	SO_3	+	SO_2

When water is present, and this is generally the case, some of the sulphuric anhydride dissolves in it, forming sulphuric acid (as above), and some of this anhydride dissolves in the acid thus formed. This acid is called *Nordhausen* acid, after the town in Saxony where it has been made for many years. This was one of the earliest ways of making sulphuric acid, but common oil of vitriol is manufactured differently.

242. **Manufacture of Sulphuric Acid.**—This acid has one more atom of oxygen in it than sulphurous acid, and therefore can be made from the latter by adding this amount of oxygen to it. When sulphur burns it forms sulphurous anhydride, and will not take up any more oxygen from the air; hence this oxygen must be added in an indirect manner, as shown in the following sentences: Sulphurous anhydride produced by burning sulphur, or by roasting iron or copper pyrites, is conducted together with steam into an apartment lined with lead, on the floor of which is some water. But there is sent in with this some nitric acid; this acid on meeting the sulphurous anhydride gives up to it a part of its oxygen, and the *sulphuric* anhydride thus formed dissolves in the watery vapor present, making sulphuric acid. Meanwhile the nitric acid, having parted with some of its

oxygen, is no longer nitric acid, but nitric oxide; this immediately absorbs oxygen from the air in the leaden chamber, becoming nitric peroxide. Then this nitric peroxide, meeting sulphurous anhydride, again gives up its oxygen; and this process is repeated over and over. Thus you see the nitric peroxide answers simply as a medium for delivering over to the sulphurous anhydride the oxygen from the air.

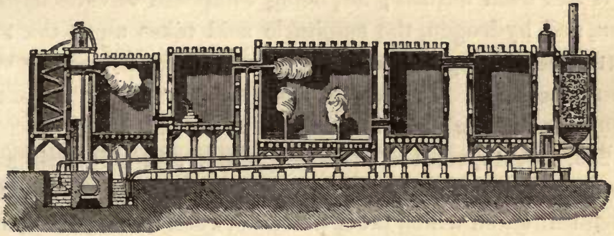

Fig. 79.

The sulphuric acid that is formed becomes dissolved as fast as it is made in the water in the lead chamber. In order to facilitate this solution steam is constantly admitted into the chamber, so that each particle of the acid may be dissolved as soon as it is formed. The water is in this way sent in search of the acid.

243. **Explanation in Formulæ.**—There are three stages:

	Sulphurous anhydride.		Nitric acid.		Water.		Sulphuric acid.		Nitric oxide.
(1)	$3(SO_2)$	$+$	$2(HNO_3)$	$+$	$2(H_2O)$	$=$	$3(H_2SO_4)$	$+$	$2(NO)$

	Nitric oxide.		Oxygen.		Nitric peroxide.
(2)	NO	$+$	O	$=$	NO_2

	Nitric peroxide.		Sulphurous anhydride.		Water.		Sulphuric acid.		Nitric oxide.
(3)	NO_2	$+$	SO_2	$+$	H_2O	$=$	H_2SO_4	$+$	NO

then (2) is repeated, (3) follows, and so on.

244. **Properties.**—Sulphuric acid is the most powerful of all the acids, and is therefore one of the most important

agents of the chemist in his operations. "What iron is to the machinist," says Stöckhardt, "sulphuric acid is to the chemist. It stands, as it were, the Hercules among the acids, and by it we are able to overpower all others, and expel them from their combinations." It chars most vegetable and animal substances. If a bit of wood be introduced into it, it becomes black, and in fact is reduced to coal, as if it had been burned; for, being composed of carbon, oxygen, and hydrogen, the sulphuric acid takes away the two latter, combining them to form water, and leaves the carbon untouched. It does the same thing to sugar, as that is composed of the same ingredients as wood.

245. **Development of Heat.**—If water and sulphuric acid be mixed together, considerable heat is evolved by the chemical union which takes place between them. This may be shown very prettily by the following experiment: Put some tow or cotton around a wine-glass, with some little bits of phosphorus placed in it in such a way as to be in contact with the glass. If now you pour into it some sulphuric acid, and then some water, the heat produced will burn up the combustible material around the glass. It is supposed that the heat is caused by a condensation which takes place in the union of the acid and the water. If 50 measures of the acid are mixed with 50 of water, we do not have as the result 100 measures of the mixture, but only 97, showing a contraction or condensation which is considered adequate to the production of the heat.

246. **A Practical Direction.**—The heat caused by the union of water and sulphuric acid explains the reason of a practical direction that may be given in regard to an accident which sometimes happens with sulphuric acid. If some of the acid be spilled upon the skin, just wipe off as much of it as you can with a piece of dry cloth or paper, and then use a large quantity of water in washing off the rest, so that

the acid may be well diluted. If you should apply water at first, the heat produced by its union with so much acid would cause an immediate corrosive action upon the skin. That the acid itself acts rather slowly, and its action may be greatly hastened by putting some water with it, may be seen in the following experiment. Drop a little of the acid upon paper, and you will see that the decomposition takes place slowly; but add a few drops of water, and the decomposition or corrosive action will be instantaneous from the influence of the heat produced.

247. **Uses of Sulphuric Acid.**—The sulphuric acid that we commonly use is, when it is the strongest, nearly one fifth water by weight, and its tendency to absorb water makes it very difficult to keep it of this strength. Exposed to air it will continually absorb its moisture, and of course increase in bulk. In air that seems to us perfectly dry this acid will find some moisture to drink. The chemist sometimes wishes to obtain some gas in an entirely dry state, and for this purpose lets it pass through sulphuric acid. The work is thoroughly done. As the gas bubbles up through the acid it loses every particle of water, and comes out perfectly dry.

As sulphuric acid has such strong and varied chemical powers, it is largely used in the arts. It is used, for example, in bleaching, in dissolving indigo for use in dyeing and calico printing, in manufacturing sodium carbonate and nitric and hydrochloric acids, in the refining of gold and silver, in the purification of oils, in the manufacture of superphosphate of lime, so much used now in agriculture, etc.

Sulphuric acid having two atoms of hydrogen which can be replaced by a metal, forms two classes of salts, neutral and acid. Thus we have sodium sulphate, Na_2SO_4, which reacts neutral, and hydro-sodium sulphate, $NaHSO_4$, which reacts acid. The second forms when excess of acid is present; on heating the acid salt to redness, sulphuric acid is expelled and the neutral salt remains.

Hydro-sodium sulphate.		Sodium sulphate.		Sulphuric acid.
$2NaHSO_4$	=	Na_2SO_4	+	H_2SO_4

A large number of the sulphates are very soluble; the sulphates of the alkaline earths are notable exceptions. Sulphates are often formed in nature from the sulphides by the latter taking up oxygen from the air.

248. **Sulphuretted Hydrogen,** H_2S.—This may best be prepared by acting on ferrous sulphide with hydrochloric or sulphuric acids; heating is not necessary.

Ferrous sulphide.		Sulphuric acid.		Ferrous sulphate.		Sulphuretted hydrogen.
FeS	+	H_2SO_4	=	$FeSO_4$	+	H_2S

The apparatus used is shown in Fig. 80. The gas which comes over is colorless, and has a very strong odor of rotten eggs. It is produced in the decomposition not only of eggs, but of other animal substances, and also of such vegetable substances as contain sulphur, as pease, beans, onions, etc. When at all concentrated this gas has a very decided effect upon various metals and their salts. Thus it blackens white paint because it attacks the white-lead in it, forming a sulphide of lead. Silver or copper vessels exposed to it become dark from the formation of sulphurets of these metals. There is some little of this gas very generally in the atmosphere, and hence silver articles become slowly tarnished. When much concentrated it is a very deadly gas, and it is this which occasionally destroys the lives of men engaged in cleaning

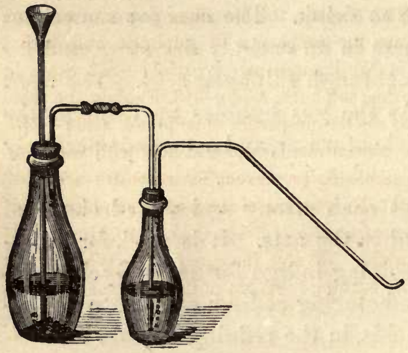

Fig. 80.

out vaults and sewers. Sulphuretted hydrogen burns with a pale blue flame, producing sulphurous anhydride and water, $H_2S + O_3 = H_2O + SO_2$. It dissolves in water freely, and the solution is of great service to the analytical chemist as a reagent, for it forms colored sulphides with solutions of many of the metals. This solution does not keep perfectly, sulphur precipitating, and hydrogen escaping or uniting with oxygen.

QUESTIONS.

233. How does sulphur occur in nature in the mineral kingdom? How in the vegetable? How in the animal?—234. What is said about the forms of sulphur? What is the meaning of dimorphous?—235. How can soft sulphur be made? Why is it called amorphous?—236. How are flowers of sulphur made?—237. What are the properties of sulphur?—238. What does burning sulphur produce?—239. How is sulphurous anhydride prepared? How are sulphites formed?—240. Explain the bleaching power of sulphurous anhydride.—241. What are the properties of sulphuric anhydride? How is it prepared? What is Nordhausen oil of vitriol?—242. State in full the process of manufacturing sulphuric acid.—243. Explain the reactions by equations.—244. What are the properties of sulphuric acid?—245. What happens when you mix concentrated sulphuric acid with water?—246. What remedy should be employed to prevent the corrosive action of sulphuric acid on the skin?—247. Name some of the uses of sulphuric acid. What is the distinction between neutral and acid salts?—248. How is sulphuretted hydrogen best prepared? What is the equation? What are its properties? What is said of its burning? What of its solution?

CHAPTER XIII.

PHOSPHORUS.

249. **Properties of Phosphorus.**—This substance, discovered more than two hundred years ago, and obtained now extensively from bones, has very remarkable properties, with which you have already become somewhat acquainted. It is a nearly colorless substance, having a waxy appearance. Exposed to the air it smokes, and in the dark emits light, from which it gets its name, derived from two Greek words signifying together to bear light. It is, you remember, inflammable at ordinary temperatures, and therefore in order to preserve it we must keep it in water. From the readiness with which it takes fire, and the violence with which it burns, it is necessary to be careful in handling it. It should be cut under water, and when taken from the water it should be held by a forceps or on the point of a knife, as even the warmth of the hand may set it on fire. We should use small quantities in experimenting, and have a vessel of water at hand to quench it in case it should take fire accidentally when we do not wish it. Phosphorus is a violent poison, and is therefore used in getting rid of rats and mice. The common rat electuary is made of a dram of phosphorus and eight ounces each of hot water and flour. Phosphorus is insoluble in water, but is soluble in ether, alcohol, and oils.

250. **Experiments.**—Observing the cautions given, you can try many interesting experiments with phosphorus, some of which we will notice.

Put into a phial half an ounce (a tablespoonful) of ether, and then a piece of phosphorus twice the size of a pea. Cork the phial, and put it aside for several days, occasionally shaking it. Pour the clear liquid now into another phial, and it is ready for use. If you moisten your hands with some of this solution, the ether will speedily evaporate, leaving the phosphorus in small quantities all over the skin, which of course combines with the oxygen of the air, and in doing so gives out a light which in the dark is very bright. By rubbing the hands you make the light more vivid, because you quicken this union of the phosphorus and oxygen. The quantity of phosphorus used in this case is so small that little heat is evolved, and we have a slow combustion, producing phosphorous anhydride.

Moisten a lump of sugar with this solution, and throw it into hot water. The ether and phosphorus rise together to the surface, and the moment they reach the air they take fire. The combustion is here rapid and perfect, and therefore phosphoric anhydride, which has more oxygen in it than the phosphorous anhydride, is formed.

Pour some of the solution upon fine blotting-paper, and it will burst into flame as soon as the ether is evaporated.

If you boil water in a flask with some phosphorus in it, the escaping steam will be luminous.

251. **Amorphous Phosphorus.**—When ordinary waxy phosphorus is heated for many hours in tightly closed vessels in such a manner that it can not burn, a great change in its properties takes place, and we obtain what is known as amorphous phosphorus. This is dark-red in color, is opaque instead of transparent, its specific gravity is higher, it is insoluble in the liquids which dissolve ordinary phosphorus, and, most remarkable of all, it no longer takes fire in the open air at low temperatures. It may be heated quite hot, beyond 200° C., without inflaming. This red phosphorus

is another case of allotropism, which, you remember, in the case of ozone and carbon was attributed to a difference in the arrangement of the atoms.

252. **Lucifer-Matches.**—As phosphorus can be ignited by friction, it is used in the manufacture of lucifer-matches. The substance on the ends of the matches is a mixture of phosphorus with other substances that contain considerable oxygen, the composition being done up in mucilage of gum arabic. The object is to supply oxygen in the immediate neighborhood of the phosphorus, that the friction may readily produce combustion. The particles of the phosphorus are so much shut in from the air in the dried mass that the oxygen of the air can get admission to comparatively a small portion of them. The substances containing oxygen that are commonly used are red-lead (oxide of lead), potassium nitrate, and potassium chlorate. A formula given by Stöckhardt is this: 1¾ parts of phosphorus, 4 each of gum-arabic and water, 2 of nitre, and 2 of red-lead. Safety matches are made with amorphous phosphorus, which is less liable to be set on fire by accidental friction. Sometimes the phosphorus composition is applied only to the surface of the box, and then the matches ignite only when rubbed on this surface.

253. **Mode of Obtaining Phosphorus.**—As already stated, phosphorus is obtained from bones. These are composed mostly of an animal substance, gelatine, and a mineral substance, phosphate of lime. The gelatine is first burned out, and the phosphate of lime which is left is reduced to powder. This powder is digested with dilute sulphuric acid, and in consequence a sulphate of lime is formed, which is an insoluble substance. As, therefore, phosphate of lime is composed of phosphoric acid and lime, the lime being removed, we have the phosphoric acid dissolved in the dilute sulphuric acid. This solution, after being strained, is mixed

with powdered charcoal, and when the mixture is dry it is put into a stone-ware retort, *a*, Fig. 81, to the neck of which is attached a copper tube, *b*, the mouth of which dips under water in a vessel. The retort being subjected to a white heat, the charcoal unites with the oxygen of the phosphoric acid to form carbonic oxide, and the disengaged phosphorus becomes vaporized. The vapor and the gas pass over together through the tube, *b*, the phosphorus becoming condensed and dropping into the water, and the gas passing out through the small tube in the vessel. Phosphorus is commonly in the form of small round sticks, this form being given to it by melting it in glass tubes in warm water.

Fig. 81.

254. **Diffusion of Phosphorus in Nature.**—Phosphorus is quite widely diffused, not as phosphorus, for it is never found as an element, but in combination with other substances. There is in the body of an adult man from 500 to 800 grammes of phosphorus. It is not all in the bones, but there is some in the blood and the flesh, and especially in the brain. Now the phosphorus that is in animals must come from vegetables, and these must get it from the mineral world. The phosphate salts appear in all kinds of grain, and in leguminous and many other plants, especially in their seeds. If there were no such salts in the soil these seeds could not be produced, and hence in part the great usefulness of bones, in many cases, as a manure, supplying the deficiency of these salts in the soil. From all this you see that phosphorus has a wide and constant circula-

tion in the chemical and vital operations going on in the world.

255. **Phosphoretted Hydrogen**, H_3P.—This is a colorless gas having the odor of garlic. A beautiful phenomenon attends its production if it be allowed to escape into the air. Let about 30 grammes of potassium hydrate be put into a small retort, Fig. 82, and pour in upon it half a tumbler of water; then add a bit of phosphorus-stick half an inch long and a teaspoonful of ether, and apply the heat, the beak of the retort being under the surface of the water in the bowl. The ether has nothing to do with making the gas, but this is made by the action of the phosphorus and potassium hydrate and water together. The object of the ether is to prevent an explosion, which would be liable to occur if the gas escaped directly into the air in the retort. The ether does this very effectually, for, being vaporized by the heat, it rises, driving the air out before it, and then the gas, which is generated as the heat increases, passes out behind the ether, which acts thus as a sort of advance-guard. The gas, as it comes up out of the water in the bowl, takes fire spon-

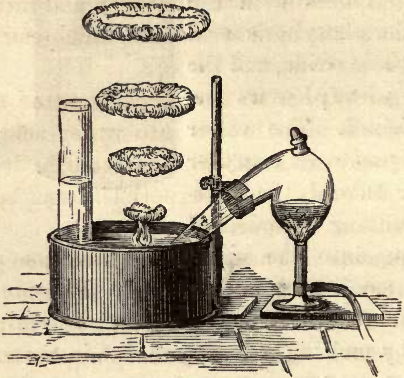

Fig. 82.

taneously, emitting a bright yellow light; and the smoke rises in rings, which enlarge as they go up, exhibiting at the same time a singular rotary movement. The reaction is complicated:

Phosphorus.		Water.		Potassium hydrate.		Phosphoretted hydrogen.		Potassium hypophosphite.
P_4	+	$3H_2O$	+	$3KHO$	=	H_3P	+	$3KPH_2O_3$

It is this gas, forming with hydrogen and nitrogen in the decomposition in the mud of marshes, which causes the light called "will-o'-the-wisp."

256. **Another Way of Making Phosphoretted Hydrogen.**—Phosphide of calcium thrown into water acidulated with hydrochloric acid gives off phosphoretted hydrogen, which ignites spontaneously. This experiment can be made in a wine-glass without danger.

257. **Compounds of Phosphorus with Oxygen.**—These are two in number. First we have phosphor*ous* anhydride, formed by slow combustion, as exemplified in the first experiment in § 250. Then we have phosphor*ic* anhydride, the result of perfect combustion, as in the second experiment, and in the burning of phosphorus in oxygen gas, noticed in § 58. Both of these anhydrides dissolve in water, forming corresponding acids. Phosphoric acid is made in another way, however, as this is inconvenient. Phosphorus is heated with moderately strong nitric acid, the phosphorus is oxidized by the acid, and on concentrating the solution the excess of nitric acid is expelled and a sirupy liquid remains. Phosphoric acid, H_3PO_4, containing three atoms of hydrogen, is a tri-basic acid, and forms a great variety of salts.

A third acid is known, hypophosphorous acid, the compounds of which are used in medicine. Its anhydride has not as yet been prepared.

QUESTIONS.

249. How long has phosphorus been known? What are its properties? How does it act physiologically? In what is it soluble?—250. Describe some experiments with a solution of phosphorus.—251. How is amorphous phosphorus obtained? What is allotropism?—252. What is the chief use of phosphorus?—253. Detail the method of obtaining phosphorus.—254. Where and in what state does phosphorus occur in animals? How do animals get it?—255. What is the composition of phosphoretted hydrogen? What is its nature? Explain a method of obtaining it. What name is given to it when occurring in marshes?—256. Mention another way of making this gas.—257. What compounds does phosphorus form with oxygen? What is said of the acids?

CHAPTER XIV.

SILICON AND BORON.

258. **Silicon.**—This element never occurs in nature in a free state, but its compound with oxygen—silicic anhydride, SiO_2—is most important and abundant. Silicon itself is capable of existing in three allotropic forms, like carbon; the form corresponding to lampblack is a dark-brown powder, destitute of lustre; the diamond form is crystalline, and so hard as to scratch glass. These substances are mere chemical curiosities, and their preparation does not interest us. United with oxygen it forms silicic anhydride, commonly called silica; this unites with the elements of water, forming a true acid, which, when freshly prepared, appears like a transparent jelly. On igniting, water is driven off and silica remains. Compounds of silicic acid and metallic oxides are called silicates.

259. **Abundance of Silica.**—It is estimated that silica constitutes about one sixth of the bulk of the earth. It appears in various forms and combinations. It is nearly pure

in quartz and flint. Various precious stones, carnelian, amethyst, opal, jasper, etc., are silica, their different colors being caused by the presence of metallic oxides. Common sand is silica, generally rendered yellow by the hydrated oxides of iron or iron rust. Then silica is present in many salts called silicates, constituting part of an abundant class of rocks. In the granite rocks we have mingled with the quartz, which is silica, two silicates—feldspar and mica. There are silicates in many other rocks also. In clays there are variable quantities of various silicates; but the silicate of alumina is largely predominant, and is the essential basis of all clays. The best porcelain clay, which is perfectly white, is nearly pure silicate of alumina. As earthenware is made of clay, it is composed of silicates. The same thing is true of the various kinds of glass.

260. **Silica in Water and in Plants.**—Through the agency of potash silica is rendered soluble to some extent, and therefore is found in water and in plants. If spring-water be evaporated, what remains in solid form is in part silica; and so if we burn plants, it is found in their ashes. There is considerable silica in grasses and the various kinds of grain, and they have therefore been called silicious plants. Absorbed by the root, it goes up in the plant dissolved in the sap, and is deposited chiefly in the stalks, giving to them their requisite firmness. It is to them what the mineral matter, the phosphate of lime, in our bones is to us. Silica is also present to a considerable extent, especially in the frame-work of those minute animals, which can be seen only by means of the microscope, called infusoria.

261. **Silicified Wood.** — A singular result occurs when wood decays in water that has considerable silica dissolved in it. The water, of course, soaks into every part of the wood, taking the silica along with it. Now, as the particles of wood are loosened one after another and carried

away, a particle of silica takes the place of every removed particle of wood, so that at length all the wood is gone, and is wholly replaced by silica. Because the shape and all the lines of the wood are preserved, the common idea is that the wood is turned to stone; but, as you see, stone has merely taken the place of wood. Silicified wood is found in great quantity in certain parts of California and Oregon. Large trunks of trees are found completely silicified. Such specimens are erroneously called petrifactions, as if they were the result of turning into stone.

262. **Glass.**—In making glass, the silica or silicic anhydride is made, by an intense and long-continued heat, to unite with various bases, according to the kind of glass required. Window-glass is made by uniting silica with soda and lime; plate-glass, crown-glass, and the beautiful Bohemian glass, by uniting silica with lime and potash; and green-bottle glass is commonly a silicate of lime and alumina, combined with oxides of iron and manganese, and sodium and potassium, its green color being produced by the oxide of iron. Glass is in reality a very complex mixture of true salts. What is called enamel is an opaque glass, made so by some substance which, though it be thoroughly mixed with the glass in melting, does not melt with it. Stannic oxide is commonly used for this purpose. The silica used in making glass is in the forms of sand, quartz, flint, and old broken glass. The materials are subjected to intense heat in clay pots for about forty-eight hours, in order to bring the mass into a proper state to be worked. The manner in which the melted glass is made into various articles we will not detail. The common mode of making window-glass is described in Part I., § 216.

263. **Coloring Glass.**—The various colors are given to glass mostly by metals. We have already mentioned the bottle-green color imparted by the ferrous oxide. Ferric oxide gives

a yellowish-red color, oxide of cobalt blue, oxide of manganese purple and violet, oxide of copper a ruby red, etc.

264. **Annealing.**—Glass, like steel, must be annealed to deprive it of its brittleness. For this purpose the articles that are made are placed in the annealing furnace, which is a very long gallery containing iron trays that are moved very slowly through it by means of an endless chain. The heat at the end where the articles are put in is very great, and gradually lessens toward the other end. Every article is from twenty-four to forty-eight hours in passing through the gallery, and the particles of the glass have time, in this slow cooling, to assume such an arrangement as to give them their highest degree of firmness. We see the opposite result in what are called "Prince Rupert's Drops," which are prepared by taking up on an iron rod some melted glass and allowing the drops of it to fall into cold water. They assume the shape given in Fig. 83. The particles in this case, solidifying hastily, have an exceedingly unstable arrangement, which can be wholly destroyed by a very slight disturbance. If, therefore, you scratch the surface or break off the little end, the whole flies into powder so quickly as to cause a considerable report.


Fig. 83.

265. **Slag.**—The slag which is so often seen in reducing metallic ores is composed of silicates, and is a kind of glass. In the process of reducing iron ore, described in Chapter XVIII., the lime is used, because it makes, with the silica that is mixed with the ore, a glass that is very fusible, and is therefore easily removed. It is for this reason that oyster-shells, introduced among the anthracite coal in a stove, remove the clinker. The lime unites with the silica, and the silicate formed, melting easily, runs down and min-

gles with the ashes. So, also, if there be much lime in the clay that is used for making bricks, they will be apt to be spoiled in burning, from the too great fusibility of the silicate that is thus formed.

266. **Soluble Glass.**—Glass, as commonly made, is wholly insoluble; but soluble glass can be produced by using a very large proportion of alkali; and a solution of it was known a long time ago as the *liquor of flints.* Such a solution is sometimes employed as a fire-proof varnish for wood, canvas, etc.

267. **Earthenware.**—All earthenware is made of clay, which has as its essential ingredient silicate of aluminium. There are mingled with this in different clays silicates of potassium, sodium, calcium, etc. The coarsest clay employed is used in making bricks and common flower-pots, and the finest in making porcelain. The plastic nature of clay, and its hardening by heat, are the causes of its peculiar adaptation to the manufacture of earthenware. The moistened clay, after being well kneaded, is shaped, either by pressure in moulds, as in brick-making, or by the hand of the potter as he makes it revolve with his lathe, thus pressing into his service centrifugal force, as indicated in Part I., § 213. The articles are first dried in the sun, and then are baked in furnaces, both of which processes cause considerable shrinking, especially the baking. The reddish-brown color of bricks and flower-pots is owing to the presence of ferric oxide. The bricks of the Egyptians, in the making of which straw was used as one of the constituents, were merely sun-dried. The bits of straw mingled with the clay were of the same use as hair is in mortar which is used in plastering.

268. **Glazing.**—Although earthenware by baking becomes hard and firm, it is quite porous, so that water can exude through it. This is not objectionable in the case of flower-

pots, but would be decidedly so for most of the purposes to which earthenware is applied. To remedy this defect the ware is covered with a coat of glass. This glazing, as it is called, is done in various ways. Common earthenware is often glazed with oxide of lead. This is very dangerous if the vessels are to be used in cooking or in preserving any eatables, for the lead may be dislodged by some chemical action of the contents, and act as a poison. Common salt is also used. Being thrown into the kiln, it is raised in vapor by the heat, and is decomposed on coming in contact with the surface of the ware. The chlorine leaves the salt, and its sodium becoming soda by attracting oxygen, the soda unites with the silica of the ware and forms a glass. For finer articles another mode is followed: A paste is made of such materials as will, under the influence of powerful heat, form a glass. These materials are reduced to an exceedingly fine powder, and this being diffused in water, the article to be glazed is dipped into it. By this means it gets a very thin coating of the glaze, for the clay absorbs at once the moisture, and the fine powder remains uniformly diffused over the surface. By intense heat this is converted into a smooth coating of glass. The paste used is often composed of feldspar, quartz, and borax. Glazing is not necessary in the case of porcelain and some kinds of stoneware, for certain materials which form glass are mingled with the clay, so that the heat of the baking fills up all the minute spaces in the clay with glass. Still, the glazing is usually done for the sake of adding to the beauty of the ware.

269. **Boron.**—The element called boron is a gray amorphous powder. It is never found in nature, but the acid which it forms, boracic acid, is sometimes exhaled from volcanic openings in the earth. The hot vapors of the lagoons of Tuscany contain it in large quantity. In collecting it,

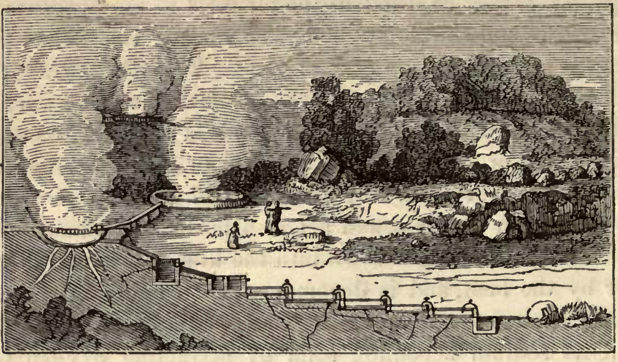

Fig. 84.—Lagoons of Tuscany

these vapors are made to pass into water, which condenses them, and then the water is evaporated, which leaves the boracic acid in large crystalline flakes, having the feeling somewhat of spermaceti. Boracic acid is not volatile when it is by itself. If heat be applied to it, it will melt, and become a vitreous mass, but no degree of heat will make it fly off in vapor. But it is volatile when it is in volatile company, as we may say; which is often true of other substances, and, we may add, persons also. Thus, if we mix some of it with alcohol in a mortar, and then set fire to the alcohol, it will burn with a green flame, because some of the boracic acid rises in vapor with it. Boracic acid forms with sodium a bi-borate, commonly called borax, which we shall notice hereafter.

QUESTIONS.

258. In what does silicon resemble carbon? What are silicates?—259. What is said of the occurrence and abundance of silica? What is quartz? What is granite? What is clay?—260. What is said of the presence of silica in plants? What animals contain silica?—261. What is silicified wood? Explain the error of common opinions regarding it.—262. How is glass

made ?—263. What materials are used to color glass ?—264. How is annealing done, and with what object ? Describe the experiment with Prince Rupert's Drops.—265. What is slag ? Why do oyster-shells remove clinker in a furnace ?—266. What is said of soluble glass ?—267. Of what is earthenware made ? Whence comes the reddish color of bricks ? Why did the Egyptians use straw in making bricks ?—268. How is glazing done ? How are finer articles glazed ?—269. What is said of the occurrence of boracic acid ? What is borax ?

CHAPTER XV.

METALS.

270. **Characteristics of the Metals.**—Metals as a class of substances have certain general characteristics. 1. In masses they are opaque bodies. It has been thought by some that gold is an exception, for they assert that light is transmitted through it when made into leaf, even when the leaf is not so thin as to permit transmission through multitudes of little openings. 2. Metals are not soluble. It is commonly stated that they are not soluble in water. But it may be said with truth that they are not soluble in any liquid ;* for, as you will see farther on in this book, in those cases in which metals are spoken of as being dissolved, it is not really the metal which dissolves, but a chemical compound is formed with the metal by the liquid, and then this compound is dissolved. 3. Metals have more or less of a certain brilliancy, which is termed, whenever it is found in other substances, the metallic lustre. 4. Metals are better conductors of heat and electricity than the non-metals, and most of them have a higher specific gravity.

Some of the properties of metals require a closer examina-

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* Certain remarkable cases excepted.

tion, especially malleability, ductility, fusibility, density or specific gravity, and tenacity.

271. **Density.**—Most of the metals are dense, and therefore heavy substances. The idea of most people is that a metal is of course heavy, and this was the idea also of philosophers until Sir Humphrey Davy, in 1807, made his discovery that potash and soda are oxides of metals. This is illustrated in an anecdote of Dr. Wollaston, a celebrated English chemist. Davy, just after he had succeeded in obtaining by a chemical process the metal potassium, of which potash is the oxide, put a bit of it into the hands of Dr. Wollaston, who spoke of it as being quite heavy, and was surprised to learn that it was lighter than water. There is a wide range in the specific gravities of the metals, as may be seen from the following table, which contains a portion of them:

SPECIFIC GRAVITIES OF METALS.

	Sp. Gr. at 15.5° C.		Sp. Gr. at 15.5° C.
Platinum	21.50	Manganese	8.00
Gold	19.50	Iron	7.79
Uranium	18.40	Tin	7.29
Mercury	13.59	Zinc	7.10
Thallium	11.90	Antimony	6.80
Palladium	11.80	Arsenic	5.88
Lead	11.45	Aluminium	2.67
Silver	10.50	Magnesium	1.75
Bismuth	9.90	Calcium	1.58
Copper	8.96	Rubidium	1.52
Nickel	8.80	Sodium	.972
Cadmium	8.70	Potassium	.865
Cobalt	8.54	Lithium	.593

The comparison in this table is made with water, that being considered 1. There is, you observe, a gradual diminution in specific gravity in the list till we come to the last seven. These are very light, three of them are even lighter than water, and one of them, lithium, being lighter than any known liquid.

272. **Color.**—The colors of almost all the metals are various shades between the pure white of silver and the bluish gray of lead. Bismuth has a reddish-white color. There are only two metals that have very decided colors—gold, which is yellow; and copper, which is red.

273. **Tenacity.**—There is great variety in different metals in their tenacity or power of holding together, iron being the strongest and lead the weakest. This quality is tested by using wires of the different metals of the same size and appending weights to them, observing how much each wire can possibly hold without breaking. In the following table the experiments were made on wires one millimetre in diameter:

Metals.	Breaking weight: wires one millimetre in diameter.	Relative tenacity.
Lead	3.1 lbs.	1.00
Tin	6.9 "	2.20
Cadmium	9.5 "	3.06
Aluminium	18.0 "	5.80
Zinc	23.5 "	7.58
Gold	27.0 "	8.71
Silver	29.0 "	9.35
Copper	37.0 "	11.90
Platinum	44.0 "	14.20
(Brass	56.0 "	18.00)
Iron	56.5 "	18.20
(Steel	96.0 "	30.00)

274. **Malleability.**—Malleability, derived from the Latin word for hammer, is the capability of being beaten into leaves. Laminability, from the Latin for leaf, *lamina*, is sometimes used for the same quality, as exhibited when the leaves are made by pressure rather than by blows, as when iron and other metals are flattened by passing between heavy rollers of steel. More properly it should be used as

including both this and malleability, for in either case laminæ or leaves are formed. Gold is the most malleable of all the metals. It has been beaten so thin as to require nearly 300,000 leaves to make an inch in thickness if they could be pressed into a solid mass. A leaf of this book equals forty or more of such leaves in thickness. Some metals are perfectly malleable when cold, as gold, silver, lead, and tin; while others, as iron and platinum, are only slightly malleable when cold, but very much so when heated.

275. **Ductility.**—This quality, named from the Latin word *duco*, to lead or draw, is the capability of being drawn out in the form of wire. It is very nearly allied to malleability. Wires are made small by being drawn successively through smooth conical holes in a steel plate, each hole being a little smaller than the one through which the wire was previously drawn. Dr. Wollaston made a gold wire so fine that one hundred and sixty-one metres (five hundred and thirty feet) of it weighed but sixty-four milligrammes (one grain), and he succeeded in making a wire of platinum six times as fine as this. This, then, is more ductile than gold, while it is not by any means as malleable.

276. **Relations of the Metals to Heat.**—The melting points of the metals, or the degrees of temperature at which they melt, are very different. Thus it requires a much less degree of heat to melt lead than it does iron; and platinum resists the heat of the hottest furnace, and can only be melted in the flame of the oxyhydrogen blow-pipe or the current of a galvanic battery. This metal stands at one extreme in regard to fusibility, while mercury stands at the other. So low is the degree of temperature at which this latter melts, or, in other words, so little heat is required to melt it, that it is in the solid state in no weather except that of winter in the arctic regions. Many metals are quite volatile—that is, capable of being made to fly off in vapor

by the application of heat; some of them at quite a moderate temperature. Thus mercury, arsenic, and zinc are volatile below a red heat. Indeed, at ordinary temperatures mercury is somewhat volatile, and there is always a thin vapor of this metal in the vacuum of the thermometer, so that it is not strictly a vacuum.

TABLE SHOWING THE FUSING POINTS OF METALS.

		F.	C.
Fusible below a red heat.	Mercury	—39°	—39.4°
	Rubidium	101.3	38.5
	Potassium	144.5	62.5
	Sodium	207.7	97.6
	Lithium	356	180
	Tin	442	235
	Bismuth	497	258
	Thallium	561	294
	Cadmium	599	315
	Lead	626	330
	Arsenic	Unknown.	
	Zinc	773	412
	Antimony	842	450
Infusible below a red heat.	Silver	1873	1023
	Copper	1996	1091
	Gold	2016	1102
	Cast iron	2786	1530
	Nickel, Cobalt, Manganese, Palladium,	Highest heat of forge.	
	Chromium, Titanium, Osmium, Iridium, Platinum,	Infusible in ordinary blast-furnaces.	

277. **Welding.**—Some of the metals, as they approach to the melting point, become semi-fluid or pasty. This is the case with iron. In this state it can be welded—that is, two pieces of it can be made to unite by hammering them to-

gether. Lead, potassium, and sodium can be welded without being heated, and mercury can be welded when it is frozen.

278. **Alloys and Amalgams.**—Metals unite together to form alloys. Some of the most common of these we will mention. Brass is an alloy composed of copper and zinc, the copper making from two thirds to three fourths of the whole. The color of the mixture is intermediate between the deep color of the copper and the light color of the zinc. What is called pinchbeck is a kind of brass, with a larger proportion of zinc than ordinary brass. What is called German silver is a sort of brass with the addition of another metal, nickel, the whiteness of which gives this alloy its resemblance to silver. Bronze is an alloy of copper and tin, the latter being commonly one tenth of the whole. Bell-metal is the same, with a larger proportion of tin. Common type-metal is an alloy of lead with different proportions of zinc, tin, bismuth, and antimony. Solders are commonly alloys of lead and tin. Pewter is tin alloyed with lead or antimony. What is called Britannia ware is a kind of pewter. The alloys which various metals form with mercury are called *amalgams.* A familiar example you have in the silvering of mirrors. The amalgam is formed in this case by pouring mercury upon tin-foil laid over the glass.

279. **Nature of Alloys.**—An alloy is generally considered as a mixture, and not a compound, for two reasons: 1. In making alloys there are no fixed proportions in which the metals must be combined. 2. The qualities of alloys are intermediate, for the most part, to those of their constituents. Thus the color of brass is intermediate to the colors of the copper and the zinc, and the hardness of type-metal to that of the copper and that of the lead. But there are some marked exceptions to this second characteristic of mixtures, which seem to indicate the existence of some degree of chemical affinity, sufficient to produce decidedly new quali-

ties. For example, an alloy of copper and tin, in the proportions of 90 of the former and 10 of the latter, called speculum metal, is as brittle as glass and almost white. Now if it were merely a mixture, its color should be that of copper lightened by the small proportion of tin, as zinc lightens the copper-color in brass, and the tin should give to it but a slight degree of brittleness. A single example more will suffice. There is an alloy which is sometimes used as a source of amusement, for teaspoons made of it will melt in a cup of very hot tea. It is composed of 8 parts of lead, 15 of bismuth, 4 of tin, and 3 of cadmium. If it were only a mixture, the melting point of the alloy would be somewhere between the melting points of its constituents. But in fact it is far below them. Lead must be heated to 330° to melt it, bismuth to 258°, tin to 235°, and cadmium to 315°; but this alloy melts at about 70°—that is, 30° below the boiling point of water.

280. **Ores.**—The ores of metals are certain compounds from which the metals are usually obtained. These compounds are commonly oxides or sulphides. When any metal is found in its uncombined state it is said to be *native.* Some metals, as gold and platinum, are always found in this state, and therefore, strictly speaking, have no ores, though this word is sometimes loosely applied to them. Such metals are often found alloyed with other metals. Thus gold is usually alloyed with silver, copper, etc. Silver is found in the three conditions, native, alloyed, and combined. The word ore is not applied to all combinations of metals, but only to those which are used in obtaining the metals. Thus the carbonate of iron is an ore; but the carbonate of calcium, occurring in the different forms of chalk, limestone, marble, etc., is not an ore. So while an oxide of iron is an ore, limestone, the carbonate of calcium, is not.

281. **Classification of Metals.**—Metals may be divided for the sake of convenience into nine groups, according to their attraction for oxygen and their chemical relations generally:

Group I.—*The Metals of the Alkalies:* Potassium, Sodium [and the very rare metals Lithium, Cæsium, and Rubidium].

Group II.—*Metals of the Alkaline Earths:* Barium, Strontium, and Calcium.

Group III.—*Metals of the Earths:* Aluminium [and the very rare metals Glucinum, Yttrium, Erbium, Cerium, Lanthanium, Didymium].

Group IV.—*Magnesian Metals.* Magnesium, Zinc [Cadmium, and Indium].

Group V.—*Iron Group.* Manganese, Iron, Cobalt, Nickel, Chromium [and Uranium].

Group VI.—*Tin Group.* Tin [and the exceedingly rare metals Titanium, Zirconium, Thorinum, Columbium, Tantalum, Molybdenum, and Tungsten].

Group VII.—*Arsenic Group.* Arsenic, Antimony, Bismuth [and Vanadium].

Group VIII.—*Three Metals not closely related.* Copper, Lead [and Thallium].

Group IX.—*Noble Metals.* Mercury, Silver, Gold, Platinum [and the accompanying metals Palladium, Rhodium, Ruthenium, Iridium, and Osmium].

Of these forty-nine elementary substances we shall study only twenty-three, the remainder (inclosed in brackets in the above paragraphs) are far too rare and of too little importance and interest to engage our attention. Sometimes arsenic and antimony are placed for chemical reasons among the non-metallic bodies alongside of phosphorus, but this is only a matter of taste. The line drawn between the non-metals and the metals is not absolute, but merely a convenient way of distinguishing them.

There is another way of grouping metals often followed, viz., with reference to their atomicity; but this separates metals which seem to belong naturally in one class, as you see in the following list, where all the metals are thus arranged, the rare ones being in brackets :

MONADS.	DYADS.	TRIADS.	TETRADS.	PENTADS.	HEXADS.
K	Ba	[Tl]	Pt	As	Cr
Na	Sr	[In]	[Pl]	Sb	[U]
[Li]	Ca	Au	[Ir]	Bi	[W]
[Cs]	Mg		[Ro]	[Vd]	[Mo]
[Rb]	Zn		[Ru]	[Ta]	
Ag	Cd		[Os]	[Cb]	
	Hg		Sn		
	Cu		[Ti]		
	[Gl]		Pb		
	[Yt]		[Zr]		
	[Er]		[Th]		
	[La]		Al		
	[Dd]		Fe		
			Mu		
			Co		
			Ni		
			[Ce]		

QUESTIONS.

270. What are the chief characteristics of metals?—271. Illustrate the fact that metals are not necessarily dense. Name the heaviest metal and the second heaviest. Name the lightest metal.—272. What three metals have distinct colors?—273. What is meant by tenacity? Which is the least tenacious metal? Which the strongest?—274. What is meant by malleability? Which is the most malleable of metals?—275. What is ductility? How fine a platinum wire did an English chemist make?—276. How does a difference of temperature affect metals? Which metals are volatile? Which is the most fusible metal? Which the most infusible?—277. What is welding?—278. What is said of alloys and amalgams? Of what is solder made? Of what German silver?—279. Is an alloy a true chemical compound? Why not? What are the ingredients of fusible metal? At what temperature does it melt?—280. Give in full what is said of ores.—281. Into how many groups may the metals be divided? What two bodies are sometimes placed among the non-metals?

CHAPTER XVI.

GROUP I.—POTASSIUM AND SODIUM.

282. **Potassium and Sodium.**—These metals have so great an attraction for oxygen that they are never found native. They occur only in combination, usually as salts. They decompose water at ordinary temperatures, setting hydrogen free; this is of itself a sufficient reason for their not existing native. Their oxides and hydrates are exceedingly soluble in water, forming intensely alkaline caustic solutions. They form important compounds with the non-metals and with the principal acids.

283. **How Potassium is Obtained.**—Potassium was originally obtained by Davy by decomposing the hydrate, by means of a galvanic battery. But it is now commonly obtained by decomposing potassium carbonate by a process which we will describe. The carbonate and some charcoal finely pulverized and well mixed are exposed to a white heat in an iron retort, *a*, Fig. 85 (p. 207). Observe now what the chemical changes are. Potassium carbonate is composed of K_2CO_3. This is decomposed, the oxygen uniting with the carbon to form carbonic oxide. We have then formed two things, carbonic oxide and the metal potassium:

Potassium carbonate.		Carbon.		Potassium.		Carbonic oxide.
K_2CO_3	$+$	$2C$	$=$	K_2	$+$	$3CO$

Now the heat is so great that the metal is in the state of vapor, and this vapor and the carbonic oxide gas pass out together through the tube, *i*, into the copper receiver, *h*. The upper part of this receiver is surrounded by a wire

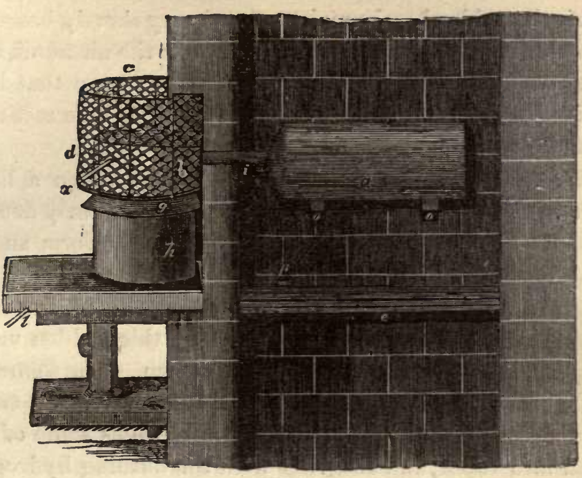


Fig. 85.

basket, *b x c d*, which is filled with ice. The object of this is to condense the vapor of the metal, while the gas, the carbonic oxide, is allowed to escape through an opening. The condensed metal falls to the bottom of the reservoir into some mineral naphtha. This is a liquid which contains no oxygen, its ingredients being only carbon and hydrogen, and therefore it will not have any effect upon the potassium. There are some minute details in this process which we have omitted in order that the main points may be clear to you. The process is expensive and difficult, and the metal is obtained in small quantities, and therefore it bears a high price.

284. **Properties of Potassium.**—Potassium is so light that it floats on water. It is a white metal with a cast of blue, and is very brilliant in its lustre if a piece be cut so as to expose a fresh surface. But so great is its attraction for oxygen that the cut surface immediately tarnishes from uniting with the oxygen of the air, and if left exposed to

the air the oxide absorbs moisture, and very shortly becomes potassium hydrate. It can not be kept in the air at all, and is ordinarily kept in naphtha for the same reason that it is received into that liquid when it is made. It is so soft that it can be worked by the fingers like wax.

285. **Potassium Set on Fire by Water.**—When a little piece of this metal is thrown upon water it instantly decomposes the water, taking the oxygen to itself to form an oxide. Hydrogen, the other ingredient of water, being set free, immediately takes fire, Fig. 86, from the heat which is produced by this sudden union of the oxygen and potassium. The flame of the burning gas is of a beautiful violet color. This is because the heat changes some of the metal into vapor, and this rises with the burning hydrogen. As the metal burns it runs about on the surface rapidly. This is owing to the hydrogen gas which is constantly developed from the water, the steam produced from the water by the heat, and the vapor of the metal. These act on the little bit of potassium as the gases of burning powder do on a rock. The motion is irregular, because the production of the gas and steam and vapor is going on upon all sides of the piece of metal. The results of this energetic action are potassium hydrate and free hydrogen; the latter, however, immediately burns, *i. e.*, unites with oxygen, forming water. $K+H_2O=KHO+H$ and $H_2+O=H_2O$. The same phenomena and results occur if potassium be thrown upon ice. So strong is its attraction for oxygen that the coldness of the ice makes no difference.


Fig. 86.

286. **Caustic Potash.**—What is commonly termed caustic potash is a hydrate of potassium, KHO. So strong is the disposition of the oxide of potassium to become hydrated, that the anhydrous oxide can be obtained only by exposing the metal potassium to air or oxygen that is perfectly dry.

This is of course an expensive process, as potassium is a costly metal. And, besides, this anhydrous oxide rapidly becomes hydrated on exposure to common air by attracting its moisture. The hydrate is a white solid. It has a soapy feeling, owing to its dissolving the cuticle, forming with it a kind of soap. It is a strong caustic, decomposing and dissolving the flesh, and making with it a soapy jelly. It eagerly absorbs water from the air, and becomes dissolved in it. It can therefore be kept in its solid state only by keeping it shut in from the air. It can be dissolved in half its weight of water. It has strong purifying powers, and hence is used in making soap, which will be spoken of particularly in another part of this book, when we show what the chemical union is that it forms with fatty substances. This and the other alkalies turn reddened litmus solution blue, as stated in § 80.

287. **How Potash is Obtained.**—Neither potassium nor potassium hydrate occur native, but are always found combined with acids forming salts, as potassium chloride, carbonate, nitrate, etc. Thus combined it is a very abundant substance in nature. Potassium carbonate abounds in vegetables, and the name potash comes from the pots in which the vegetables from which it was obtained used formerly to be burned, the alkaline carbonate remaining with the ashes at the bottom of the pots. It is from this carbonate that the caustic potash is ordinarily obtained. The carbonic acid can not be driven off by heat, but it can be taken away by some substance which has a stronger affinity for it than the potash has. Such a substance is lime. This added to a solution of potassium carbonate in proper quantity takes the carbonic acid, forming calcium carbonate, and leaves the potassium hydrate free in solution. On evaporating this solution, by heating it in a basin of iron, we obtain caustic potash :

Potassium carbonate.		Calcium hydrate.		Calcium carbonate.		Potassium hydrate.
K_2CO_3	+	CaH_2O_2	=	$CaCO_3$	+	$2(KHO)$

The same thing is done in part in the common leach-tubs. Lime is put into the lower part of the tub, so that as the dissolved carbonate of potash comes down a part of it is deprived of its carbonic acid, and therefore becomes caustic potash. The lye thus produced is then a solution of the caustic potash and the carbonate together.

288. **Potassium Carbonate,** K_2CO_3.—If a lye be obtained from wood-ashes, and be evaporated to dryness, we have in the mass which is left the common crude potash of commerce. There are in this many impurities mingled with the potassium carbonate, for there are other soluble salts in the ashes which appear in the lye. Pearlash is this common potash partially purified from these impurities. Potassium carbonate is decidedly alkaline, having an alkaline taste, and turning red litmus paper blue. It has to some little extent the cleansing power of caustic potash. Though quite insoluble in alcohol, it is very soluble in water, though not so much so as potassium hydrate. It dissolves in twice its weight of water, while potassium hydrate requires only half its weight of water to dissolve it. It is a very deliquescent salt, and therefore to preserve it dry it must be kept in well-stopped bottles.

289. **Experiment.**—You learned in § 287 that although no degree of heat can drive away carbonic anhydride from potassium carbonate, it can be taken away by a substance which has a stronger affinity for it than potassium has, as, for example, lime. It can also be driven off by any acid stronger than carbonic acid. Such an acid we have in acetic acid, the acid of vinegar, as may be shown by the simple experiment represented in Fig. 87 (p. 211). Put a teaspoonful or more of pearlash into a tumbler containing

Fig. 87.

vinegar. There will be an effervescence, because the acetic acid expels the carbonic anhydride and forms potassium acetate. As the gas fills the tumbler it will extinguish a burning taper introduced into it.

290. **Saleratus.**—This is the bicarbonate of potash, or, strictly speaking, hydro-potassium carbonate, $KHCO_2$, containing precisely twice as much carbonic acid as the common carbonate. It is formed by passing carbonic anhydride through a cold solution of potassium carbonate, and then evaporating the solution. On heating the hydro-potassium carbonate, the extra amount of carbonic acid may be driven off. It therefore loses some of its carbonic acid if it be dissolved in hot water; or, rather, some of it is converted into the carbonate, and you have in the solution a mixture of the two salts. The amount of carbonic anhydride in this salt makes it useful in raising bread and cake. The acid which is employed with it takes the potash to itself, and sets free the gas, which by its expansive force puffs out the dough, forming in it innumerable air-cells, and thus makes it "light." The acid which is in sour milk is as good as any other for this purpose.

291. **Potassium Nitrate, or Saltpetre.**—This salt, also called nitre, is of special interest to us as being one of the ingredients of gunpowder. It is a natural product in some soils in hot climates, as in India and South America. The manufacture of potassium nitrate is a curious chemical process. First a calcium nitrate is produced in the following manner: Animal substances, flesh, hides, etc., are mixed with lime and earth, and this mixture is moistened and left to putrefy. Ammonia results, the elements of which, nitrogen and hydrogen, unite with the oxygen of the air to form two things

—water and nitric acid. You see how this is. The oxygen unites with the hydrogen of the ammonia to form water, and with its nitrogen to form nitric acid. Then as lime is ready on the spot, the acid at once unites with it, forming calcium nitrate. This is obtained in solution from the mass, and converted into potassium nitrate by treating with potassium carbonate. Insoluble calcium carbonate is precipitated, and potassium nitrate goes into the solution.

292. **Gunpowder.**—Gunpowder is composed of potassium nitrate, charcoal, and sulphur, each carefully ground, and the three well mixed in proper proportions. The effectiveness of saltpetre as a constituent of gunpowder depends on the fact that it quite readily parts with its oxygen gas, which constitutes nearly one half of the salt. Bloxam thus explains the chemistry of the explosion of gunpowder: "The oxygen of the saltpetre converts the carbon of the charcoal chiefly into carbonic anhydride, part of which assumes the gaseous state, while the remainder combines with the potassium of the nitre to form potassium carbonate. The greater part of the sulphur is converted into sulphuric acid, which forms sulphate of potassium. The chief part of the nitrogen contained in the potassium nitrate is evolved in the uncombined state." Several other substances are formed in small quantity besides those named, among which are carbonic oxide, marsh gas, potassium sulphide, and sulphuretted hydrogen. The disagreeable odor of burned gunpowder comes from the formation of sulphuretted hydrogen by the action of the moisture of the air upon the sulphide of potassium. The blackening of the surface of the gun-barrel comes from the formation of sulphide of iron. There is no water of crystallization in nitre. If there were any, it would unfit it for being an ingredient in gunpowder; for this water, being released by the heat, would tend to put

out the fire which the oxygen and carbon are disposed to get up together.

293. **The Explosion Explained.**—If the gases thus evolved by the burning of gunpowder could remain condensed, occupying the same space that they do in the powder, there would be no explosion. But the moment they are evolved they immediately expand so as to occupy a space several thousand times greater than before. And it is this expansive force which causes the sound of the explosion, and which constitutes the power of the burning powder in propelling balls, rending rocks, etc. It is the concussion or blow which the suddenly expanding body of gas gives to the surrounding air that causes the detonation. Observe the difference between this explosion and that which occurs when gases unite suddenly to form a liquid, as in the formation of water by the explosion of oxygen and hydrogen (§ 144). In the latter case there is condensation, while there is none in the former. Now if the condensation were the sole cause of the detonation, the explanation would be this: A vacuum is created by the condensation, and the air rushing into it from all quarters, and therefore coming together, produces a sound very much as clapping two hands together does. But this explanation will not hold, for there is not only no evidence of collapse at the moment of explosion, but, on the other hand, decisive evidence of expansion. For example, when the gases are discharged in the gun, in the experiment in § 191, the cork is driven *out*, showing that there must be expansion at the first, although eventually there is condensation. But how is this expansion produced? It must come from the fact that the water is formed in the midst of the great heat which always attends the combustion of oxygen and hydrogen together, and is therefore steam largely expanded, to be condensed, however, at the next instant. Whether this condensation has any agency in the production of the sound is uncertain.

294. **Sodium.**—This is a soft, light metal, somewhat resembling potassium, and, like it, never occurs in a free state in nature owing to its powerful attraction for oxygen. This attraction is not quite so strong as in the case of potassium; so when sodium is thrown upon cold water it runs about with a hissing sound, but does not usually set fire to the hydrogen evolved. By using hot water, the sodium will set the hydrogen on fire, which then burns with a bright

yellow flame. Compounds of sodium are most abundant in nature.

295. **Experiment.**—A very neat experiment can be tried showing the decomposition of water by sodium. Boil some water for about fifteen minutes in order to expel the air from it, and after it is cool fill a bowl and a test-tube with it. Close the test-tube with the finger, and invert it under the water in the bowl, as seen in Fig. 88. Throw a bit of sodium on the water, catch it with a spoon of wire gauze, and thrust it quickly to the opening of the test-tube, and disengage it from the spoon by turning it over. As it is lighter than water, it will rise at once to the top of the tube, and there will busy itself in decomposing the water. By taking the oxygen of the water and half the hydrogen the sodium becomes sodium hydrate, and the rest of the hydrogen, being thus set free, accumulates in the tube, forcing down the water that is in it. When the sodium has all disappeared, close the tube with the finger, and remove it from the vessel. If now, holding the tube with its opening upward, you apply a light to it, the hydrogen will burst into a flame.


Fig. 88.

296. **Common Salt.**—The chloride of sodium, NaCl, is the most abundant and important of the compounds of this metal. This salt is composed of two elements that are entirely different from the compound which they form. One of them is a gas, which is so suffocating that no one can breathe it undiluted and live. The other is a metal, which has such an affinity for oxygen that if it were introduced into your mouth it would set the moisture there on fire in seizing its oxygen. And yet the compound which these two elements make is a very mild substance, which we take into our mouths every day in our food. It is most widely diffused in the animal and vegetable as well as the mineral

world. It all originally comes from the mineral world, and being absorbed from the soil by plants, through them it gets into the blood of animals by their food. What its special uses are in animals, beyond the fact that no food can be digested without it, we know not; but that it is essential its constant presence in the blood shows. Salt is sufficiently soluble for all practical purposes. It does not deliquesce easily, troubling us in this respect only when the air happens to be very damp. Unlike most other salts, it dissolves almost equally well in cold and hot water. It is scarcely soluble at all in alcohol. It crystallizes in the form of cubes. Sometimes the crystals have an arrangement which is hopper-shaped, as represented in Fig. 89. This is because that which is first formed on the surface sinks a little in the solution, and then there is an addition upon its outer edge all around; and this goes on continually, the outer edge all the time enlarging, and the solid salt all the time sinking as it increases. The upper edge is during the whole process just at the surface, evaporation adding continually to it.

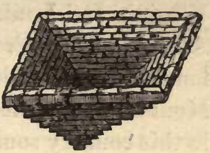


Fig. 89.

297. **Decomposition of Salt.**—Salt is decomposed in many chemical operations, but its elements are so firmly united that it is by no means easily decomposed. Heat, for example, can not drive off the chlorine, as it does carbonic anhydride, from limestone. Most of the substances with which salt is apt to come in contact can not decompose it. Strong as is the attraction of oxygen for sodium, it can not take it away from chlorine. If now, on the other hand, salt were easily decomposed, as it circulates by means of water constantly among a great variety of substances—in the sea, in the soil, and in the fluids of vegetables and animals—it would be a source of continual danger. The evolution of

the suffocating chlorine, which would take place here and there, would produce the most disastrous results.

298. **Localities of Salt.**—While salt is so widely diffused, there are some localities where it is found in great abundance. There are extensive beds of it in Spain, in some cases rising in hills three or four hundred feet high. The same is true of the north part of Africa. Then there are extensive beds in various parts of the continent of Europe, in Cheshire, England, in Persia, China, India, and South America. The most remarkable salt-mines are in Prussia, Poland, and Hungary. Some deposits have been found in this country, in Virginia and Louisiana. There are extensive salt lakes in Africa and South America. In this country there is the famous Great Salt Lake, on a height among the Rocky Mountains, 4200 feet above the level of the sea. There are in this country some salt springs which are very productive. The most celebrated are those at Salina and Syracuse, the latter producing annually five millions of bushels of salt.

299. **Modes of Obtaining Salt.**—The rock-salt is sometimes nearly pure, as at Norwich, in Cheshire, England, where large masses from five to eight feet in diameter are found, and it is prepared for use by crushing between rollers. Commonly, however, it is impure, and to purify it the salt is dissolved in water; and when the impurities have settled, the solution is drawn off and evaporated, that the solid salt may be obtained. In this country the salt is gathered by evaporating the brine which is flowing continually in. For this purpose wells are made from 50 to 150 feet deep, and the brine, as it is pumped up, is conducted by troughs to large boilers. Sometimes the evaporation is left to occur without the application of heat, by exposing the brine to the sun in large shallow vats. This process is often made use of in hot climates for obtaining salt from sea-water. A number of extensive shallow basins having a smooth bot-

tom of clay are made near the sea, all communicating with each other. The water is let into the one adjoining the sea at high tide, and when they are all filled it is shut off. The sea-water affords a bushel of salt to every 300 or 350 gallons, while the brine from the best springs gives a bushel to every 40 gallons.

300. **Amount of Salt in the Sea.**—About one thirty-sixth part of sea-water is common salt. The proportion in the best of our salt springs is one seventh; in the water of the Great Salt Lake it is over one fifth; and in the Dead Sea it is even more than that. The whole amount of salt in all the seas and oceans of the earth is estimated to be at least five times the mass of the Alps. It is enough to cover an area of seven millions of square miles with a layer a mile in thickness.

301. **Sodium Carbonate,** Na_2CO_3.—This salt is contained in the ashes of sea-plants, as the carbonate of potassium is in those of land-plants; and originally it was obtained almost wholly from that source by lixiviation—that is, by making a lye. But it is now obtained entirely, because more easily, from common salt by certain chemical reactions, which are somewhat complicated; briefly, however, the process is as follows: (1) Sodium chloride is heated with sulphuric acid, forming sodium sulphate, or, as it is technically called, "salt cake;" (2) this is mixed with coal and limestone, heated in a furnace of peculiar form, and thereby converted into very crude sodium carbonate ("black ash"); (3) this is then purified by solution in water and crystallization ("soda ash"). During the first step, the manufacture of salt cake, immense quantities of hydrochloric acid gas are given off, which are condensed in water. During the second step abundance of calcium sulphide is formed as a waste product.

The importance of this manufacture will be faintly appreciated by learning that 200,000 tons of "soda ash" (crude sodium carbonate), worth ten million dollars, are made annually in Great Britain alone. Carbonate of soda, when crystallized, has a remarkably large amount of water combined with it—63 parts in every 100. When it is wholly anhydrous—that is, when it has lost all its water of crystallization—it is of more than twice the strength of the crystalline salt. If the crystals be heated, they fuse in their own water of crystallization. Many mineral waters contain considerable of this salt.

302. **Sodium Bicarbonate.** — This salt is, strictly speaking, hydro-sodium carbonate, $NaHCO_3$. It is much used in making soda-powders. The powder in the blue paper is the bicarbonate of sodium, while that in the white paper is tartaric acid. When these are dissolved in water in separate tumblers, and the two solutions are poured together, the tartaric acid at once seizes the soda, forming tartrate of sodium, and the carbonic anhydride, set free, effervesces strongly. The same effect is produced if you mingle the two powders intimately, and then throw the mixture into the water.

303. **Sodium Sulphate, or Glauber's-Salt,** $Na_2SO_4 + 10H_2O$. —This salt received the name of Glauber's-salt because it was first obtained by means of a chemical process by a German chemist of that name. It occurs in nature, but not abundantly, except in a few localities, one of which is a cave in the island of Hawaii, from which the natives gather it for medical use. Ordinarily it is obtained by the action of sulphuric acid upon common salt. More than half of this salt in its crystalline state is water, and exposed to the air the crystals effloresce, and fall to powder.

There is another sodium sulphate containing less sodium, $NaHSO_4$; this is formed when the sulphuric acid is used in excess. It has a very acid reaction.

304. **Borax.**—Chemically this substance is sodium biborate. It is found native in some of the lakes of Asia and of California, and is also prepared by neutralizing with sodium carbonate boracic acid obtained from hot springs in Italy. It contains half its weight of water of crystallization, having the composition $Na_2B_4O_7+10H_2O$. Borax is much used in the trades for soldering. If you hold with pincers over a spirit-lamp a piece of copper on which are placed a bit of tin and of iron wire, the tin will melt, but will not adhere to either metal. But if you smear the three metals over with a paste made of moistened borax, and repeat the experiment, you will find that the wire is firmly soldered to the copper. The explanation is this: Metals will adhere to each other only when they have a pure surface; but heating them always produces at once a film of oxide, and so prevents their adhering. Now the borax serves to keep the surfaces bright by forming with this oxide a sort of melted glass, which is easily pushed aside by the melted solder. There are various substances used in soldering, and they all act by removing in some way the oxides produced by the heat.

305. **Soda Saltpetre.**—This salt, sodium nitrate, $NaNO_3$, resembles common saltpetre. It is found in large quantities in South America, where extensive plains are covered with it, and it is exported to other countries under the name of Chili saltpetre. It has the same amount of oxygen in it that nitre has, and parts with it as readily, as is shown by its brisk deflagration on glowing coals. But it will not answer in place of nitre in gunpowder, simply because it is strongly disposed to attract water from the air. Keeping the powder dry would be difficult if one of its ingredients be deliquescent.

306. **Ammonium.**—With the group of metals we are studying, the salts of ammonium may be conveniently ranged.

The alkaline gas ammonia is composed, you remember, of hydrogen and nitrogen, or is NH_3. Now a solution of this gas in water acts like the hydrate of an alkaline metal, combining with acids to form crystallizable salts. This analogy has caused chemists to conjecture that, since NH_3+H_2O is the same as NH_4HO, there is a metal NH_4, of which NH_4HO is the true hydrate, just as KHO is the hydrate of potassium. This compound metal reminds us of cyanogen, which, you remember, was a compound also, and was called a *radical.*

Note that if there be an ammoniacal metal, it is not an element, as all other metals are, but a compound. It is composed of nitrogen and hydrogen, just as is the ammoniacal gas, and it differs in composition from this gas only in having one third more hydrogen in it. Though no one has ever succeeded in obtaining this metal, all chemists seem to believe in its existence. The evidence on which this belief is based is twofold. First, the salts of ammonia are so much like other salts that have a metallic base that it would be a very strange thing if they did not also have such a base. Thus in sal ammoniac we have a salt so similar to other salts that we should expect to find, as we do in them, that one of the constituents is a metal. But it is composed of three gases—chlorine, nitrogen, and hydrogen. It is supposed, therefore, that as common salt is composed of chlorine and the metal sodium, so this salt is composed of chlorine and a metal ammonium, the nitrogen and hydrogen being so combined as to act in this latter capacity. But by whatever method the chemist separates the chlorine from this combination, the metal eludes his grasp, and he gets only nitrogen and hydrogen, each by itself. The evidence, therefore, that there is a metal here is incomplete. But there is, secondly, another proof of a more decided character. If sal ammoniac—that is, chloride of ammonium—be mixed with an amalgam of mercury and sodium, a change takes place resulting in the formation of common salt, or chloride of sodium, and an amalgam different from that which was put into the mixture. How is this? The sodium has left the mercury to unite with the chlorine of the sal ammoniac. What has taken its place in the amalgam? Something from the sal ammoniac, and that something must be a metal, for nothing but a metal has ever been known to form an amalgam with mercury. The proof, therefore, is quite decided that sal ammoniac is a chloride of a metal, and therefore its proper name is chloride of ammonium.

307. **Ammonium Salts.**—This hypothetical metal forms a whole series of important salts. Thus we have ammonium sulphate, ammonium nitrate, which was used in the preparation of laughing-gas, ammonium phosphate, ammonium carbonate, etc. This last-named salt is the common *sal volatile* of the pharmaceutist, used as smelling-salts. It is so volatile that it slowly passes away in the air in the form of vapor. It is evolved in the decay of all animal and vegetable substances that contain nitrogen, and gives the peculiar pungent odor to the stable and the manure heap. As produced in manures and brought down from the air in the rain, it is a valuable agent in vegetation, and will be considered in this light in another part of this book.

QUESTIONS.

282. Why does potassium never occur native?—283. How is potassium obtained? Write the equation showing the reaction.—284. What are the properties of potassium? Under what liquid is it kept?—285. What happens when potassium is thrown into water? Explain.—286. What is the composition of caustic potash?—287. How is it obtained?—288. How is potassium carbonate made? What are its properties?—289. How does acetic acid act on potassium carbonate?—290. What is saleratus? What *raises* bread and cake?—291. Where does saltpetre occur? How is it made?—292. Of what is gunpowder made? Explain the chemistry of the explosion.—293. Whence comes the power when gunpowder is burned? Whence the noise?—294. Mention the properties of sodium.—295. Describe the decomposition of water by sodium.—296. What is the most abundant and useful compound of sodium? What is said of it?—297. What would happen if salt were easily decomposed?—298. Mention the principal localities of salt deposits.—299. Describe the modes of obtaining salt.—300. What is said of the amount of salt in different kinds of salt water?—301. Name the three steps in the manufacture of carbonate of sodium. How much water of crystallization does it contain?—302. What is hydro-sodium carbonate?—303. What is Glauder's-salt?—304. What is borax, and whence comes it? What is the philosophy of its use by blacksmiths?—305. What is said of sodium nitrate?—306. Explain what is said of the ammonium theory.—307. Name some ammonium salts.

CHAPTER XVII.

GROUP II.—BARIUM, STRONTIUM, AND CALCIUM.

308. **Barium and Strontium.**—These metals do not occur native, their properties being in this respect much like those of Group I. Barium salts are widely distributed, but not in very great quantity. Strontium compounds are comparatively rare. Both occur as sulphates and carbonates. Barium sulphate or *barytes* is used to adulterate white-lead paint. Barium salts are poisonous. Barium nitrate is used in making the green fire of fireworks, and strontium nitrate for the red fire. We will give you a receipt for a red fire if you will be careful in making it: Take 80 parts of dry strontium nitrate, 22 of sulphur, and 5 of lampblack; mix these intimately in fine powder; then add 20 parts of potassium chlorate cautiously and without rubbing. Mix well on paper. This burns with a brilliant crimson flame. Make no more than you want to burn, for it is dangerous to keep it.

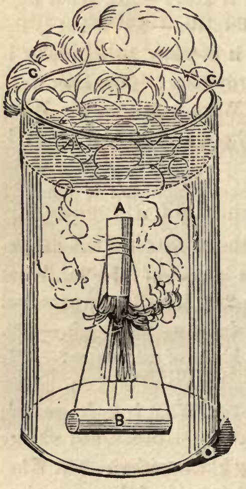


Fig. 90.

309. **Fire Under Water.**—If this mixture be put into a paper case, A, well stopped with varnish at the end, and then, after being set on fire, be introduced into a jar of water, C C, it will continue to burn under water,

the red flames making a brilliant display. B is a piece of lead pipe fastened with copper wire to the case to hold it, with its orifice downward. The oxygen in this mixture is contained in the potassium chlorate and the strontium nitrate, while the sulphur and carbon are the combustible substances. The red color is given to the flame by the strontium nitrate.

310. **Calcium.**—This metal has no interest for us, but its oxide and its hydrate, as well as many other of its compounds, are of the greatest importance. Quicklime is calcium oxide, CaO; slaked lime is calcium hydrate, CaH_2O_2. We often use the word lime when we ought strictly to say calcium. Lime is never found in nature, but abounds in combination with acids. In this way it forms more than half of chalk, limestone, and marble, is the base of plaster of Paris and alabaster, and constitutes the greater part of the mineral portion of the bones of animals. Lime is considered as occupying a middle place between the alkalies and the earths. It is, therefore, called an alkaline earth. The earths are insoluble, the alkalies are very soluble, but the alkaline earths are but sparingly soluble. The alkaline earths are also midway between the earths and the alkalies as to being caustic, for they are somewhat caustic, while the alkalies are very much so, and the earths not at all, but perfectly inert. That lime is somewhat caustic you can perceive by the feeling occasioned when you rub a little of it, made into paste, between your fingers. It is from this caustic quality that the milk of lime—that is, lime diffused in water—is used to remove the hair from hides. So, also, lime is often mixed with weeds to quicken their decomposition.

311. **Manufacture of Lime.**—Quicklime is obtained from the carbonate in its various forms—chalk, limestone, marble, oyster-shells, etc.—simply by the application of strong heat,

the carbonic acid being driven off. The operation is carried out on a large scale in a kind of furnace called a lime-kiln, shown in Fig. 91. The decomposition takes places at a lower temperature in a current of air than otherwise, and this is effected by building a tall kiln.

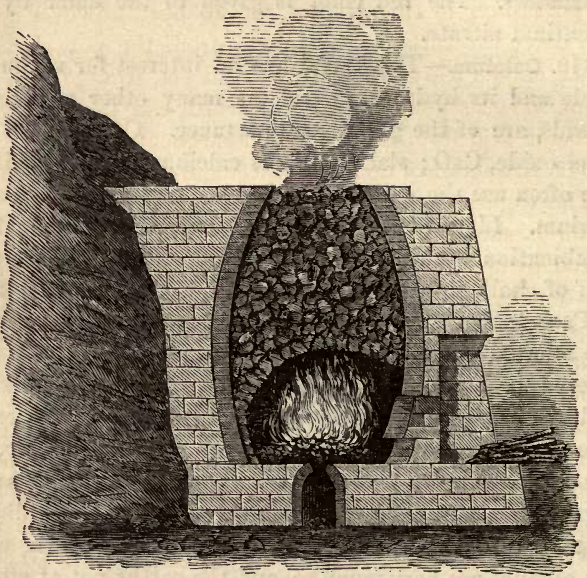


Fig. 91.

How simply heating their bodies effects their decomposition we will explain: Heat expands all bodies, or, in other words, puts the particles in them farther apart. But, as you have already learned, it is necessary that particles of different substances should be in immediate contact, or exceedingly near to each other, in order that the attractive force may come into action. Now it is supposed that in the case of the carbonate of lime the heat, in expanding it, puts the particles of the carbonic anhydride at such a distance from the particles of the lime that they are out of the range of their attraction, and so they escape. The effect of heat is, you see, just opposite to that of solution, the latter bringing particles more nearly together. The carbonate of lime is quite in contrast with the carbonate of potassium in this respect, for no heat, however great, can drive the carbonic acid away from the potassium hydrate, as you learned in § 287. And yet, strange as it may seem, lime, as you also there learned, can take away the carbonic acid from the potassium carbonate.

312. **Attraction of Lime for Water and Carbonic Anhydride.**—The eagerness with which lime unites chemically with water is shown in its slaking. So great is the heat produced by the rapid union that takes place that even gunpowder has been ignited by it. It very readily ignites phosphorus. Put a little quicklime in a heap upon a board, and place on the top of it a bit of phosphorus. To avoid wetting the phosphorus moisten the heap at the bottom, and as the moisture spreads through the lime it will very soon produce heat enough to set the phosphorus on fire. Another experiment, showing the amount of heat produced, may be tried as follows: Put some lime in a bowl, and, moistening it, place a glass bell-jar over it, Fig. 92. At first the steam which rises from the slaking lime will be condensed upon the inside of the glass. But soon the heat will be so great that the steam in the bell-jar will form a transparent atmosphere in it. If now you raise the glass, the steam as it escapes loses its transparency, and becomes a thick cloud, because it is changed into a kind of fog by the condensing influence of the cold air. By the union of lime with water there is formed a hydrate of lime, there being in every 100 grammes of dry slaked lime about

Fig. 92.

25 grammes of water. Lime has also a considerable affinity for carbonic acid. When, therefore, it is exposed for some time to the air, it unites with the carbonic anhydride of the air as well as its moisture, and air-slaked lime is therefore a mixture of hydrate and carbonate of lime.

313. **Solubility of Lime.**—While lime has so great an affinity for water, the dry substance which results after its thirst is slaked is very sparingly soluble. It is in strong contrast in this respect with the alkalies. While potassium hydrate is soluble in half its weight of water, the hydrate of lime requires one thousand times its weight of water to dissolve it. It is very remarkable that cold water will dissolve more of it than warm. Lime-water, as the solution of lime and water is called, is sometimes used as a medicine. With sweet-oil it makes a soapy mixture which is often used as an application to burns.

314. **Mortar.**—The most important use of lime is in making mortar. As glue holds pieces of wood together, so does mortar bricks and stones. In the making of mortar we stir sand, lime, and water together, and the sand becomes intimately mixed with the hydrate of lime while it is forming. As the mortar becomes dry by the evaporation of all the water that is not used up in the formation of the hydrate, there occurs also another chemical change—carbonic anhydride is attracted from the air, and unites with a portion of the lime; so that we have in the mortar a mixture of carbonate and hydrate of lime, which has more firmness than either of these substances separately. Then, again, mortar becomes hard gradually, from a chemical action between the sand and lime, whereby silicate of lime is formed. The sand serves to give both body and firmness to the mortar. When mortar is used as plastering, hair is added, the fibres serving to hold the mortar more thoroughly together.

315. Carbonate of Calcium, $CaCO_3$.—This salt presents itself in various forms—chalk, common limestone, and the beautiful granular marble. The mineral calcite, which sometimes appears in large, magnificent crystals of various colors, is one of the forms of this salt. The variety of form which this salt presents is analogous to the variety that we so commonly see in sugar, which is perfectly crystalline in rock-candy, like calcite, imperfectly so in the granular loaf-sugar, like marble, and without any trace of crystallization when pulverized finely, like common chalk. Carbonate of lime is very abundant, and is in fact one of the chief constituents of our earth. There are hills and ridges of mountains built up with limestone. In a pulverized state it exists extensively in the soil, in some districts being very prominent, making what is called a calcareous soil. Oyster-shells, and the shells of shell-fish generally, are composed almost entirely of carbonate of lime. So are the shells or frame-work of many very small animals, some of them exceedingly minute, and yet, by their numbers, occupying much space in the earth. The skeletons of the coral animals, of which so much of some portions of the earth has been built up, are made chiefly of this salt.

316. Depositions of Carbonate of Calcium.—If you breathe into lime-water there will be precipitated carbonate of calcium, or chalk, as you learned in § 125. If, after this precipitate is formed, however, you continue to breathe into the lime-water, some of the precipitate will disappear, a part of it being dissolved again. How is this, when carbonate of calcium is insoluble in water? It is because you have now something more than water in the vessel; it is water considerably charged with carbonic anhydride. Now, while pure, simple water can not dissolve carbonate of calcium, water charged with this gas can do it. Hence the disappearance of a part of the precipitate. If now you let the liquid stand for a time exposed to the air, it becomes turbid again, because the carbonic anhydride escapes, which takes from the water its power of keeping the carbonate in solution, and this salt is therefore again precipitated. And here we have a key to the explanation of some very interesting phenomena. Water, as it makes its way among the particles of the soil, finds carbonic acid as one of the results of decay, and dissolves it; and therefore, as it issues from the earth in springs, it contains not only carbonic acid, but also carbonate of lime, which it has found in the soil and dissolved by the aid of the acid. But as soon as the water is fairly exposed to the air the carbonic anhydride begins to escape from it, and accordingly the carbonate of lime begins to be deposited. Hence comes the grand difference between the *hard* water of springs and wells, and the *soft* water that runs in brooks and rivers. The water as it runs along exposed to the air has discharged much of its carbonic acid upward, and therefore precipitated much of its carbonate of lime downward. Water can be more thoroughly freed of its carbonic acid, and therefore of its carbonate of lime, by boiling it than by mere exposure to the air, which explains the considerable deposition of this salt in large steam-boilers when hard water is used, collecting gradually as a hard crust. Such incrustations are of course particularly apt to occur in limestone districts.

317. **Stalactites and Stalagmites.**—The roofs of caverns in limestone regions often have stalactites of carbonate of lime suspended from them like icicles in shape. The reason is obvious. The water, as it percolates through the soil above the cavern, becomes charged with carbonic acid from decaying vegetable matter, and therefore dissolves some of the limestone; and then, as it is exposed to the air

in dripping, losing in part its carbonic acid, and therefore its solvent power, deposits some of its carbonate, which accumulates gradually in the stalactite form. But as the solvent power of the water is not all lost, some of the carbonic acid still remaining, the water, as it falls upon the floor of the cavern, loses another portion of the acid, and so deposits more of the lime in eminences called stalagmites. These are of course less slender and pointed than the stalactites. You see the same difference in form between icicles and the accumulations below them. There are splendid displays of these formations in many of the caves of the earth. Some of the most celebrated are, Weyer's Cave, in Virginia; the Cave of Thor, in Derbyshire, England; and the Grotto of Antiparos, on an island of the same name in the Grecian Archipelago. A part of this grotto is represented in Fig. 93. You can get an

Fig. 93.—The Grotto of Antiparos.

idea of the size of these formations, the accumulations of constant dripping for ages, by the human figure at the foot of one of them.

318. **Carbonate of Calcium in the Sea.**—Though rain-water may be free from carbonate of lime, water which has percolated through the earth is never wholly free from it. Though it may deposit it as it comes out of the springs and runs along brooks and rivers to the ocean, yet even when it arrives there it retains some of it in solution, for it has still dissolved in it some of the carbonic acid which it derived from the soil. If it were not so, the shell-fish would have no material for the formation of their external skeletons, or houses, as they may more properly be called.

319. **Sulphate of Calcium,** $CaSO_4$.—The common name of this salt is gypsum. It has also the name of plaster of Paris, which it received from the fact that it was first used in the form of plaster in Paris, there being immense quantities of it in the neighborhood of that city. It is a white and quite soft mineral, occurring in various forms, some of them very beautiful. One of its forms, alabaster, which is snowy white, is cut into vases and ornaments of various kinds. Sometimes it is crystallized in exceedingly thin leaves, laid together so nicely that a multitude of them make a white crystal clearer than the clearest glass. Then there is the satin-spar, so called from the splendid lustre of its fibrous arrangement. Gypsum is about one fifth water. This water can be driven off by heat, and then this powdered anhydrous gypsum has the property of "setting" with water; or, in other words, becoming with water a firm, coherent, and dry mass. For this purpose it is moistened with water to about the consistency of cream. In this state it can be poured into moulds, or it can be put upon walls as hard finish, the water disappearing as it hardens, partly by evaporation, and partly by becoming a part of the solid,

dry substance. The hardening takes place quite rapidly. The moistened plaster can also be moulded into casts, plaster heads, ornamental work for walls, called stucco-work, etc. It is remarkable that, in making the gypsum anhydrous, if the heat be carried above a certain point, its affinity for water will be destroyed, and there will be no "setting" of the plaster.

320. **Casts of Coins.**—Copies of coins and medals can be taken very readily with the moistened plaster. For this purpose put the coin into a paper box, or, if you have not one of the proper size, fasten a slip of paper around the coin, securing the loose end by a little sealing-wax, and pour the plaster in upon the coin. After a few minutes it will become so hard that both the paper and the coin can be removed. A reversed impression will be formed on the under surface of the plaster. To get from this a real copy of the coin, smear the impression with a very little of a strong solution of soap, having a few drops of oil mixed with it, and then pour upon it some of the plaster.

The use of gypsum in agriculture will be spoken of in another part of this book.

321. **A Singular Case.**—If sulphate of calcium (gypsum) and carbonate of ammonium be mingled together in solution, there will result carbonate of calcium, or chalk, and sulphate of ammonium. Now if we take these two substances thus resulting, and, powdering them finely, mix them together, and expose the mixture to a red heat in a close vessel, we shall have the original sulphate of calcium and carbonate of ammonium produced again. Here we have heat occasioning a chemical process exactly the reverse of that caused in a solution at an ordinary temperature.

322. **Chloride of Lime.**—The salt which sometimes goes by this name, and sometimes by the name of bleaching powder, is a white powder, having the odor of chlorine gas, because this gas escapes from it continually in a small amount. The reason of its escape is that the carbonic an-

hydride of the air unites with the lime gradually, thus liberating the chlorine. In using this salt for bleaching the gas is liberated by some acid which is applied. The article to be bleached is first soaked in a solution of the chloride, and then in a dilute sulphuric acid. Here you have chloride of lime and sulphuric acid brought together, and the result is that the acid takes the lime and releases the chlorine. What does the released chlorine do? Being set free in immediate contact with the cloth, it acts at once upon the coloring matter. The operation is not all done at once; but as strong solutions are apt to injure the cloth, the solutions are made weak, and the articles are moved back and forth from one solution to the other several times. White figures are sometimes made on colored cloth by this bleaching process. The figures are first stamped upon the cloth with a mixture of tartaric acid and gum-water, and then the cloth is soaked in the solution of the chloride. You see what the result is. The chloride is decomposed by the acid, and therefore the chlorine whitens only where the figures are stamped. This bleaching powder is very valuable because we have the bleaching gas condensed in it, a form convenient for transportation, which would not be true of either chlorine gas or chlorine water.

323. **Composition of Chloride of Lime.**—The name which is so universally given to this preparation is a very incorrect one. It is impossible to have a real chloride of *lime*, for the chlorine can not be made to unite with an oxide of a metal, but will unite only with the metal itself. If therefore this salt be a chloride, it must be chloride of *calcium*, the metal of which lime is the oxide. But it has been found that it is composed only in part of this chloride. It is a mixture of chloride of calcium, calcium hydrate, and a salt called hypochlorite of calcium. This latter salt is a compound of calcium with hypochlorous acid, an acid com-

posed of chlorine and oxygen. Perhaps the reason that the old name chloride of lime is retained is that it is difficult to fix upon a proper name for this mixture of two salts.

Chloride of lime is made by exposing slaked lime, slightly moistened, to chlorine gas; this is eagerly absorbed by the lime, forming calcium hypochlorite and calcium chloride, while some of the calcium hydrate remains unchanged. The bleaching powder thus prepared is very uncertain as to the amount of its bleaching properties, and these are very liable to be impaired by exposure to air and other circumstances. As offered in the market it varies much in its value according to its age, care in keeping it, and also care in its original preparation.

324. **Calcium Phosphate,** $Ca_3(PO_4)_2$.—While carbonate of lime is the mineral out of which all shells are made, the phosphate of calcium, mixed with very small quantities of the carbonate and sulphate and fluoride, forms the mineral portion of bones. It is estimated that the amount of phosphorus contained in this salt in the bones of a full-grown man is from 500 to 800 grammes. Phosphorus is obtained from bones, and the process is described in § 253. As phosphate of lime exists so largely in animals, it is necessary that it be provided for them in the food that they eat. Accordingly it is present in all cereal grains, in leguminous plants, and many other vegetables, the soil of course furnishing it to them. It is not only, then, the animal substance in bones, the gelatine, that makes them a good manure; but the mineral part is of essential service, to some crops especially, if the soil be at all deficient in phosphate of lime.

Calcium phosphate occurs abundantly also in the mineral kingdom, as you will learn more particularly in the study of Mineralogy, Part III.

GROUP III. ALUMINIUM (ETC.).—GROUP IV. MAGNESIUM AND ZINC.

325. **Aluminium.**—This metal, the base of the oxide alumina, though it was unknown until a few years ago, is already used for a variety of purposes. It is a white metal, resembling silver in color and hardness, as well as in its power of resisting the action of air and water, but differing from it greatly in weight, silver being four times as heavy. It is admirably fitted for ornamental purposes, and has already been so employed to a considerable extent. It is very sonorous, and therefore will make good bells. The French government at one time used it for helmets and cuirasses, for which it is well fitted, as it is both light and strong. Formerly this metal was very costly, but in the year 1854 M. Deville, who had charge of the private laboratory of the Emperor of France, discovered a process by which it can be obtained in large quantities, and at comparatively low price. And as silver is four times as heavy, articles can be made of this beautiful metal for less than the cost of silver.

326. **Aluminium Oxide, or Alumina,** Al_2O_3.—This earth is the essential ingredient of all clays, and is present more or less in all fertile soils and in many of the slaty rocks. The metal of which this is an oxide is therefore quite abundant, and widely diffused in the earth, though it is never found in its metallic state, but is always in combination with other substances. Alumina appears in some beautiful forms. The sapphire, which in some of its varieties is, next to the diamond, the most costly of gems, is pure alumina crystallized. Blue is the true sapphire color. When this gem has other colors it receives other names: when red, *Oriental ruby;* when yellow, *Oriental topaz;* when violet, *Oriental amethyst;* and when green, *Oriental emerald.*

The largest Oriental ruby yet found came from China, and is now a jewel in the imperial crown of Russia. Emery is nearly pure alumina. This, besides being used by the ladies in their "emery-bags," is extensively employed in polishing metals and precious stones.

327. **Common Alum.**—In this salt we have sulphuric acid united with two bases, potassium and aluminium, forming a sulphate. It is therefore said to be a double salt, and has the composition $Al_2K_2(SO_4)_4+24H_2O$. It is not a mere mixture of the two salts, but a chemical compound always precisely the same in the proportions of its constituents. The water of crystallization in this salt constitutes nearly one half of it. If it be heated, the escape of this water causes it to foam and melt, and swell up into a large porous mass. This is what is called burnt alum. This salt, like all the salts of aluminium, has an astringent taste. Warm water will dissolve much more of it than cold. It is much used in dyeing and calico-printing for the purpose of fastening the colors, or, in other words, making the colors unite thoroughly with the fibre of the cloth. It is not, however, the alum that does this, but the alumina which is in it. The alum is decomposed in preparing the *lakes*, or fast colors. Thus an infusion of Brazil-wood, with alum dissolved in it, presents a brilliant red color. If now there be added a solution of carbonate of potassium or sodium, a precipitate is produced, which is the alumina of the alum united with the red coloring matter. This dried is the Brazil-wood lake of commerce. In like manner other lakes are prepared from other vegetable coloring substances. The alumina is said to act in these lakes as a *mordant*, a word which is derived from the Latin verb meaning to bite. It is because the compound which it forms with the coloring matter takes such strong hold of the cloth. Alumina is also employed in the production of those beautiful blue pigments called *smalts* and *ultramarine.*

328. **Other Alums.**—Although there is but one substance which is commonly called alum, the chemist recognizes several different salts as alums. The common alum he calls potassium alum. Then there is a sodium alum, in which sodium has taken the place of potassium, and the salt is therefore sulphate of aluminium and sodium, $Al_2Na_2(SO_4)_4 + 24H_2O$. We have also an ammonium alum, in which ammonium takes the place of the potassium, making a sulphate of aluminium and ammonium. There are others which we will not mention. Now in all these different alums the water of crystallization is exactly the same. And what is more remarkable still, the crystals are alike in all these salts. They are therefore termed *isomorphous* salts, this name coming from two Greek words, *isos*, equal, and *morphe*, form.

329. **Magnesium.**—This is a white malleable and ductile metal, somewhat resembling aluminium, but far lighter and more readily oxidizable. A wire or tape of this metal burns with a magnificent white light, which is sometimes used for lighting up the interior of buildings for the purpose of photographing.

Magnesium oxide, hydrate, carbonate, sulphate, chloride, and iodide are all used in the arts. Magnesium oxide, obtained by heating the carbonate to redness, is often called *calcined magnesia.* This carbonate occurs native, but is generally prepared artificially. Mixed with magnesium hydrate, it forms the *magnesia alba* of pharmacy. The sulphate of magnesia was originally called Epsom-salt, because the waters of Epsom Spa, in England, contained so much of it. In its crystalline state, $MgSO_4 + 7H_2O$, more than one half of it is water, and it is efflorescent.

330. **Other Earths.**—There are several other earths, but they are all rare, some exceedingly so. One of them, glucina, is one of the constituents of the precious stones called emerald, beryl, and chrysoberyl. Crystals of another, zirconia, are in common use in jewelry.

331. **Zinc.**—The principal ores of this metal are the sulphide, the silicate called *calamine*, the oxide, and the carbonate. In obtaining the metal, if the sulphide and carbonate are used, they are first roasted, the heat driving off the carbonic acid from the carbonate, and the sulphur from the sulphide, in the form of sulphurous anhydride. This leaves the ore in the state of oxide. The ore is now mixed with charcoal, and introduced into an iron crucible, a vertical section of which is given in Fig. 94. The crucible is closed at the top, and has an iron tube passing through a hole in the bottom, and also down through the floor of the furnace in which the crucible is placed. The upper opening of this tube is above the surface of the mixed ore and charcoal, and the lower opening is very near to the surface of water in a reservoir. When the heat is applied the carbon, uniting with the oxygen of the oxide, forms carbonic oxide and anhydride, which pass out through the tube and escape. Now as the zinc is volatile, it passes out also with them in the form of vapor, but, condensing as it gets in the tube below the fire of the furnace, it drops as a liquid into the reservoir of water, where it becomes solid. Zinc is a bluish-white metal. It has but a single oxide, ZnO. It takes fire when heated to a bright red heat, and burns with a brilliant white flame, with a tinge of green. As it burns the oxide formed flies off in flakes, which the alchemists fancifully called *lana philosophica*, philosopher's wool, and *nihil album*, white nothing.

Fig. 94.

332. **Carbonate of Zinc**, $ZnCO_3$.—The thin whitish film which forms over the surface of zinc by exposure to air is a carbonate of zinc, the water and the carbonic anhydride of the air both entering into its composition. The carbonate of zinc, under the name of *smithsonite*, is an important ore of this metal.

333. **Chloride of Zinc,** $ZnCl_2$.—This is a white substance which is quite soft, and melts, if heated, a little above the boiling point of water. When the old names in chemistry were in vogue, this substance, on account of its softness and fusibility, had the name of *butter of zinc.* It has a great attraction for water, and therefore is active as a caustic, a use to which it is appropriated. While it thus destroys when concentrated, if diluted it acts as a preservative against putrefaction, and is employed by the anatomist for preserving bodies for dissection.

Sulphate of zinc—$ZnSO_4$—sometimes called white vitriol, is a powerful emetic. It crystallizes in long, white needles, and is very soluble in water. It is often obtained in the laboratory as a residue in making hydrogen gas. Zinc, sulphuric acid, and water yielding zinc sulphate and hydrogen, thus:

$$Zn + H_2SO_4 = ZnSO_4 + H_2$$

334. **Uses of Zinc.**—Though zinc is quite an abundant metal, it was formerly used but for little else than making brass and pinchbeck. The variety of uses to which it is now applied comes from a discovery which was made in regard to its malleability. When cold it is very brittle; but when heated to within a certain range of temperature (100° to 150° C.), it becomes quite malleable, and may be rolled into thin sheets. It retains the malleability thus acquired after it becomes cold. It is a curious fact that if this metal be carried beyond the range of temperature alluded to, it becomes brittle again. When in this range it becomes ductile as well as malleable. The discovery of these facts has introduced this metal to very numerous valuable uses. It is now used in the manufacture of many articles which were formerly made of lead, copper, and iron—as nails, gasometers, gas-pipes, gutters, roofing, lining for refrigerators and sinks, etc. It is harder and yet lighter

than lead. It is cheaper than copper. It is not affected by air and water as readily as iron. Zinc melts at 412°, and boils at 1040°. At a still higher heat it may be distilled. So-called *galvanized* iron is merely sheet iron coated with zinc.

QUESTIONS.

308. What is said of barium and strontium compounds?—309. Describe an experiment in which strontium nitrate is used.—310. Where and how does calcium occur in nature? What is quicklime? What is said of alkaline earths? What of the caustic power of lime?—311. Explain the manufacture of quicklime. How does heat effect this decomposition?—312. Illustrate the attraction of lime for water, and for carbonic anhydride.—313. What is stated as to the solubility of lime? To what uses is lime-water applied?—314. What are the ingredients of mortar? What chemical changes occur in mortar as it hardens and dries?—315. Under what forms is carbonate of calcium found? Mention some animals which furnish it.—316. Explain the deposition of carbonate of calcium from natural waters.—317. What are stalactites? What stalagmites? Where found? How formed?—318. What is said of calcium carbonate in the sea?—319. What is gypsum? How is plaster made? Explain the "setting" of plaster.—320. How may casts of medals be made?—321. Describe the mutual reactions of sulphate of calcium and carbonate of ammonium under different circumstances.—322. How is chloride of lime used in bleaching?—323. Of what is it composed? How made?—324. How does calcium phosphate occur in nature?—325. What are the properties of aluminium?—326. What is clay? Name some precious stones containing alumina.—327. Of what is common alum composed? How is it used in dyeing? What is a mordant?—328. Name some other alums.—329. What are the properties of magnesium? What is Epsom-salt?—330. Name some of the rare earths occurring in precious stones.—331. How is zinc obtained? What is "philosopher's wool?"—332 and 333. What is said of the salts of zinc?—334. What of its uses?

CHAPTER XVIII.

GROUP V.—MANGANESE, IRON, COBALT, NICKEL, CHROMIUM.

335. **Manganese.**—This metal is never found in nature, and it is rather difficult to obtain it from its ores on account of the great stability of its oxides and its high melting-point. It is remarkable for the number of the compounds which it forms with oxygen. There are six of them. Here follow their names and formulæ:

1. Manganous oxide	MnO.
2. Manganese sesquioxide	Mn_2O_3.
3. Manganous manganic oxide	Mn_3O_4.
4. Manganese dioxide	MnO_2.
5. Manganous anhydride	MnO_3.
6. Permanganic anhydride	Mn_2O_7.

The first two form numerous compounds. Number 4 we have already used for preparing oxygen. Numbers 5 and 6 are not known in the free state, but their compounds are important; they combine with bases forming manganates and permanganates respectively. Potassium permanganate is used in dilute solution as a tooth-wash. Its solution has a magnificent purple color. It is a powerful oxidizing agent.

336. **Iron.**—Iron when pure is almost white, and is rather soft, but very tenacious. It is quite malleable. It can be made into leaves so thin that it would take over three hundred of them to make half an inch in thickness. But even the best of iron found in the market is far from being pure. It contains small amounts of carbon and other substances. Perfectly pure iron is never obtained except in small quan-

tities, and by the chemist in his laboratory. The most striking property of iron is its magnetic power.

337. **Importance and Abundance of Iron.**—As iron can be applied to a greater variety of uses than any other metal, it is very abundant. Stöckhardt says of it, "If gold is called the king of metals, iron must be deemed by far the most important and useful subject in the metallic realm. It is not only converted into swords and cannons, but into plowshares and chisels, and into a thousand other implements and machines, from the simple coffee-mill to the wonderful steam-engine. It is the ladder upon which the arts and trades have mounted to such an extraordinary height. It is the bridge upon which we now glide over mountains and valleys with the rapidity almost of magic." Besides all this, it is present in all soils and in almost all plants, and is an ingredient of the blood in a large portion of the animal world. Although we understand but little in regard to its influence upon plants and animals, we have sufficient facts to show that, small as its amount is, it is as essential in the chemical operations of the living world as are common salt, lime, and some other substances.

338. **Oxides of Iron.**—There are three oxides of iron: the monoxide, FeO; the sesquioxide, Fe_2O_3; and the so-called magnetic oxide, Fe_3O_4. The first named has not been prepared in a pure state owing to the rapidity with which it takes up oxygen and passes to the sesquioxide. It occurs in nature in combination with acids, forming important minerals. Ferrous sulphate, or green vitriol; ferrous carbonate, or spathic iron ore; ferrous sulphide, FeS_2, also called iron pyrites, are the most abundant. On adding ammonium hydrate to a solution of a ferrous salt, a white precipitate forms consisting of ferrous hydrate, but this immediately begins to change in color, passing through green to brownish red by absorption of oxygen from the air, and

becoming ferric hydrate. The second oxide, called sesquioxide, forms one of the abundant ores of iron. It is sometimes crystallized, as in *iron-glance;* or compact, as in *red iron-stone;* or radiated, as in *red hematite;* or earthy, as in *red ochre.* When mixed with clay it is the *clay iron-stone.* It is that which gives the red color to so many stones and bodies of earth. The *red chalk*, so called, used in making red pencils, is one form of this oxide. This sesquioxide may be prepared artificially by heating ferrous sulphate to redness, or by igniting ferric hydrate, obtained by precipitating a ferric solution with an alkaline hydrate.

Ferric hydrate—$Fe_2O_3.3H_2O$—also occurs in nature; in large masses it is the brown iron ore, or limonite, from which the metal can be profitably obtained. Mixed with clay it forms the *yellow clay iron-stone*, yellow ochre, etc. The yellow or brown color of soils and of stones which have been long exposed to the air is owing to ferric hydrate. The ochrey deposit which is seen always about the edges of chalybeate springs is ferric hydrate, made in this case chiefly from the carbonate, the carbonic acid passing off and leaving the oxide to become a hydrated sesquioxide. Observe the difference in color between the hydrated sesquioxide and that which is not hydrated; the former is yellow, the latter red. The reason that bricks become red by burning is that the water is expelled from the iron rust which is in the clay, and it therefore becomes *anhydrous.* This term, which is much used in chemistry, means dry, or without water, the prefix *an* meaning without. Iron rust is the ferric hydrate, $2Fe_2O_3.3H_2O$. This water is a part of the dry solid, being combined intimately with its ingredients. It is really, therefore, water solidified without freezing. In every hundred grammes of it there are about fourteen and a half grammes of water, and nearly forty grammes of oxygen. Both are condensed in uniting with the iron, the oxygen very much so. As about twenty-seven gallons of this gas are used up in forming a pound of rust, it must be vastly condensed to occupy so little space. This remarkable condensation of oxygen takes place in the formation of all the solid oxides.

The third oxide, Fe_3O_4, is sometimes considered as a combination of the first and the second oxides, $FeO.Fe_2O_3$, and hence is also called ferroso-ferric oxide. This oxide forms no salts, but it occurs in nature very largely, forming an important ore. This is endowed with magnetic properties. The common loadstone is ferroso-ferric oxide. Its color is black, and many dark and green stones owe their color to it. The celebrated Swedish iron is mostly made from it. The scales thrown off from heated iron by the hammer of the blacksmith are formed of this black oxide.

339. **Meteorites.**—Abundant as iron is, it is never found in metallic form except in meteorites, and then it is alloyed with nickel and some other metals. In the large meteorite in the cabinet of Yale College, brought from Texas, and weighing nearly two tons, there is from eight to ten per cent. of nickel, the mixture of the two metals not being uniform throughout.

340. **Production of Iron from its Ores.**—In order to obtain iron from its ores they must be deprived of their oxygen, and of the impurities that are mingled with them. The oxygen is removed by subjecting the ores to intense heat in a furnace with charcoal. This causes the oxygen to leave the iron, and unite with the carbon of the charcoal to form carbonic oxide and anhydride, which fly off. But another thing is necessary to remove the impurities, silica, clay, etc. For this purpose limestone is introduced into the furnace, which forms with the impurities a slag or glassy substance, which, as the iron is permitted to run out, floats on the surface of the melted metal, and is raked off. The

stream of iron runs off into channels made in sand, and when it becomes cool it forms what is called *pig-iron.*

Fig. 95 represents a common form of the blast-furnace

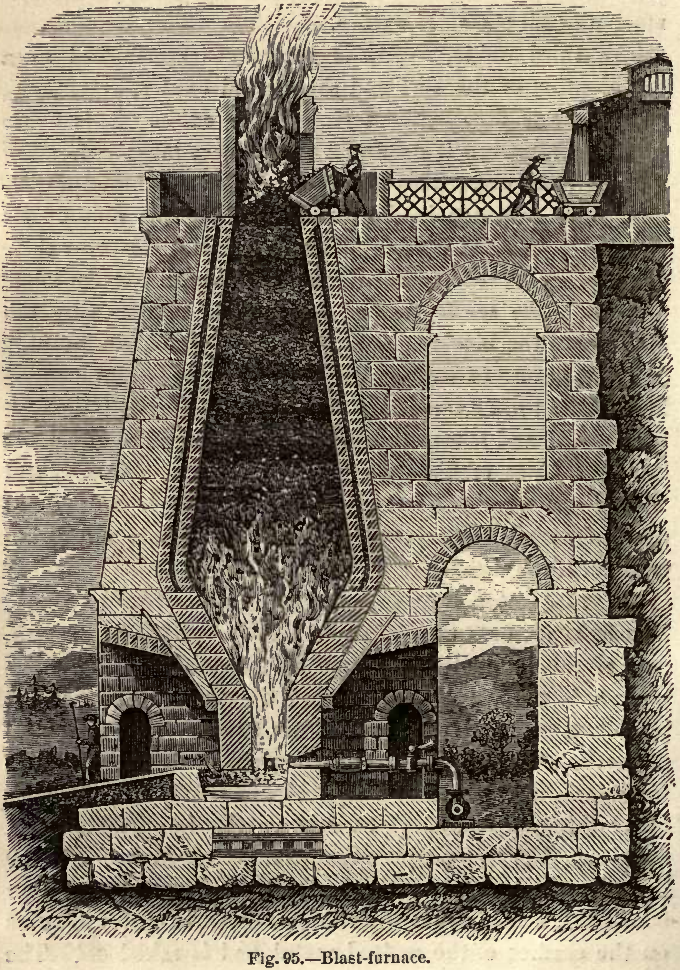


Fig. 95.—Blast-furnace.

used. Ore and fuel are dumped in at the top, the material gets hotter and hotter as it descends, reduction of the ore takes place, and the melted iron settles down into the lower part of the tall furnace, whence it is run off from time to time on the inclined plane to the left. The arrangement for the blast of air, by means of which the combustion is accelerated, is seen at the right hand in the lower portion of the picture.

341. **Cast Iron.**—This pig-iron is used for making castings. It is fit for this purpose from having had combined with it in the process above described about five per cent. of carbon. It is from this addition that the metal runs so readily into the moulds. If it were pure iron, or if it contained much less carbon, it would not do this. Besides, this combination of carbon and iron, as it passes from the liquid to the solid state in cooling, increases a little in bulk, and so fills out the mould in every line. This is owing to the crystallization which takes place every where in it. Cast iron is very brittle, and is not in the least malleable or ductile. Its hardness and its capability of being cast in moulds fit it for a great variety of uses, while its brittleness unfits it for many uses to which other modifications of this metal are especially adapted.

342. **Wrought Iron.**—This is obtained from cast iron by taking advantage of the fact that carbon is more combustible than iron. The carbon is mostly burned out of the cast iron. It is done by exposing the iron to a current of air when it is strongly heated in what is called a reverberatory furnace. The result is that the oxygen of the air unites with the carbon of the cast iron, and passes off as carbonic oxide. Fig. 96 (p. 246) will give you an idea of the construction of the furnace. The upper figure is a vertical, and the lower a horizontal section. At *a* is the fire, and *b* is the ash-pit; at *c* is a wall called the *bridge*, which serves to direct

the body of flame and heated air strongly against the arched ceiling of the furnace, whence it rebounds, or is *reverberated* down upon the iron which lies on the floor or hearth, *d*. The openings, *g* and *i*, are for the introduction of the iron, and at *p* is a damper by which the draught is regulated. When the "puddling" is finished the metal is taken out in the shape of a ball, and after being subjected to great pressure by machinery, to squeeze out the slag, it is passed through a succession of rollers, each pair having a smaller space between them than the preceding. The conclusion of all this is the formation of the soft bar-iron of commerce. Its qualities are the very opposite of those of cast iron. It is soft, flexible, ductile, and malleable, while cast iron is hard and brittle. When strongly heated it becomes only semifluid, and therefore can not be made to run into moulds like cast iron. It is also different in its texture. While cast iron is granular, as you can see by examining a broken edge, the structure of wrought iron is fibrous. It is a curious fact that long-continued jarring will sometimes change the fibrous texture of wrought iron into the granular arrangement peculiar to cast iron, showing that it is not the mere absence of carbon that makes wrought iron what it is. This has sometimes taken place in the axles and wheels of railway cars, and the brittleness induced has caused serious accidents. It is on account of the peculiar structure of wrought iron that it can be welded, which can not be done with cast iron. In welding

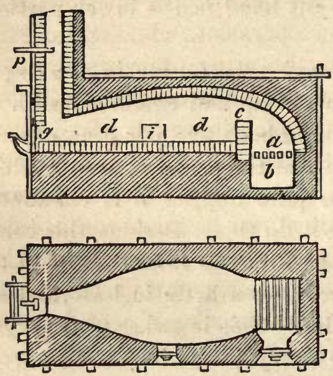


Fig. 96.

the fibres of the iron intermingle. For this reason welding adds to the strength of the material, and accordingly articles which require to be very strong, such as anchors, are made not in a single piece, but by welding together a bundle of bars of iron.

343. **Steel.**—Steel is a form of iron midway between wrought and cast iron as to the quantity of carbon it contains, which is from one to two per cent., while that of cast iron is five per cent. It may be made from cast iron by burning out half of its carbon, or from wrought iron by restoring half of the carbon of which it was deprived in its preparation. The latter is the usual process, and consists in heating the wrought iron in close iron boxes containing charcoal for several days. Steel can be made to have different properties according to the uses to which we wish to put it. If it be heated to redness, and then be quickly quenched, it is rendered hard and brittle; if cooled rather gradually it becomes elastic; and if cooled very slowly it becomes soft, ductile, and malleable, like bar-iron. When it is cooled slowly it is said to be *annealed.*

344. **Bessemer Process.**—This is a new and very rapid method of preparing cast steel, of the greatest industrial importance. It consists in burning out all the carbon and silicon in cast iron by passing a blast of atmospheric air through the molten metal, and then in adding such a quantity of a pure cast iron as is necessary to give carbon enough to convert the wrought iron into steel; the melted steel is then at once cast into ingots. In this way six tons of cast iron can be converted into steel in one operation lasting twenty minutes. This process has in large measure revolutionized the old iron industry.

345. **Tempering.**—Steel when hardened, as mentioned above, is not fit for use till it is tempered, as it is termed, to the particular use for which it is designed. This tem-

pering process consists in reheating the steel and then letting it cool slowly. The character of the effect depends upon the degree of heat to which it is carried, and this is measured by the workmen by the color caused by the heat. You can see the various colors by experimenting with a common knitting-needle. First heat it to redness in the flame of a spirit-lamp, and quench it in cold water. Now hold it again in the flame, and observe the changes of color. It first becomes a pale yellow, then orange, crimson, violet, blue, and finally dark gray. The explanation is this: A film of oxide forms, which, being at first exceedingly thin, is pale yellow, and deepens in its tint as the increased heat thickens it. The final dark-gray coating is scales of the oxide of iron. Now there is a definite degree of hardness on the one hand, and of elasticity on the other, corresponding to each one of these colors, the yellow giving the most brittleness and hardness, and the blue the most softness and elasticity, the other colors giving intermediate results. Accordingly, tools for cutting metal, which require to be very hard, are heated till they become a pale yellow; knives and planes to an orange; chisels, hatchets, etc., to a crimson; and springs to a violet or blue tint.

346. **Sulphides of Iron.**—There are three sulphides of iron. One of them, the disulphide FeS_2, is what is usually called iron pyrites. It received this name among the ancients because it strikes fire, *pur* being the Greek for fire. The idea which they had of it may be gathered from what Pliny says, who states that "there was much fire in it." It crystallizes, and has a brilliant yellowish brassy color. It has sometimes been supposed by the ignorant to be gold, and so has received the name of *fool's gold.* It is of great value in the arts in obtaining several important substances, as sulphur, ferrous sulphate, and sulphuric acid. As more

than half of this salt is sulphur, heat will drive off a large portion of it. It is therefore usually heated in clay retorts, and the sulphur which passes off in vapor is collected. The residue is taken out and thrown into heaps, and is simply left exposed to the air. By the absorption of oxygen from the air this sulphide gradually becomes a ferrous sulphate, the oxygen converting the sulphur into sulphuric acid, and the iron into oxide of iron, which unite to form the sulphate.

347. **Other Salts of Iron.**—Metallic iron dissolves readily in nitric and hydrochloric acid, forming nitrate and chloride of iron. Two of each can be obtained, one in the ferrous and the other in the ferric state. Ferric chloride is much used in medicine and in the arts; it is a valuable disinfectant. Ferric solutions are usually yellowish red in color, and ferrous solutions pale green.

348. **Cobalt.**—This is a brittle metal of a reddish-white color. It exists in nature in combination with arsenic and sulphur. There are two oxides, one of which, the monoxide, gives a beautiful blue color to glass. It is this colored glass ground to a fine powder that constitutes the *smalt* which is used to give to writing-paper and linen a delicate shade of blue. The blue colors on porcelain are also produced by cobalt, and the *zaffer* used to give a blue color to common earthenware is an impure oxide of this metal. The fly-poison, so commonly called cobalt by apothecaries, is arsenic, and has not a particle of cobalt in it. The name which this metal bears was given to it in a singular way. When the superstitious miners of the Middle Ages found the ores of cobalt, they expected, from their brilliancy, that they should obtain something very valuable from them; but they were disappointed in finding them crumble in their smelting-furnaces into gray ashes, emitting at the same time a disagreeable odor of garlic. They imagined,

therefore, that they were mocked in these results by the earth-spirits of the mines, the Kobolds, as they were called, and so named the ore after them. The name which the metal now bears is a corruption of that which was originally bestowed by the miners upon the ore.

349. **Chloride of Cobalt.**—The solution of this salt makes a beautiful *sympathetic ink*. It being of a pink color, what is written upon pink paper will be invisible. If the paper be warmed, the letters will become of a bright blue color, and then they will fade again as the paper becomes cool.

This is owing to the difference of color between the hydrated and the anhydrous salt.

350. **Nickel.**—This is a white metal, and takes a good polish. One of its chief uses is in making the alloy called German silver. It is an ingredient in the meteorites, as already noticed. Both cobalt and nickel are commonly found in company with iron, and these three metals are the only ones which are magnetic. The beautiful stone called chrysoprase is quartz colored an apple-green by oxide of nickel.

Nickel almost deserves to be classed among the noble metals, it is so little prone to oxidize. Since nickel-plating has been perfected we see nickel-covered objects in common use. The one-cent and five-cent coins are alloys of copper and nickel. Nickel forms two oxides, only one, NiO, being of importance.

351. **Salts of Nickel.**—The most abundant ore of nickel is *niccolite*, an arsenide of nickel. Nickel dissolves in nitric acid, forming a beautiful green nitrate of nickel. The carbonate, sulphate, chloride, hydrate, etc., are well-known salts, which have not obtained any extensive use in the arts. A double salt, sulphate of nickel and ammonium, is used in nickel-plating.

352. **Chromium.**—This is not very abundant in the earth.

It occurs near Baltimore combined with iron, forming so-called chromic iron.

Chromium forms a great many oxides, like manganese. That having most oxygen plays the part of an acid. Some of the salts of chromic acid are valuable. *Chrome yellow*, a well-known pigment, is a chromate of lead. *Chrome orange* is made by digesting chrome yellow with potassium carbonate, the effect of which is to remove a part of the chromic acid from the salt.

The most important of the chromates, however, is the potassium dichromate, $K_2Cr_2O_7$, a beautiful yellowish-red crystalline substance. All the compounds of chromium are strongly colored, and many of them are very beautiful. The green color of our "greenbacks" is due to the sesquioxide of chromium, Cr_2O_3, which is a very fast color, and not easily attacked by acids or alkalies.

GROUP VI.—TIN.

353. **Tin.**—Tin is one of the most extensively useful of the metals, for it is soft and malleable, and does not easily tarnish. The tin-foil which you so often see shows how malleable it is. Tin is used in making many of the alloys. Our common tin-ware is not tin alone, but thin sheet-iron covered with tin, the sheets having been dipped into the melted metal. The object of the covering of tin is to present a surface to the air and to liquids that is not easily oxidized. For the same reason iron chains are often covered with tin. Pins are made of brass, and are coated with an exceedingly thin covering of tin by a chemical process which has been described in Part I. Tin is a brilliant white metal, It is quite disposed to crystallize, as may be seen by a single experiment. Sponge a perfectly clean piece of tin which has been slightly heated quickly over with nitro-muriatic acid. After washing it in clean water

and drying it, the crystalline arrangement can be very plainly seen. Ware which has been treated in this way is called *moirê metallique.* If a bar of tin be bent it gives a peculiar sound, which is owing to the friction of the minute crystals of the metal against each other. This sound has been fancifully called "the cry of tin." There are three oxides of tin, one of which, the dioxide, SnO_2, is its common one. The most famous and most abundant tin-mines are those of Cornwall, in England. It is supposed that they were worked long before the Christian era.

354. **"Tin Salts."**—By dissolving tin in hydrochloric acid, stannous chloride, $SnCl_2$, separates from the solution in needle-shaped crystals containing water. This forms the "tin salts" so largely used by the calico-printer and dyer as a mordant. Stannic chloride, $SnCl_4$, is a fuming, colorless, heavy liquid.

355. **Sulphides of Tin.**—There are two sulphides of tin, a mono- and a di-sulphide. Stöckhardt tells us how to obtain them. To obtain the first inclose 2 grammes of flowers of sulphur in a piece of tin-foil weighing 4 grammes, and introduce the package into a test-tube. On heating the tube, half of the sulphur will burn up, and the other half will unite with the tin with a lively glowing, forming a brownish-black mass, which is the monosulphide. If you sprinkle the glass, while still hot, with water, it is rendered friable, and is easily separated from the fused salt, which will be found to weigh about 5 grammes. Pulverize this, and mix intimately with the powder 1 gramme of sulphur and 2 of sal ammoniac. Put this into a thin flask, and let it be heated in a sand-bath for an hour and a half. The disulphide will be found in the bottom of the flask in a mass having a golden lustre, and the sal ammoniac will appear in the upper part of the flask, deposited there by sublimation. The latter is not altered at all in composition, but it in some way serves to give the disulphide its golden color. The beautiful substance thus obtained has been called *aurum musivum,* or *mosaic gold,* and it may be used for giving a gold-like coating to wood, plaster of Paris, etc.

QUESTIONS.

335. Give the names and formulæ of the oxides of manganese. Which ones form salts?—336. What are the properties of pure iron?—337. What is said of the abundance and importance of iron?—338. What oxides does iron form? What is said of ferrous hydrate? Mention some of the ores of the monoxide of iron. Of the sesquioxide. Of ferric hydrate. How many grammes of water are there in 100 grammes of ferric hydrate? How many grammes of oxygen? How many gallons of oxygen in one pound of rust? What is the composition of the so-called magnetic oxide of iron? What are its properties?—339. What are meteorites?—340. Describe the process of making pig-iron. Why is limestone added?—341. What is said of cast iron?—342. What is the process of converting cast iron into wrought iron? Describe the change in properties thus produced. Why can wrought iron be welded?—343. In what does steel differ from iron? What are its properties? What is annealing?—344. In what does the Bessemer process consist?—345. What is said of tempering steel? What colors does it assume?—346. Name and describe the principal sulphide of iron. Of what use is it?—347. Name some other salts of iron.—348. What is the nature of cobalt? Whence its name?—349. What is said of sympathetic ink?—350. What are the properties of nickel?—351. Name some of its salts.—352. What are the most important oxides of chromium? What is said of the chromates?—353. What are the uses of tin? How are pins made? What is *moiré metallique?* What peculiar property has a bar of tin?—354. What is known as "tin-salts?" How used?—355. What is mosaic gold? How made? How is the monosulphide obtained?

CHAPTER XIX.

GROUP VII. ARSENIC, ANTIMONY, AND BISMUTH.—GROUP VIII. COPPER AND LEAD.

356. **Arsenic.**—What is known as arsenic in common language is a compound of this metal with oxygen, called by the chemist arsenious anhydride, As_2O_3. This arsenious anhydride is a deadly poison, so that "poisonous as arsenic" is a common expression. It is used for the destruction of

life more often than any other poison. It is much used for killing rats, moles, and other troublesome animals, and hence the name ratsbane which is often given to it. It looks much like sugar and flour, and its taste is rather sweet. The metal arsenic is crystalline, of a bright steel-gray color. It is not poisonous when free from oxide. It very soon tarnishes when exposed to the air, and at length becomes a coarse gray powder, which is a mixture of the metal and its oxide. It is sometimes sold by druggists under the names of "fly-powder," "cobalt," and "mercury." This is wrong, for people who buy it are not as cautious in its use as they would be if they knew that it was arsenic.

357. **Antidotes to Arsenic.**—Every one ought to know what to do if he chance to be with any person who has taken arsenious anhydride—*white arsenic*, as it is called. He should administer at once in considerable quantities the whites of eggs, or milk, or flour and water, or soapsuds. These, however, are but partial antidotes, doing little, if any thing, more than sheathing the membranes of the stomach from the arsenic. There is only one true chemical antidote to this poison—ferric hydrate; but it is good for nothing unless it has been freshly prepared. Its efficacy results from its forming with the arsenic a compound which is insoluble, and therefore inactive.

There are some sure chemical tests of the presence or absence of arsenic in the bodies of those who are supposed to have been killed by this poison; but such investigations belong properly only to the professional chemist, and therefore are not suited to this work.

358. **Antiseptic Powers of Arsenic.**—When arsenious anhydride is taken as a poison and destroys life, it has a marked effect in preserving the body from putrefaction. This is shown in various ways. Sometimes the whole body is remarkably preserved for a long time after death.

In this case the person lives so long after taking the poison that it goes every where in the circulation, and pervades the whole body. But sometimes, on the other hand, the stomach and intestines alone have been found preserved even after the rest of the body was far gone in decomposition. Here the person died soon after taking the arsenic, and therefore its antiseptic influence was exerted locally. It is on account of this preservative power that skins intended for shipping have arsenic rubbed on the flesh side.

359. **Arsenic-Eating.**—There is a strange habit of eating arsenic prevalent among the inhabitants of Styria, a mountainous district in Austria. The effects which are ascribed to it are hardly credible, but the statements seem to be well authenticated. It is said that the arsenic-eaters contract the habit for the purpose of improving their personal appearance. Another effect is that the respiration is improved, so that mountains can be climbed with much less embarrassment of the breathing than is usual. But the habit is attended with great dangers. The arsenic-eater begins with small doses, and gradually increases them. Great caution is required, and very often too much is taken; and then symptoms of poisoning appear, perhaps resulting in death. Then, again, when the habit is once formed, any intermission in the regular taking of the arsenic is dangerous, bringing on at once the common symptoms of arsenic-poisoning. It is said that the same results are produced on brute animals, and that in the city of Vienna men sometimes throw a pinch of arsenic into the food of horses. It makes them fat, sleek, and of good wind; but the practice once begun must be kept up. Notwithstanding all this, thorough investigation would undoubtedly show that arsenic-eating very considerably shortens life, although cases are cited in which persons who for a long

time have been slaves to the habit are in good health even at the age of sixty years or more.

360. **Arsenetted Hydrogen.** — Arsenic, like nitrogen and phosphorus, combines with hydrogen in the proportion of one atom to three. This body, arsenetted hydrogen, AsH_3, or hydrogen arsenide, as it is sometimes called, is a gas, neither acid nor alkaline, and very poisonous. A German chemist, named Gehlen, was fatally poisoned by it in 1815, while investigating its properties. It is easily obtained by throwing a little arsenious anhydride into an apparatus for generating hydrogen by means of zinc and sulphuric acid. The arsenious oxide is deprived of its oxygen, and part of the metal combines with the hydrogen, forming arsenetted hydrogen. This gas is inflammable, and burns with a lambent flame; if a cold porcelain plate be held in the flame a moment, the gas being decomposed by the combustion, metallic arsenic will be deposited on the porcelain, forming gray-black spots. This formation of arsenetted hydrogen and of a metallic deposit by the flame is made use of in testing for arsenic. The delicacy of the test is remarkable: $\frac{1}{50,000}$ of a gramme can be detected in this manner, using suitable precautions not necessary to describe here. Antimony forms a similar compound with hydrogen, SbH_3, and the flame of this gas deposits a black metallic coating on a cold porcelain surface just like ar-

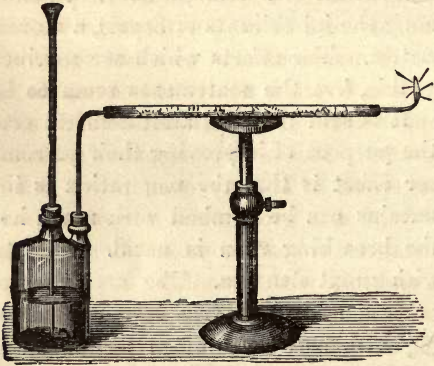


Fig. 97.

senic, but somewhat deeper black in color. The methods of distinguishing between arsenic and antimony, however, belong to works on analytical chemistry. You can easily see, however, that when a chemist is called upon to determine whether a person has been poisoned by arsenic or not, the chemist must be very careful not to mistake antimony for arsenic, for antimony, as you will learn in § 363, is a component of tartar emetic, which is sometimes given to produce vomiting when poisoning is suspected.

361. **Arsenical Pigments.**—Arsenious acid in combination with copper makes several splendid green pigments. *Scheele's Green* is an arsenite of copper formed by adding an alkaline solution of arsenious acid to a hot solution of copper sulphate. *Paris Green* is nearly the same, but contains acetate of copper also. This brilliant color is extensively used as a pigment. It is a very poisonous substance, and its use is dangerous. "It may even prove dangerous," Stöckhardt says, "as a green paint for rooms, since, under some circumstances, volatile combinations of arsenic are formed from it and mix with the air."

Brunswick Green is another arsenical pigment, prepared like Scheele's Green, only some cream of tartar is added to the copper sulphate, and some slaked lime to the arsenious solution. The facility with which compounds of arsenic can be obtained by the common people, and their cheapness, is much to be deplored.

362. **Antimony.**—This metal is not so well known as one of its salts called tartar emetic; and yet in some of the arts it is largely used. It is one of the constituents of type-metal. The alloy of lead and antimony which we have in type-metal at the moment that it becomes solid in casting expands, so that the mould is well filled out, and the type is therefore complete, with well-marked lines and angles. But neither of these metals when alone makes a good cast-

ing, because they shrink in becoming solid, instead of swelling as they do when mixed in alloy. The metal plates on which music is sometimes engraved is an alloy of tin and antimony. The *Britannia Metal*, which has taken the place of the old-fashioned pewter, is composed of one hundred parts of best block-tin, eight of the metal antimony, and either two and a half parts each of copper and brass, or two of copper and bismuth. Antimony is obtained chiefly from its sulphide, which is quite an abundant ore. It is associated commonly with ores of silver, copper, lead, zinc, etc.

363. **Compounds of Antimony.** — Antimony forms two chlorides, one of them, $SbCl_3$, has long been known under the name of butter of antimony. It forms also two oxides, Sb_2O_3 and Sb_2O_5, and two sulphides of corresponding composition. Tartar emetic is a double tartrate of antimony and potassium, $K(SbO)C_4H_4O_6$. It is obtained by boiling antimonious oxide with cream of tartar (hydro-potassium tartrate), and evaporating the solution. Nearly all the salts of antimonious oxide are decomposed on adding water to their acid solutions. Antimonetted hydrogen has been mentioned in § 360.

364. **Bismuth.**—This metal is found in but few localities, and mostly in the metallic state. By far the largest part of it comes from one locality, Schneeberg, in Saxony. It is obtained from the rocks in which it is present by reducing them to a coarse powder, which is burned in a sort of kiln. The bismuth, which is quite fusible, is thus melted out, and is collected in a trough at the bottom of the kiln. It is a white metal with a peculiar reddish tint, and a remarkable crystalline structure. It is used chiefly in forming certain alloys, as one kind of type-metal, and the metal for stereotype plates.

365. **Nitrate of Bismuth.**—If a solution of this salt be

turned into a large quantity of water, the salt loses a part of its nitric acid, and so becomes basic, and is called a subnitrate. This appears in the form of a white precipitate. This has been sometimes used as a cosmetic. It would be dangerous for a lady who had used it for this purpose to attend a chemical lecture at which any sulphuretted hydrogen should escape, for this gas blackens at once this salt.

366. **Copper.**—This metal is next to iron in strength. It is one of the very few metals which have a decided color. It is very malleable and ductile, and is therefore much used in the forms of sheet and wire. It is largely used in sheathing ships. It is a constituent of many alloys, as brass, bronze, German silver, etc. Gold and silver, both in coins and articles for use, are alloyed with copper, to give them the requisite hardness. Native copper is found in abundance in the neighborhood of Lake Superior. A mass of it has been taken thence to Washington which weighed 3704 pounds, and a mass has been uncovered in one of the mines which has been estimated to weigh 200 tons. The metal is also largely obtained from copper pyrites, a double sulphide of iron and copper—that is, an ore in which the sulphur is chemically combined with both of these metals, the particles of the two sulphides being most intimately mingled together. There are also other ores of copper—the pure sulphide, red oxide, carbonate, etc. There are two oxides of copper—the monoxide, which is black, and the suboxide, which is red. The latter is used in the manufacture of glass, giving it a splendid ruby-red color.

We have already named many of the salts of copper; the sulphate sometimes called blue vitriol forms beautiful blue crystals containing water. It is used in calico-printing and in the manufacture of green pigments, some of them containing arsenic, as you have just learned. Acetate of copper, sometimes called verdigris, is another green pigment. It is a very poisonous substance. It is formed whenever acetic acid is brought in contact with copper. No article of food, then, in which there is vinegar should be cooked or kept in a copper vessel.

367. **Experiment with Sulphate of Copper.**—If you hold a knife-blade for a few minutes in a strong solution of sulphate of copper, it will be covered with a coating of metallic copper.

The copper is precipitated upon the iron, while the iron goes into the solution. This is shown as follows:

$$\overset{\text{Sulphate of copper.}}{CuSO_4} + \overset{\text{Iron.}}{Fe} = \overset{\text{Ferrous sulphate.}}{FeSO_4} + \overset{\text{Copper.}}{Cu}$$

This experiment was tried on a large scale some years ago in Ireland. In some pits at a mine in Wicklow there was a large amount of the solution of sulphate of copper. In order to get the metallic copper from this, 500 tons of iron were placed in the pits and left there for a year. The result was that the iron was all united to the sulphuric acid, forming ferrous sulphate, which was dissolved in the water, and the metallic copper lay in the form of a reddish mud at the bottom of the pits. This was taken out, and, after being freed from its impurities, was melted and cast in bars. The same expedient has been adopted in other mines.

368. **Test for Copper.**—Polished steel, as shown by the experiment with the knife-blade, is a good test of the presence of salts of copper. If pickled cucumbers or preserved fruit have been prepared in copper vessels, we can ascertain whether copper be present in them by introducing a slip of polished steel, or, what is the same thing, a bright knife-blade. If there be any salt of copper, the metal itself will be deposited upon the steel. Of course, as the quantity, if there be any, must be small, the steel must remain in the liquid for some little time, and the deposit must necessarily be small. If the salt be acetate of copper, as it

is very likely to be, the copper is set free by the formation of an acetate of iron.

369. **Lead.**—Next to iron, lead is one of the most abundant metals. Its softness and low melting-point are its chief characteristics. It is used for a great variety of purposes. It is the chief ingredient in type-metal. Bullets and shot are made from it. The mode of manufacturing shot is given in § 60, Part I. It is also largely used for pipes for conducting water and other liquids. In the form of sheet-lead it is applied to various uses. This metal is obtained principally from its sulphide, called galena. One mode of obtaining it is to mix the ore with iron, and then apply heat. The sulphur, having a greater attraction for iron than for lead, leaves the lead to unite with the iron. The action of water upon lead we shall speak of in another place.

370. **Oxides of Lead.**—The monoxide of lead, PbO, is a yellow substance called *massicot.* If this be melted with a strong heat it solidifies, on cooling, into a reddish-yellow mass composed of brilliant scales, and is called *litharge.* It is used extensively in the arts, in the manufacture of glass, in making the lead plaster of the apothecary, in forming a varnish with linseed-oil for the cabinet-maker, in the manufacture of white-lead, red-lead, etc. The red oxide is prepared by exposing for some time to a faint red heat the monoxide which has not been fused. A brilliant red and very heavy powder results called *minium*, which is used as a cheap substitute for vermilion in painting.

The composition of the red oxide is $2PbO.PbO_2$, being a compound of the monoxide and of a chocolate-colored oxide, PbO_2, not previously mentioned.

371. **White-Lead, or Carbonate of Lead,** $PbCO_3$.—This may be prepared by mixing a solution of lead acetate or nitrate with one of sodium carbonate, a white precipitate settling.

The commercial white-lead is prepared differently, usually by exposing sheet-lead to the influence of the oxygen of the air in the presence of acetic acid or vinegar. The agency of the acetic acid of the vinegar is interesting. It dissolves successive portions of the oxide of lead, forming with it an acetate, and the moment that it does this the carbonic acid takes away the oxide from it; so that the office of the acetic acid is simply to take the oxide and deliver it over to the carbonic acid. It is very much as the nitric acid in the formation of sulphuric acid (§ 242) continually takes oxygen from the air and delivers it over to the sulphurous acid.

372. **Lead-Poisoning.**—The carbonate of lead is a poison, producing, when introduced into the system, lead colic, paralysis, and many other bad affections. Many persons have been subjected to protracted suffering, and many lives have been lost from this poison. Painters are liable to be poisoned by it, but the liability has been much diminished by precautions in the use of the article in their business. The poisonous influence more often comes from drinking water brought in lead pipes, and in that case is commonly slow and insidious. And, as a general rule, the purer the water, the more apt is it to be rendered poisonous by the lead. The reason of this is obvious. You will remember that we told you that there is always some carbonic anhydride in water. Now this acts upon the metallic lead in connection with the water, and, forming carbonate of lead, makes it poisonous. It will do so unless there be something to prevent it. If the water be quite pure, there is nothing in it to prevent the carbonic anhydride from thus acting; but if there be certain impurities, as, for example, sulphate of lime, there will be formed a thin coating over the surface of the metal, which effectually shields it. Lead pipes ought never to be used unless the water to be brought

through them has been ascertained by a skillful chemist to have the protective ingredients alluded to in it. There has been great carelessness in this matter. Because in the majority of cases there is no hazard, people have presumed on safety without any examination, foolishly running the risk of having the exception occur in their case.

Tin-lined pipes are said to be safer than ordinary lead pipes.

373. **Sugar of Lead, or Lead Acetate,** $Pb(C_2H_3O_2)_2$.—Acetate of lead is commonly called sugar of lead, on account of its sweet taste. A very pretty experiment may be tried with a solution of this salt. Dissolve 15 grammes of sugar of lead in 180 cubic centimeters of water, making the liquid clear by adding a few drops of acetic acid. If this be poured into a phial, and a slip of zinc be fastened to the cork, as seen in Fig. 98, brilliant metallic branches will grow upon the zinc, filling the phial in a day or two. These are crystals of lead which have arranged themselves in this arborescent form. This is because the zinc replaces the lead in the lead acetate, forming zinc acetate, which takes the place of the lead acetate in the liquid. This leaves the lead uncombined, and its particles, as fast as they are released, gather in crystals, the process taking its start from the zinc where the chemical change occurs. Acetic acid is $H.C_2H_3O_2$, being an organic acid composed of carbon, hydrogen, and oxygen, in the proportions named. Lead acetate is $Pb(C_2H_3O_2)_2$, therefore the reaction above described may be expressed in an equation thus:

Fig. 98.

Lead acetate.		Zinc.		Zinc acetate.		Lead.
$Pb(C_2H_3O_2)_2$	$+$	Zn	$=$	$Zn(C_2H_3O_2)_2$	$+$	Pb

QUESTIONS.

356. What is said of the metal arsenic? What is the composition of ratsbane?—357. What are the antidotes to arsenic poisoning?—358. What is said of the antiseptic properties of arsenic?—359. What of arsenic eating?—360. What is the composition of arsenetted hydrogen? How is it made? What are its properties? How delicate is this as a test for arsenic? What is said of the danger of mistaking antimony for arsenic?—361. Name some pigments containing arsenic. Of what are they composed?—362. What is said of the uses of antimony?—363. Describe some salts of antimony. What is tartar emetic?—364. What is said of bismuth? 365. What of its nitrate?—366. What are the properties of copper? What its uses? What is said of native copper? What other ores of copper are mentioned? What is said of the salts of copper?—367. Describe an experiment with sulphate of copper. Where and why was this done on a large scale?—368. What is a good test for copper?—369. How is lead obtained? For what is it used?—370. What is said of the oxides of lead? What is minium?—371. What is white-lead? How made?—372. Why is poisoning by lead so insidious? What danger is there in using lead pipes for conveying drinking-water? What pipes are safer?—373. What is the scientific name of sugar of lead? What is its composition? How can a lead tree be made? What is the theory of its formation?

CHAPTER XX.

GROUP IX.—MERCURY, SILVER, GOLD, AND PLATINUM.

374. **Mercury.** — This metal was thus named from its quickness of movement, because Mercury was considered by the ancients the most active of the gods. The alchemists called it quicksilver, because they thought it to be an enchanted kind of silver, and they endeavored by various processes to obtain from it solid silver. Mercury is the only metal which is liquid at ordinary temperatures. It freezes or solidifies at about 39½ degrees below zero, and then it is malleable like lead. It evaporates like water,

though not as rapidly, at ordinary temperatures. This you can prove by a simple experiment. Put some mercury in a phial, and fasten to the cork a little bit of wood having some gold-leaf attached to it. The gold, after a few days, will have a white color, because the mercury has risen in vapor and united with the gold, forming an amalgam. There are two oxides of mercury, one of which, called red precipitate, is with its bright red color a striking example of the great difference which is so often seen between the properties of a compound and those of its constituents. Mercury is sometimes found native. It is said that the mines of Mexico were discovered by a hunter, who, as he took hold of a shrub in climbing a mountain, tore it up by the roots, and a stream of what he supposed to be liquid silver burst forth. But the metal is commonly obtained from the ore called *cinnabar*, a sulphide.

So readily does the mercury in cinnabar part with the sulphur that merely roasting it in a current of heated air answers to reduce it. Sulphurous anhydride is formed by the union of the sulphur with the oxygen of the air, and this gas passes together with the vapor of the mercury into a cool chamber, where the liquid mercury collects by the condensation of the vapor.

375. **Vermilion.**—Cinnabar is of a beautiful red color, but precipitated mercuric sulphide is black. If this artificial sulphide is sublimed, then, without any chemical change, it becomes a brilliant red, and is the so-called vermilion. This substance is sometimes adulterated with minium or red-lead, but the fraud can be easily detected. If a little of pure vermilion be thrown upon a live coal, it is entirely volatilized or sublimed with a blue sulphurous flame; but if it be adulterated with minium it will not all volatilize, and beads of metallic lead will remain on the coal.

376. **Chlorides of Mercury.**—Mercurous chloride, Hg_2Cl_2,

is also called calomel. Mercuric chloride is commonly called corrosive sublimate; it contains twice as much chlorine as the first-named chloride, and is written $HgCl_2$.

Calomel is an insoluble and mild substance; but corrosive sublimate, merely by having this additional quantity of chlorine, is soluble, and acts as a corrosive poison, burning and eating wherever it goes. It is much used for the destruction of vermin. It has sometimes been swallowed by mistake. It produces most distressing symptoms, ending very commonly in death. The accident happens usually in one or the other of two ways: either a bottle which has had a solution of corrosive sublimate in it is carelessly put aside, and is afterward used for some other purpose, perhaps for bottling cider; or the bottle containing the solution is put among other bottles without being properly labeled, and, if the solution is made with alcohol, some of it may be swallowed on the supposition that it is some kind of liquor. It is in this latter case that such intense suffering is produced, because the poison is so concentrated. But little is swallowed, for the individual is affected at once by an intense burning in the throat, extending down into the stomach. Every one ought to know the effectual antidote which they have to this poison, for the earlier it is used the better, and every moment's delay adds to the danger of the case. Fortunately the antidote is generally at hand. It is the whites of eggs, which should be swallowed freely. The albumen in this substance acts chemically upon the corrosive sublimate, producing a compound that is not poisonous. If there be no eggs at hand, give milk, or flour stirred up in water, for there is some albumen in these.

377. **Amalgamation.**—You have already learned (§ 278) that mercury forms with some of the metals alloys called amalgams. This fact is made use of in freeing certain

metals from substances with which they happen to be mingled. Silver and gold are often obtained by this process, which is called amalgamation. Suppose, for example, that we have some quartz with gold finely scattered through it. The quartz is first powdered, and then the powder is agitated with mercury, which seeks out, as we may say, all the gold, and unites with it to form an amalgam. Sufficient mercury is used to have the amalgam liquid, so that it may be readily separated from the powder. This liquid amalgam, which is really a solution of gold in mercury, is poured upon buckskin or a closely woven cloth, which allows most of the mercury to run through, leaving the gold alloyed with a small part of the mercury. The remaining mercury is driven off by heat, and the gold is obtained pure. The dust of jeweler-shops is often treated in this way to save the gold which has been scattered by filing and other processes.

378. **Silver.**—This metal stands in regard to hardness between gold and copper, and requires to be alloyed with copper to make it wear well. In the coinage of the United States the proportion of copper is one tenth. Silver is very ductile and malleable. Its polished surface reflects both light and heat better than any other metal, and accordingly it is used for reflectors. The tarnishing which gradually occurs is not from oxidation, but from the formation of a sulphide of silver by the sulphuretted hydrogen which is generally in the air in small quantity. When this gas is present in the air in considerable amount, as in the neighborhood of some sulphur springs, silver tarnishes rapidly. It is the sulphur in the egg that discolors the spoon with which you eat it, forming a sulphide. Silver is sometimes found native, but is usually obtained from ores. The most common of its ores is the sulphide called *argentite*. This occurs abundantly in Nevada. It is sometimes combined

with antimony and arsenic. There is always some silver in the common ore of lead, galena, and sometimes there is so much of it that it is profitable to submit the lead obtained from this ore to certain chemical processes for extracting the silver alloyed with it.

379. **Extraction of Silver from Galena.**—We have already told you, in § 369, how the galena is freed from the sulphur. This gives you an alloy of lead and silver. This is melted in a large basin and allowed to cool slowly. As it cools a crust continually forms over the surface, which is composed of crystallized lead without any of the silver, this settling down in the liquid below simply because it does not crystallize as readily as lead does. This crust is taken off with an iron colander as fast as it forms, until there is left only a small amount of the melted metal. You see what the result is. You have an alloy containing much more silver in proportion than the mass which you melted. This alloy, after cooling, is submitted to a process called *cupellation*. The cupel is a shallow dish made of bone ashes, and is very porous. In this is placed the alloy, and it is submitted to a strong heat. When it is at a full red-heat a powerful current of air is thrown across it by bellows in order to blow away the litharge or oxide of lead which forms on the surface. What is not thus blown away is absorbed by the pores of the cupel. When the lead is all disposed of, and the silver is left alone, the surface suddenly becomes brilliant, and the workman, seeing this *flashing* or *lightening*, as it is technically termed, knows that the process is completed, and withdraws the cupel from the fire.

380. **Salts of Silver.**—Silver forms many useful salts. Silver nitrate is often called by physicians *lunar caustic*, being used as a caustic by the surgeon. As it grows black rapidly when exposed to the light in contact with

vegetable fibre, it is much used in solution as an indelible ink for marking linen and cotton. Mercury introduced into a weak solution of it precipitates the metallic silver in beautiful tree-like forms called *arbor Dianæ.*

There have been cases in which nitrate of silver (lunar caustic) has been swallowed in considerable quantity by mistake. The sure antidote is common salt, producing two harmless articles, chloride of silver and nitrate of sodium.

381. **The Silver Assay.**—The process by which the amount of alloy in silver is ascertained is called the silver assay. A sample of the silver to be examined is first dissolved in nitric acid. The assayer then introduces salt (chloride of sodium) into this solution, and a curdlike substance is precipitated. This substance is chloride of silver, formed by the union of the chlorine of the salt with the silver. He adds the salt slowly till there ceases to be any precipitation, and then stops, because he knows that there is no more silver for the chlorine to unite with. Now observe how he tests by this process the amount of silver in the specimen. Of course, the more silver there is and the less alloy, the more salt is required to precipitate all the silver. The assayer, therefore, judges of the purity of the specimen by the amount of salt which he is obliged to use to complete the process, and in order to ascertain this accurately he employs a solution of a certain strength, which he pours from a graduated glass. He knows beforehand just how much of this is required to precipitate a certain amount of pure silver—for example, a gramme. If now he is obliged to use only half as much for a gramme of any sample, he infers that it is only half silver; if three fourths, it is three fourths silver, etc. The explanation of the process is this: The solution of the silver in nitric acid is a solution, not of silver, but of the salt called nitrate of silver. This is decomposed, as is also the chloride of sodium when the two solutions mingle, producing chloride of silver and nitrate of sodium, as indicated in the equation:

$$AgNO_3 \quad + \quad NaCl \quad = \quad AgCl \quad + \quad NaNO_3.$$

382. **Gold.**—Gold is nearly always found in its metallic state. It is usually, however, alloyed with silver. Sometimes it occurs in masses, but commonly in small round or flattened grains. It is also found in veins in various rocks.

Its properties are, a splendid yellow color, brilliancy, high specific gravity, softness, great malleability and ductility, and indisposition to combine chemically with other substances, especially oxygen. Gilding is usually performed by means of gold-leaf, except in case of the metals, on which it is commonly done by amalgamation, a process just explained. Gold is so soft a metal that it is not fit for use in its pure state, and is therefore always alloyed with silver and copper to give it the requisite hardness. The gold coin of this country is one-tenth part an alloy of silver and copper. The word *carat*, used so much in expressing the degree of purity in specimens of gold, signifies one twenty-fourth. If, therefore, it is said of any specimen of gold that it is 18 carats fine, it means that the pure gold in it is 18 parts out of the 24, or that it is three fourths gold. Perfectly pure gold is, of course, 24 carats fine. The word is of Eastern origin, and comes from a word meaning *bean*.

Gold is not soluble in nitric acid, nor in hydrochloric, but in a mixture of the two it dissolves readily, as explained in § 225.

383. **Chloride of Gold.**—This salt can be made in two ways. If gold-leaf be put into chlorine water, the chlorine will unite with it, and chloride of gold will be found in the solution. But it is most commonly made by treating gold with aqua regia. The chemical action is described in § 225. If the solution thus obtained be evaporated, a brownish-red salt will appear, which is the chloride of gold. It is very easily decomposed, as can be shown by the following experiment: Dip a test-tube which has been wiped dry into a dilute solution of chloride of gold, and then heat it over a spirit-lamp. It will become gilded, showing that heat suffices to disengage the chlorine from the gold. The chloride of gold is quite in contrast with the chloride of sodium in

this respect, for no heat can decompose the latter. The compound, then, of gold with chlorine can be called an unstable compound, as are its compounds with oxygen.

Chloride of gold is used to a limited extent in the arts, chiefly in photography.

384. **Platinum.**—The color of this metal is between tin and steel. It is the heaviest of all substances; it has great ductility and tenacity; it is very malleable, especially when heated, and it may then be welded, though not as perfectly as iron. In fusibility this metal stands at one end of the scale of metals, mercury being at the other. Mercury may be said to melt at about 40° below zero; while, on the other hand, platinum withstands the heat of the hottest furnace, and requires the intense heat of the oxyhydrogen blowpipe to melt it. Hence the crucibles of the chemist are often made of this metal. It is used, also, somewhat in the arts —in the manufacture of apparatus for the distillation of sulphuric acid, and in enameling glass and porcelain. If it were an abundant metal, it might be put to many common uses, and be a great convenience, for the utensils made of it would never rust, and would not be in any danger of melting, and when they became dirty they could be cleaned and made bright again by heating them red-hot.

Platinum, like gold, dissolves in aqua regia only; the solution on evaporation gives a deliquescent brown-red mass consisting of platinic chloride, $PtCl_4$. This is used in chemical laboratories as a test solution, and in photography to a limited extent.

385. **"Döbereiner's Lamp."**—By a certain chemical process platinum may be obtained in a finely divided state, furnishing a soot-like substance called "spongy platinum." This produces remarkable effects upon certain gases. If a little of it be introduced into a mixture of oxygen and hydrogen gases, an explosion is produced as quickly as if a lighted

taper had been introduced. So, also, if a piece be held in a current of hydrogen it becomes red-hot, and then sets fire to the gas. This is what takes place in Döbereiner's Lamp, so called after the inventor. By turning a stop-cock in this lamp you let a current of hydrogen strike upon a bit of spongy platinum, and you have the result just mentioned. In Fig. 99 you have a plan of this lamp, *a* being a glass jar covered by a brass lid, *e*, which has a stop-cock, *c*, with its opening opposite to a brass cylinder, *d*, which contains the spongy platinum. There is a small bell-jar, *f*, communicating at the top with the stop-cock, and having suspended in it a cylinder of zinc, *z*. When the lamp is to be used the jar, *a*, is two thirds filled with a mixture of one part sulphuric acid and four parts water, as indicated by the circular line. As the bell-jar is open at the bottom, the acid and water attack the zinc in it, producing hydrogen gas, just as it is produced in the apparatus described in § 143. If the cock be opened the hydrogen gas will escape, and be directed against the spongy platinum in *d*, and will make it red-hot, and then this will set fire to the gas.

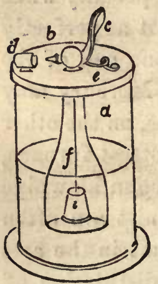


Fig. 99.

386. **Other Illustrations.**—This curious property is not confined to *spongy* platinum, but the metal in its ordinary condition shows it to some extent. For example, if some ether be poured into a glass jar, Fig. 100, and a coil of platinum wire recently ignited be put into it, the metal will glow so long as there is any ether present. Ozone is formed at the same time. In Fig. 101 (p. 273) you have essentially the same experiment in a prettier form.

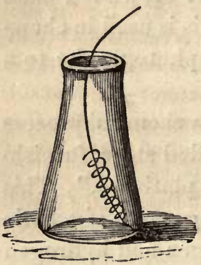


Fig. 100.

Take a common alcohol lamp, and, cutting the wick rather short, surround it with a coil of small platinum wire about half an inch high. Light the lamp, and when the wire becomes red-hot blow it out. The wire, instead of cooling at once, as any common wire would, will continue to glow till all the alcohol is consumed. These curious phenomena depend upon the power possessed by platinum of condensing gases upon its surface.

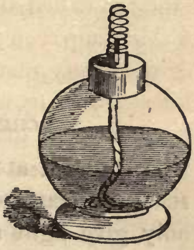


Fig. 101.

387. **Iridium and Osmium.**—There are several very rare metals found associated with platinum, and having similar properties. Two of these, iridium and osmium, form the hardest alloy known, a mineral called by the mineralogist *iridosmine*, a name compounded of the names of the two metals. One use has been found for this mineral: it is used to point gold pens, its great hardness fitting it admirably for that purpose.

QUESTIONS.

374. Whence the name mercury? How can the evaporation of mercury be shown? What is cinnabar? How is mercury obtained from it?—375. What is vermilion? When is it black? When red?—376. What is the composition of calomel? What of corrosive sublimate? What are their properties? What antidote is recommended? How does it act?—377. What is amalgamation? How carried on?—378. What is said of the properties of silver? Its uses? Explain the tarnishing of silver.—379. In what mineral does silver occur? How is it extracted? What is cupellation?—380. What is the composition and nature of lunar caustic, so called?—381. Describe the silver assay.—382. How is gold found in nature? With what is it alloyed? What are its properties? Explain the term carat.—383. How is gold chloride made? For what used?—384. Give in full what is said of the properties and uses of platinum. In what acids does it dissolve?—385. Describe and explain Döbereiner's Lamp.—386. Describe the experiment with ether and a coil of platinum wire. Explain this briefly.—387. What other metals belong to the platinum group?

CHAPTER XXI.

CHEMICAL INFLUENCE OF LIGHT.

388. **Chemical Influence of Light.**—You have already had some illustrations of the fact that the rays of the sun not only give light and heat to the earth, but also stimulate many chemical operations. For example, you saw in § 223 that chlorine and hydrogen are very ready to unite under the stimulus of light, when, if light be shut out, no such union takes place. So strong is this disposition to unite under this stimulus, that if a mixture of the two gases be exposed to the direct rays of the sun, the union is so sudden as to occasion an explosion. A solution of ferrous sulphate may be kept a long time in the dark without any change; but expose it to sunshine, and a precipitation of ferric oxide at once begins. Indeed, it is ascertained that precipitation in many cases may be quickened by the rays of the sun. You have a familiar example of the chemical influence of solar light in the blackening of common marking-ink when the marked articles are exposed to the light. In sun-bleaching, also, the sun's rays stimulate the chemical changes which take place.

389. **Universality of this Influence.**—Wherever light goes it acts chemically. It was said by Niepce, who was associated with Daguerre in the investigations which led to his great discovery, that " no substance can be exposed to the sun's rays without undergoing a chemical change." Though, with the common notion which was prevalent that the sun, the great source of light and heat, had little to do

with chemical results in nature, the remark of this philosopher when it was made was considered extravagant, and his light-pictures were looked upon by his friends as mere pleasant curiosities, there is at the present time every day more and more realization among chemists of the great truth which he uttered. The solar ray is now regarded as one of the grand chemical powers of our earth.

390. **Chemical Influence of Light on Vegetables.**—Light produces chemical results in all of the three kingdoms of nature, but they are perhaps the most observable in the vegetable world. The green coloring substance called *chlorophyll*, which, appearing in the leaves and other parts of plants, makes the general face of nature so pleasant to the eye, is entirely dependent upon the stimulus of light, as may be seen in many common facts. The sprouts of vegetables in our cellars, for example, are destitute of this coloring substance exactly in proportion to the exclusion of light. This explains the deep green of leaves in tropical countries, where "the sun shines forever unchangeably bright." Light has the same influence upon other colors, and hence the rich deep colors of tropical fruits and flowers, and the subdued tints of those of colder regions. But the stimulus of light not only acts thus upon the colors of vegetables, but it is absolutely essential to the formation of their substance. That chemistry of the leaves which, as you learned in § 128, furnishes to plants from the air so large a part of their carbon, can not go on without the influence of light. Indeed, as stated in § 129, the leaves rest from this chemical work, this laying in of carbon, when the light is withdrawn at night.

391. **Light and Locomotives.**—It was in relation to the influence of light upon vegetable growth that George Stephenson, the great inventor of locomotives, said that light was the power that moved them. The conversation in

which he said this is thus related: Mr. Stephenson asked the late Dean Buckland, "Can you tell me what is the power that is driving that train?" alluding to a train which happened to be passing at the moment. The learned dean answered, "I suppose it is one of your big engines."—"But what drives the engine?"—"Oh, very likely a canny Newcastle driver."—"What do you say to the light of the sun?"—"How can that be?" asked Buckland.—"It is nothing else," said Stephenson. "It is light bottled up for tens of thousands of years; light absorbed by plants and vegetables, being necessary for the condensation of carbon during the process of their growth, if it be not carbon in another form; and now, after being buried in the earth for long ages in fields of coal, that latent light is again brought forth and liberated, made to work—as in that locomotive—for great human purposes."

392. **Chemical Influence of Light on Animals.**—The influence of light upon color is very much the same in animals as in vegetables. Accordingly, the plumage of birds in tropical climates presents the richest hues, while the prevailing color in the colder regions is a russet brown. So, also, those fishes that swim near the surface have various and rich colors, while those that live in deep water are gray or brown or black. Those that live at so great a depth that very little light reaches them are nearly colorless. It is pretty well ascertained that at depths where no light can penetrate there are no fishes or other animals of a high order, showing how dependent animal life is upon light. The influence of light upon life and health has attracted considerable attention of late; and, although some extravagant things have been said about it by superficial enthusiasts, there is no doubt that it is an influence which should be seriously taken into the account in the arrangement of our houses and workshops, and in the formation of our habits of living.

393. **Light Dissected.**—Light that does all this is not one thing; but in every ray, besides the seven colors which, blended together, make the white light, there are two distinct powers—heat and chemical power. The dissection of light effected by the prism is depicted in Fig. 102. We have in Part I. described the manner in which this spectrum, so called, is made, and commented upon the colors that compose white light, and we need to say no more here on these points. The chemical power is what concerns us now. This is greatest at the violet end of the spectrum, diminishing as you go from there toward the other end. The greatest heat, on the other hand, is at the red end. We have, then, bound up in every ray of light that comes from the sun three powers—viz., light, heat, and chemical power. This last has been called *actinism*, or the actinic power. The reason that these three powers can be partially separated in the spectrum, as well as the different colors, is that different parts of the ray are differently refrangible—the calorific part the least, the actinic part the most, and the illuminating part between the two. Then of the colors, the least refrangible is the red, the most so the violet. You observe that we speak of the separation of

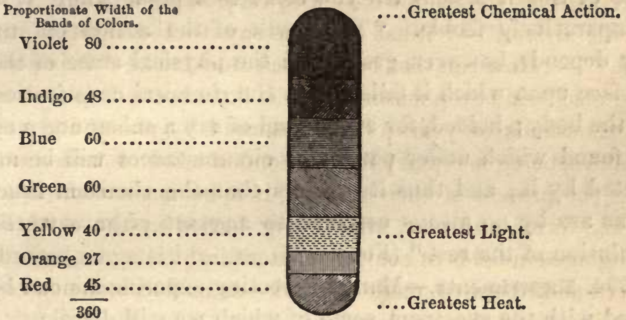


Fig. 102.

the three forces or powers in the spectrum as being partial. We will explain this. As the ray of light is bent out of its course by the prism, and the spectrum is formed on the screen, each of the three powers has a point in the spectrum where its influence is most concentrated. On each side of this it lessens till you come to a point where it is comparatively feeble. "The result of the action of any ray depends, however, greatly on the physical state of the surface upon which it falls and in the chemical constitution of the body; indeed, for every kind of ray a substance may be found which under particular circumstances will be affected by it; and thus it appears that the chemical functions are by no means confined to any set of rays to the exclusion of the rest" (Fownes).

394. **Experiments.**—Many interesting experiments can be tried with the spectrum, some of which we will detail:

Brush over some paper with a solution of nitrate of silver, and then expose strips of it to different parts of the spectrum. A strip applied at the lower part where the red color or ray is will be scarcely affected, for the chemical rays there have little or no power to affect this substance. A strip at the violet end, on the other hand, will be darkened quite rapidly, because there is the centre of the influence of this power. So, also, a strip in the green ray will not be affected so much as one in the blue, because the latter is nearer to that centre.

Paper charged with chloride of silver is still more sensitive to light than that charged with the nitrate, and therefore gives more decisive results. It may be charged in the following manner: The paper is first wet in a solution of common salt or chloride of sodium. Then it is brushed over with a solution of nitrate of silver. This decomposes the salt, leaving on the paper chloride of silver in place of the chloride of sodium:

$$\overset{\text{Chloride of sodium.}}{NaCl} + \overset{\text{Nitrate of silver.}}{AgNO_3} = \overset{\text{Chloride of silver.}}{AgCl} + \overset{\text{Nitrate of sodium.}}{NaNO_3}$$

Strips of paper thus prepared, placed in parts of the spectrum where the chemical power resides, will be darkened, because the chloride of silver is decomposed, the chlorine passing off and leaving the silver attached to the fibres of the paper. It is to be remembered in preparing these papers that exposure to the light has the same effect upon them that placing them in the chemical limits of the spectrum does, for every ray of white light has the chemical power bound up in it. For this reason the papers must be prepared in a dark room, and, after being dried by blotting-paper, must be put between the leaves of a book to prevent the light from coming to them.

Some other experiments akin to these may be tried with colored glasses. Glass stained dark blue with oxide of cobalt lets scarcely any light pass through, but offers no hinderance to the passage of actinism, as may be seen by using the papers charged with chloride of silver. Yellow glass, on the other hand, will let the light and heat pass, but not the actinism. You remember that a mixture of hydrogen and chlorine exposed to the direct light of the sun explodes, so rapid is their union, while they do not unite at all if the mixture be kept in the dark. Now when the mixture of the two gases is exposed to the sun in a vessel or tube of red glass scarcely any effect is produced; but if it be exposed in a tube of violet-colored glass the gases combine rapidly with an explosion, just as they do when the glass is without color.

395. **Light-Pictures.**—If lace be spread over paper charged with chloride of silver, on exposure to light for a few minutes its whole shape, to the minutest thread, will be traced in white lines. The explanation is this: The chemical

power of the sunlight acts upon the chloride of silver, darkening it, except where the threads of the lace prevent it from doing so. The tracings of the lace consist, then, of the chloride of silver unchanged; while in the dark parts there is metallic silver minutely divided. In the same way skeletons of leaves, or even the leaves themselves, may be copied. So, also, we may copy engravings, if we oil them so that the light may shine through the unprinted portions. The dark parts of the engraving will of course be light, and the light parts dark in the copy. This constitutes what is called a "negative;" and a "positive" or true copy can be obtained by dealing with the "negative" as you do at first with the engraving itself. In Fig. 103 you have represented a "negative" of a leaf, the darkest parts of the picture corresponding to the thinnest parts of the leaf, as the light coming through them decomposes the

Fig. 103.

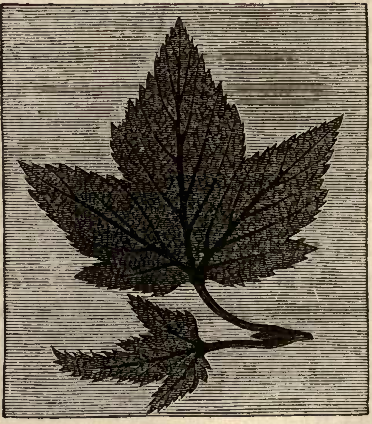


Fig. 104.

chloride of silver. In Fig. 104 (p. 280) you have the "positive" of the same leaf.

396. **Fixing the Picture.**—The figures of which we have spoken can not be permanent, for exposure to light will destroy them by making the whole surface equally dark. To verify this, take a copy of lace and hold it up to a window. The white lines of the tracery will disappear quickly, the whole surface being subjected to the chemical power of the light, and becoming therefore covered with the dark silver. This effect, however, will not occur if the window be covered with a heavy yellow curtain, for this will not allow the chemical power to pass through. Now if after a picture is made we could by means of any substance remove from it all the chloride of silver, and at the same time leave the metallic silver untouched, we should have a picture which the light can not affect. Such a substance we have in sodium hyposulphite. This dissolves out the undecomposed chloride of silver, but produces little or no effect upon the metallic silver which constitutes the parts of a "positive" picture.

397. **Photography.**—We have given you a brief outline of the principles on which the beautiful art of photography is based. To pursue this interesting subject any farther will lead us too deeply into this important branch of Applied Chemistry.

QUESTIONS.

388. Give some examples of the chemical influence of light.—389. What is said of the universality of its influence?—390. State in full what is said of its influence on vegetables.—391. Give the anecdote of George Stephenson.—392. State in full what is said of the influence of light on animals.—393. What three powers are there in the sun's rays? Show how these are arranged in the spectrum. Why can they be thus partially separated? What is actinism? Where in the spectrum is the point of greatest light?

Where the centre of actinic power? Where the point of greatest heat?—394. State the experiments with paper charged with nitrate of silver. How can you charge paper with chloride of silver? What is said of the effect of light upon it? What experiments can be tried with variously colored glasses?—395. State in full what is represented in Figs. 103 and 104.—396. What is said of "fixing" the picture obtained with the chloride of silver?

CHAPTER XXII.

SPECTRUM ANALYSIS.

398. **Continuous Spectra.**—You have learned in Part I. that when light from the sun passes through a prism it is separated into its different colors, because rays of different colors are unequally refracted. The first band in the figure on p. 287 represents roughly the spectrum thus obtained.

Suppose light from other sources than the sun is thus analyzed by a prism, what are the results? Briefly, the results vary according to the nature of the light emitted; how this is we will now explain to you. In the first place, the emission of light is a question of temperature; any solid body heated high enough emits light. Now it is found that all solid bodies heated to incandescence—that is, until they glow with light—produce spectra resembling in the main that of the sun, at least so far as the nature and order of the colors are concerned. For example, a glowing platinum wire, a candle, and a gas flame give the same sort of spectrum, uninterrupted in the shading of its colors and containing them all. Such spectra are termed *continuous.*

399. **Discontinuous Spectra.**—There is another kind of spectrum called discontinuous or broken. These are produced by *glowing gases.* You have already learned that

some chemical substances burn with colored flames; potassium with a violet flame, and sodium with a yellow flame, as seen when burning on water, or when common salt is thrown into a fire. Then, again, strontium compounds burn with a beautiful red flame, and barium with a green flame, so that they are used in making fireworks.

Now in all these cases the flames are colored by the bodies named in the state of *gases.*

If you examine the light from burning sodium by means of a prism—that is, allow the light from incandescent sodium vapor to pass through a prism—you will obtain a discontinuous or broken spectrum: only one color will be seen, viz., yellow, and this yellow color will fall at the same point in the spectrum that the yellow rays of the sun spectrum would strike. It appears, then, that sodium vapor heated red-hot gives out rays of a particular refrangibility; now this illustrates a well-defined law: That every chemical element in the *state of gas*, when heated until it becomes luminous, gives off a peculiar light. In the example taken, light of all one color was given out by the substance heated; this is not the rule, however, but rather exceptional, for most bodies emit light of various kinds, possessing different degrees of refrangibility; thus the light from glowing strontium vapor analyzed by a prism gives a spectrum made up of several yellow and red rays, together with one blue one.

400. **Use of the Slit.**—The appearance of a continuous spectrum, obtained from light of any source, depends much upon the size and shape of the opening through which the light passes before passing through the prism. If a round opening be used, a series of disks will be seen overlapping each other, as shown in Fig. 105 (p. 284). If an opening having parallel sides be employed, the different colors will shade off into each other imperceptibly,

the brightest light appearing in the centre of the yellow portion. By making an opening of this shape very narrow, there is less overlapping of the different colors, and a purer spectrum is obtained. A very narrow opening with parallel sides, called a slit, is generally employed in examining the spectra of different bodies; and in the case of discontinuous or broken spectra, the *colored image* of the slit is what produces the *banded* appearance of such spectra. A narrow ray of yellow light produces a yellow band of light in the spectrum, a red or a blue bundle of rays produce a red or a blue *line* or *band* in the spectrum. This is shown in Fig. 105.

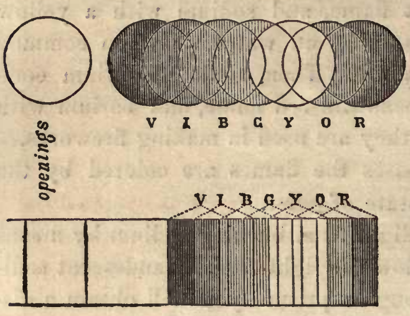


Fig. 105.

401. **The Spectroscope.**—This is the name of the instrument employed for thus analyzing the light emitted from different sources. A brief description of Fig. 106 (p. 285) will suffice. A spectroscope consists essentially of a prism, a telescope, and a slit. In the figure before you the prism, A, is placed on a plate of metal supported by a tripod, the telescope is at B, and the slit is attached to the tube C, which contains also a lens at the end next to the prism. The substance to be examined, held on a platinum wire supported by the stand *f*, is heated in the non-illuminating flame of a Bunsen burner, *l*—the cone, *n*, at the top of the burner serving simply to steady the flame. The light passes from the flame, *l*, through the slit at the end of the tube C into this tube; the rays are made parallel by the lens in this tube before they fall upon the prism, A. The

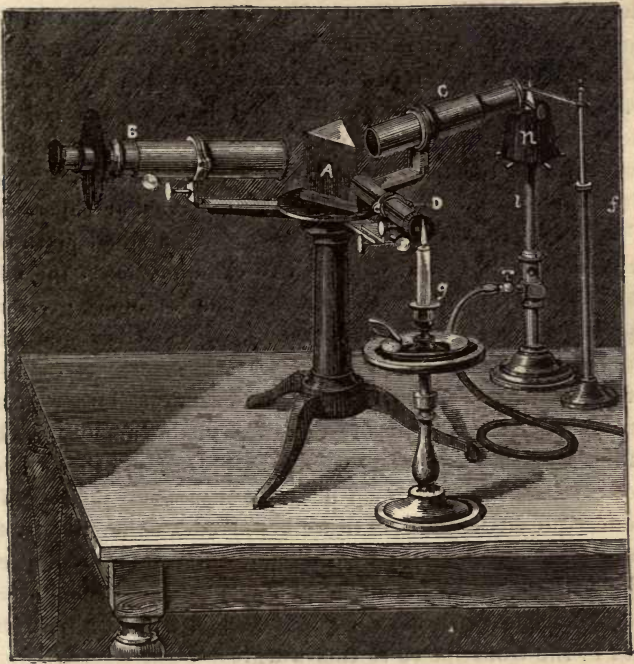


Fig. 106.—The Spectroscope.

rays are then refracted, and the image of the refracted rays is observed through the telescope, B. In the instrument here pictured, a third tube, D, contains a scale engraved on a glass plate, and this being illuminated by the candle flame, *g*, can be seen at the same time with the spectrum; one face of the prism *reflecting* this scale through the telescope, B, to the observer.

402. **Spectrum Analysis.**—The spectroscope, invented in 1859 by two distinguished Germans, a chemist (Bunsen) and a physicist (Kirchhoff), is of great importance to the chemist, for it places in his hands a means for detecting certain substances with great accuracy and extraordinary

delicacy. It follows from what we have told you in the preceding sections that any chemical substance capable of being converted into an incandescent vapor by the heat of a Bunsen burner must give out light of a particular degree of refrangibility; and consequently any one looking through the telescope, B, will see a pictorial image in brilliant colors characteristic of that particular substance. Practically this is done as follows: Dip a small platinum wire into the material you wish to examine, insert the substance into the flame (which, being non-luminous, gives no spectrum), and place your eye at B. Now it is found that only a certain number of chemical substances are capable of being volatilized in the heat of a Bunsen burner or of an alcohol lamp; these are the salts of the alkalies, many of the salts of the alkaline earths, besides some other bodies not classifiable; or, stating it differently, spectrum analysis, under the circumstances described, enables the chemist to detect sodium potassium (lithium, cæsium, rubidium), calcium, strontium, barium, copper, boracic acid, and some other bodies. The spectra seen are shown in Fig. 107 (p. 287), and in the frontispiece to this work.

The first band represents the spectrum of the sun, the vertical black lines in which you may for the present disregard.

Sodium gives a single yellow line or band, occurring at *a* on the scale; potassium gives a red line at the right end of the spectrum, a blue one at the extreme left, and a long luminous band between. Barium gives a large number of lines and bands, several red, orange, yellow, and four very bright green ones. These lines and bands always occur at the same point on the scale of the same spectroscope; the scales of various instruments vary, but the positions of lines can be compared by preparing maps of the various spectra referred to a constant scale. Thus

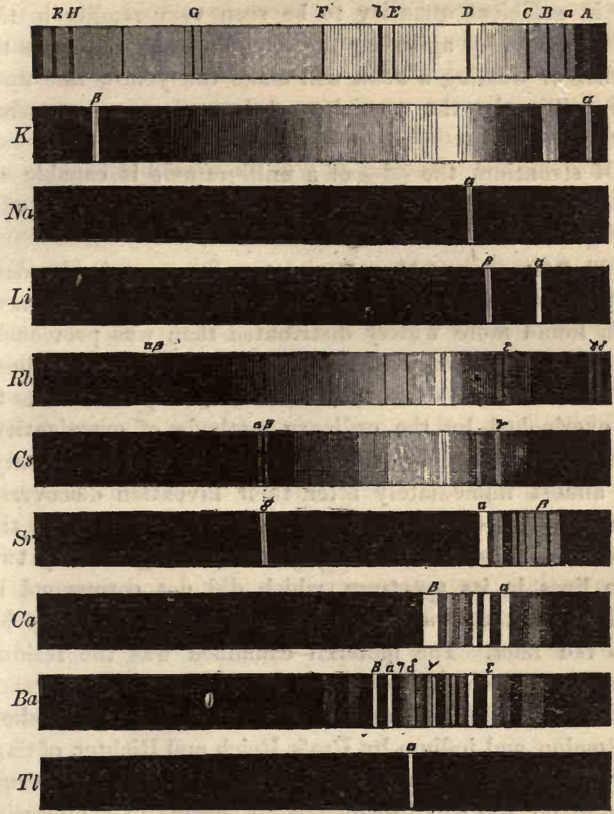


Fig. 107.

you see the accuracy of the analysis is all that can be desired.

We have referred to the delicacy of this method of analysis. This delicacy varies with different substances; of sodium, the one three-millionth of a milligramme ($\frac{1}{3,000,000,000}$ gramme) can easily be detected. Sodium in some shape, combined with chlorine chiefly, is always present in the air in sufficient quantity to be seen very readily in the spectroscope by agitating the air; clapping the hands together or dusting a book will make the yellow line flash out brilliantly, the particles of dust always containing salt.

Of strontium, the $\frac{6}{100,000}$ of a milligramme is capable of detection; of calcium the same; of lithium, the $\frac{1}{100,000}$ of a milligramme.

403. **Discovery of New Elements.**—So great is the delicacy of spectrum analysis that many known elements have been found more widely distributed than was previously supposed, and four new elementary substances have been discovered which existed in such minute quantities as to be overlooked by the ordinary methods of examination. Bunsen and Kirchhoff, the discoverers of spectrum analysis, almost immediately after their invention discovered two elements, cæsium and rubidium, which belong to the class of alkaline metals. Cæsium was recognized by two blue lines in its spectrum, which did not correspond in position to the blue line of strontium, and rubidium by two red lines. The material examined was the residue from the evaporation of certain mineral waters.

Since then thallium has been discovered by Prof. Crookes, of London, and indium by Profs. Reich and Richter, of Saxony. These bodies are mere chemical curiosities, occurring in far too small quantities to become of commercial value unless some unexpected and rich source is awaiting discovery. In the chapters on metals we have barely alluded to them by name.

404. **Spectra of the Heavy Metals.**—The heavy metals and their salts as a rule do not give spectra when heated in the non-illuminating flame of a Bunsen burner, but this is only because the temperature is not high enough to volatilize them. To obtain spectra of these substances, there-

fore, a strong current of electricity is used, excited by a powerful galvanic battery, and the material heated in the electric arc is converted into incandescent vapor, and thus yields a spectrum. Maps have been made showing the thousands of lines which are seen in the spectra of nearly all the elements. The apparatus is difficult to manage and very expensive, so for ordinary work the chemist depends upon the Bunsen burner or alcohol lamp, and confines his research to the lighter metals.

405. **Celestial Spectroscopy.**—We have not previously referred to certain peculiarities in the sun's spectrum, because we did not want to tell you too many things at once. If you examine the sun's spectrum with a good spectroscope having a narrow slit, you will see fine black lines crossing the spectrum. These were observed many years ago by Fraunhofer, a German optician, but no attempt was made to explain them until after the perfection of the spectroscope by Kirchhoff. For good and sufficient reasons, which we can not explain to you in this book, it is believed that those black lines give us indications of the elementary bodies burning in the sun. A careful study of these lines by many eminent men has led to a remarkably accurate knowledge of the constitution of the sun. Thus, wonderful as it may appear, we have good reason for believing that the sun contains sodium, calcium, magnesium, iron, copper, zinc, hydrogen, and many other metals; and that the sun does not contain gold, silver, mercury, potassium, lead, arsenic, or platinum. More perfect instruments may eventually remove some element from this last list and place it among the bodies known to exist in the sun. Not only have astronomers, thus aided by the chemist, examined the light of the sun, but they have studied the fixed stars, the nebulæ, and comets, thus developing a special branch of spectrum analysis called *celestial spectro-*

scopy. A description of the methods employed, the instruments used, and the results obtained would be interesting, but must be passed by in the present work.

QUESTIONS.

398. Do lights from other sources than the sun yield spectra? Upon what does the emission of light depend? Give examples. What are continuous spectra?—399. What produces discontinuous spectra? What bodies color flames? What kind of a spectrum does sodium give? What strontium?—400. Explain the use of a narrow opening for the passage of light. What produces the banded appearance of discontinuous spectra?—401. Describe and explain the spectroscope. How does the light pass?—402. Who invented this instrument? When? How is it made practical? What can be detected by it at the temperature of a Bunsen burner? What kind of a spectrum does barium yield? What is said of the delicacy of this instrument?—403. What elements were discovered by Bunsen and Kirchhoff? How? From what source? What other elements have been discovered by this means?—404. How can spectra of heavy metals be obtained?—405. State in full what is said of celestial spectroscopy.

CHAPTER XXIII.

ORGANIC CHEMISTRY.

406. **Introduction.**—Formerly the term Organic Chemistry was applied to that branch of chemistry treating of substances which derived their existence from the operations of either vegetable or animal life; it was erroneously supposed that the production of these substances was due to a mysterious power, called *vital force*, residing in the organs of plants and animals, and that this class of substances could not be artificially formed. Under this view organic chemistry was considered as the Chemistry of Life.

Within from twenty to thirty years, however, many substances have been made in the chemist's laboratory which were formerly regarded as solely the products of the agency of life, and consequently the theory of a special vital force governing the attractions of matter in plants and animals has been gradually abandoned. Urea (a constituent of urine), alcohol, acetic acid, alizarine (a beautiful dye-stuff), and indigo, are some of these organic bodies which have been *synthetically* prepared—that is, by a *putting together* of so-called inorganic materials.

The branch of chemistry you have been studying is sometimes called Inorganic, because opposed to Organic Chemistry; another and very suitable name is Mineral Chemistry, since it concerns chiefly mineral substances. This division into Mineral and Organic Chemistry is, however, a mere matter of convenience, and not countenanced by Nature. The same elements compose the bodies and substances existing in the three kingdoms—mineral, vegetable, and animal; and the same laws of attraction hold these elements together, and govern their combinations.

Certain organic substances do, indeed, differ radically in their nature and formation from mineral bodies, exhibiting a fibrous and cellular structure, and forming parts of organs peculiarly the product of life; these are termed *organized bodies*, and must not be confounded with organic bodies. As an example of this difference take the case of a fruit; the fibrous, cellular, pulpy matter forming the woody framework of the fruit is an *organized* body; but the acids, the sugar, the gum, the starch, the coloring matter, etc., contained in these living organs are *organic* bodies. Whether the chemist will ever be able to imitate organized structure is exceedingly problematical. The distinguishing power between organic and organized bodies lies in the microscope.

407. **Constituents of Organic Substances.**—We have stated

that organic bodies are composed of the same elements as mineral bodies, and while this is perfectly true, the statement must be qualified. The number of elements which enter into the composition of organic bodies is comparatively small. You remember there are sixty-three elementary substances at present known to the chemist: now of these four build up nearly the whole of the innumerable organic bodies; these four are carbon, hydrogen, oxygen, and nitrogen.

Some of the other elements occur, it is true, but to a comparatively limited extent. Thus we have calcium and phosphorus in the bones, iron in the blood, silicon in the stalks of grains and grasses, and various other elements in very small quantities for various purposes. The four grand elements—C, H, O, and N—we have learned about in studying mineral chemistry; one of them, you observe, is a solid, while the other three are gases. They are all without taste or smell, and the solid element is in its ordinary form of a dark color; and yet from these few materials what an endless variety in taste, smell, color, and other properties is produced in the vegetable and animal world!

Let us not be understood to say that other elements besides the four—C, H, O, and N—are of little importance. They are not only of use in their place, but they are essential, some of them as much so within a certain range as the grand elements.

408. **Sources of the Elements in Organized Substances.**—The elements of which vegetable and animal substances are composed come from three sources — earth, air, and water. In the case of the plant they enter by the root and the leaves. By the root, with its millions of little mouths, they are drunk up dissolved in water, and in the sap they flow upward to the leaves, where carbon is added from the air. It is in the leaves that the sap, the build-

ing material of the plant, is completed, so as to be fit for use in constructing all the various parts—the wood, the bark, the flowers, the fruit, etc. Animals, also, receive their elements in part from the earth, but not in a direct manner. They receive them from the plants which they eat. The plant, then, gathers up, as we may say, the elements from the earth for the use of the animal. They are combined together in the blood, which is to the animal what the sap is to the plant—the common building material of the body. But as in the case of the plant, so with the animal, all is not derived from the earth. A part of the oxygen needed comes from the air, being admitted by the pores of the lungs, as part of the carbon of the plant goes into it by the pores of the leaves. It is believed that the leaves of plants decompose the carbonic acid that comes to them from the lungs of animals, separating it into its elements, carbon and oxygen, and that the carbon is absorbed to make a part of the plant, while the oxygen thus set free again returns to the lungs of animals. Every leaf, therefore, is a laboratory to purify the air, and maintain its proper supply of oxygen for the use of the animal kingdom.

409. **Subservience of Plants to Animals.**—You see, then, that the subservience of plants to animals is twofold. First, they supply to animals the elements of their growth by gathering them from earth, air, and water into their own substance. This subservience is direct in the case of herbivorous animals. It is no less real, though indirect, in the case of the carnivorous, for they eat the flesh of the herbivorous. Secondly, plants, by their chemical action upon the air, keep up that supply of oxygen which is needed by animals.

410. **Difference of Vegetable and Animal Structures in Composition.**—In this subservience of plants to animals there is one very interesting fact to be noted in regard to

the difference in their composition. All the four grand elements—carbon, hydrogen, oxygen, and nitrogen—enter into the structure of animals, but only the first three are found in the structure of vegetables. The inquiry then arises in what way the nitrogen is supplied to animals. Nitrogen constitutes four fifths of the air which is so constantly entering their lungs, and yet not a particle of it is supplied to their bodies in this way. The blood in the lungs receives oxygen from the air, but no nitrogen, as you learned in § 132. The nitrogen which is needed is supplied through the agency of plants. For this purpose, though there is none of this element in their structure, many of them have it in their juices and fruits. It is especially present in Indian corn, the grains, pease, beans, etc., so extensively used for food. In such cases the plant may be said to gather up this element, and deposit it, not in its own structure, for it is not wanted there, but in repositories, where man and other animals can take it and appropriate it to their use. There is no case in which the design of the Creator is manifested in a more marked manner than it is here.

411. **Definition of Organic Chemistry.**—Of the four elements—C, H, O, and N—playing such a wonderful part in the vegetable and animal kingdoms, the first of these, carbon, is by far the most important, its presence being characteristic of organic substances. Hence organic chemistry is often defined as the *Chemistry of Carbon Compounds.* This definition includes the simple carbon compounds, carbonic oxide, carbonic anhydride, and others which we have just studied under the head of mineral chemistry; but it is impossible to draw any precise line of distinction, especially since the same elements and laws of union are common to the two divisions. Organic bodies are characterized by great complexity and instability of the molecules.

412. **Molecules in Organic Bodies.**—Organic substances are generally more complex in their constitution than mineral substances, their molecules containing a far larger number of atoms. For example, while carbonic anhydride has in each molecule one atom of carbon and two of oxygen, CO_2, and sulphuric acid two of hydrogen, one of sulphur, and four of oxygen, H_2SO_4, making 7 atoms in the molecule, each molecule of tartaric acid contains 16 atoms, as indicated in the formula $H_2C_4H_4O_6$; while a molecule of starch is believed to contain 63 atoms (starch $= C_{18}H_{30}O_{15}$), and of stearin 173 atoms.

One of the most complex of organic bodies is albumen, which is supposed to contain several hundred atoms in a molecule; but this number will probably be reduced when its composition is better understood.

413. **Instability.**—Organic substances are unstable compounds, that is, very easy to decompose, because they are so complex. It is with them as it is with machinery. The greater the complication, the greater is the liability to derangement. The more atoms there are in a molecule, therefore, the more easily can it be broken up, and the more kinds of atoms there are in it the greater is the liability to this result. Not only do organic substances differ from the inorganic in this respect, but they differ among themselves. We have a good example of this in bleaching. The coloring matter of the cloth is broken up and dissipated, while the cloth itself remains, for the simple reason that the molecule of the coloring matter is composed of four elements—carbon, hydrogen, oxygen, and nitrogen—while that of the vegetable tissue, the substance of the cloth, is composed of only three—carbon, hydrogen, and oxygen. The more complex substance is decomposed first; but if the process be continued after the cloth has become white—that is, after the coloring substance is all destroyed

—the vegetable tissue will be attacked, and the cloth will become more or less rotten from the destruction of some of its molecules.

414. **Difference in Properties with Similarity of Composition.**—There is often found in organic chemistry great similarity of composition with wide difference in properties. We will give a few examples. Alcohol, cotton, sugar, and acetic acid are four substances certainly not much alike in their properties, and yet these widely dissimilar bodies are made of the same elements—carbon, hydrogen, and oxygen. By examining the formulæ of these bodies, here given,

Alcohol	C_2H_6O	Grape sugar	$C_6H_{12}O_6$
Cotton	$C_6H_{10}O_5$	Acetic acid	$C_2H_4O_2$

you will see that these three elements are combined in very different proportions; and this illustrates as well the complexity of the molecules referred to in § 412, for each of the formulæ above represents one molecule. We have selected only four bodies made of these three elements, but actually there are many thousands of bodies composed of these three elements only.

415. **Isomerism.**—Strange and mysterious as these facts appear, a much more apparently inexplicable feature remains to be shown. Examine closely the formulæ of the last two bodies named, grape sugar and acetic acid; you see that if we should multiply by three the little figures, or co-efficients, of the atoms of C, H, and O in acetic acid, we will get the formula of grape sugar; thus:

$$\begin{array}{lcr} \text{Acetic acid} & = & C_2H_4O_2 \\ & & \cdot\ 3 \\ \hline \text{Grape sugar} & = & C_6H_{12}O_6 \end{array}$$

Here, then, we have two bodies made up of the same elements in the same proportion, and differing only in their molecular weights, and yet how different in their properties! One is sweet, crystalline, capable of fermenting, neutral to litmus paper, being neither an acid, a base, nor a salt; the other is sour, liquid at ordinary temperatures, and capable of combining with bases to form a large series of salts.

We have said these bodies differ in their molecular weights; we will explain why this is. You learned in § 30 that the molecular weight of a body is equal to the sum of its atomic weights; hence we calculate thus:

	Acetic acid.	Grape Sugar.
C = 12;	$C_2 = 24$	$C_6 = 72$
H = 1;	$H_4 = 4$	$H_{12} = 12$
O = 16;	$O_2 = 32$	$O_6 = 96$
	Molecular weight = 60	Molecular weight = 180

Substances which thus have the same chemical constitution, and yet are dissimilar in their qualities, are called *isomeric* substances, this term coming from two Greek words, *isos*, equal, and *meros*, part.

Isomeric substances may even have the same molecular weight; they are then said to be *metameric*.

Thus the molecular formula $C_3H_6O_2$ represents three different bodies possessing different properties and different constitutions; how this can be is shown in the following formulæ:

$C_3H_6O_2$ may be arranged thus: $C_3H_5O.HO$—which is Propionic Acid.
" " " " $C_2H_3O.CH_3O$ " Methyl Acetate.
" " " " $CHO.C_2H_5O$ " Ethyl Formate.

It is not necessary to know the nature of these bodies—their names show you that they are essentially distinct. One, you observe, is an acid, the other two are compound ethers belonging to the class described in § 423.

416. **Explanation of Isomerism.**—The explanation which the atomic theory affords of this isomeric state is illustrated by Stöckhardt by the various grouping of white and black squares which can be made on a chess-board, as seen in

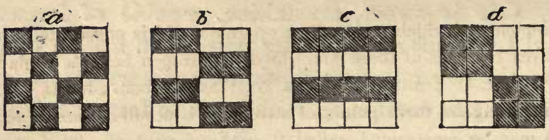


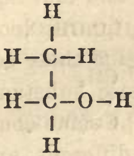
Fig. 108.

Fig. 108. Here each figure is composed of eight white and eight black squares; but though the number is the same in all, the grouping is different. In *a* one and one, in *b* two and two, in *c* and *d* four and four squares are so joined together as to make the figures look very different from each other. If we imagine these squares to be atoms we obtain an idea of isomeric substances, and can see how there may be bodies of the same constitution and form, yet presenting an entirely different appearance, and having very different properties.

Isomeric bodies are far more numerous in organic than in mineral chemistry, because the molecules of organic substances are more complex than those of inorganic; for the difference in properties can not be owing to any thing else than a difference in arrangement of the atoms, and the more atoms there are in a molecule obviously the greater is the range afforded for differences in arrangement. This may be illustrated by reference to Fig. 108. Each of the squares contains eight small black squares, and eight white ones, sixteen in all. It is obvious that more and greater changes in arrangement can be made here than there could be if the number of small squares were less—four, for example; and so, also, more differences in arrangement can be had in a molecule if it be composed of sixteen atoms than there can be if there be only four atoms in it.

417. **Graphic Formulæ.**—Another method of explaining isomerism makes use of so-called *graphic formulæ*. You learned in § 44 that the elements differ in atom-fixing power, and that they are divided into groups, monads, dyads, triads, tetrads, etc., according to this power. The four

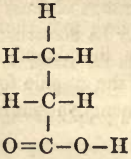
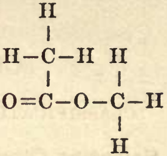
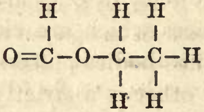
grand elements of which most of the organic world is constituted are representatives or types of these four classes, hydrogen being a monad, H'; oxygen a dyad, O''; nitrogen a triad, N'''; and carbon a tetrad, C^{iv}. By taking advantage of these points of attraction, a peculiar kind of pictorial formulæ may be constructed, called "graphic formulæ." Thus the ordinary formula for water is H_2O; but if we represent the dyad oxygen by $-O-$, and the monad hydrogen by $H-$, we have by combining them $H-O-H$, a graphic formula for water. Take a more complex example, from organic chemistry. Alcohol has the formula $C_2H_5.HO$, graphically represented thus:



$$\begin{array}{ccccccc} & & H & & & & \\ & & | & & & & \\ H & - & C & - & H & & \\ & & | & & & & \\ H & - & C & - & O & - & H \\ & & | & & & & \\ & & H & & & & \end{array}$$

$-\overset{|}{\underset{|}{C}}-$ being a tetrad, $-O-$ a dyad, and the rest monad hydrogen, each *bond of affinity* is satisfied by arranging the atoms in this manner. Now you will see how graphic formulæ help to explain metamerism, the highest kind of isomerism. Take the three bodies which have already served us as examples. On the following page you have the ordinary formulæ, the constitutional formulæ, and the graphic formulæ side by side, showing how differently the atoms are arranged in the molecules of each body. We can not explain to you how chemists are able to arrive at any probable knowledge of the arrangement of atoms in the interior of a molecule, for the subject belongs to the highest branch of chemical philosophy. Of late years the most wonderful progress has been made in precisely this field, and indeed the whole aim of modern investigators is directed to this study of internal atomic structure.

GRAPHIC EXPLANATION OF ISOMERISM.

Substances.		Constitutional Formulæ.	Graphic Formulæ.
Propionic Acid	have the same composition, $C_3H_6O_2$, which may be resolved thus:	$C_3H_5O.HO$, *or* CH_3 | CH_2 | COOH	
Methyl Acetate		$C_2H_3O.CH_3O$, *or* CH_3 | $CO(OCH_3)$	
Ethyl Formate		$CHO.C_2H_5O$, *or* H | $CO(OC_2H_5)$	

QUESTIONS.

406. Explain the change of views which has taken place with reference to organic substances. What examples of synthesis are given? What is said of the division into mineral and organic chemistry? What are organized bodies? How do they differ from organic bodies? Give examples.—407. What are the four chief constituents of organic bodies? What others occur also?—408. What is said of the sources of the elements in organized bodies? Show how leaves purify the air for animal life.—409. Show that the subservience of plants to animals is twofold.—410. How is nitrogen furnished to animals?—411. Give a definition of organic chemistry. Explain it.—412. Show that the molecules of organic bodies are complex in constitution. How many atoms in a molecule of tartaric acid? Of starch? Of stearine?—413. What is said as to the instability of organic substances? Give an example from bleaching.—414. Of what three

elements are cotton, alcohol, sugar, and acetic acid composed? How do you account for the difference in their properties?—415. Show what is meant by isomerism. Take acetic acid and grape sugar as examples. When are substances metameric? Give examples.—416. Explain isomerism by reference to a chess-board. Why is isomerism more common in organic than in mineral chemistry?—417. What are graphic formulæ? Illustrate by the graphic formula of water. Explain it. What is said of the arrangement of atoms in the molecule? Explain the table on page 300.

CHAPTER XXIV.

CLASSIFICATION OF ORGANIC SUBSTANCES.

418. **Scientific Classification.**—Two methods of classifying organic bodies for the convenience of study may be followed; in one an empirical arrangement connects substances which are closely related in nature, and treats in groups bodies possessing similarity of origin or properties; the other is a strictly scientific classification based on the atomicity of the tetrad carbon. In this work we will follow the former arrangement, prefixing it, however, with a brief synopsis of the scientific method, in order to introduce to you a number of bodies which would otherwise find no place in the so-called natural system. Scientifically considered, organic bodies may be classified as follows:

I. Hydrocarbons.
II. Alcohols.
III. Ethers.
IV. Aldehydes (and Ketones).
V. Acids (and Anhydrides).
VI. Amines (including Alkaloids).
VII. Organo-metallic Compounds.

This is a greatly abbreviated scheme, and does not include many bodies produced in the living organism, the chemical relations of which are not yet well enough understood to bring them within a scientific system: such are gelatin, albumen, vegetable resins, and other compounds formed in the bodies of plants and animals.

We will now review briefly the chemical relations of the above-named groups, reserving details until we meet with them again farther on.

419. **Hydrocarbons.**—You have already become somewhat familiar with two important hydrocarbons in the first part of this work — marsh gas, CH_4, and olefiant gas, C_2H_4. But besides these there is an immense number of other bodies, solid and liquid as well as gaseous, made up solely of C and H in various proportions. No two elements are capable of combining in so many different forms as carbon and hydrogen. On page 324 you will find a table giving the names and formulæ of a large number of hydrocarbons of the so-called Marsh Gas Series, occurring in American petroleum. On examining the formulæ you will notice that in each of the two series the hydrocarbons differ by exactly CH_2; that is, each successive formula may be obtained by adding CH_2 to the preceding one; this is another and striking example of isomerism.

Besides the long series of hydrocarbons given on page 324, there are several other series differing from each other by H_2, and the members in each differing by CH_2. Thus olefiant gas, C_2H_4, belongs to a series which takes its name from this its important member. In the following table you have this series with the formulæ, and the corresponding alcohol and acid, to which we will have occasion to refer a little later. In this table olefiant gas is called *Ethylene.*

THE OLEFINES, OR ETHYLENE SERIES OF HYDROCARBONS.

NAME.	FORMULA.	BOILING POINT.	CORRESPONDING ALCOHOL.	CORRESPONDING ACID.
Methylene..	CH_2	Gas	Wood-Naphtha.....	Formic.
Ethylene...	C_2H_4	Gas	Alcohol	Acetic.
Propylene..	C_3H_6	−17.7°	Propylic...........	Propylic.
Butylene...	C_4H_8	+3	Butylic.............	Butyric.
Amylene...	C_5H_{10}	35	Amylic (Fusel-Oil)..	Valerianic.
Hexylene..	C_6H_{12}	69	Caproic............	Caproic.
Heptylene..	C_7H_{14}	95	Œnanthic..........	Œnanthic.
Octylene...	C_8H_{16}	115.5	Caprylic...........	Caprylic.
Nonylene ..	C_9H_{18}	140		Pelargonic.
Decatylene.	$C_{10}H_{20}$	160		
Cetylene...	$C_{16}H_{32}$	275	Ethal..............	Palmitic.
Cerotene...	$C_{27}H_{54}$	Solid	Cerotene...........	Cerotic.
Melissene..	$C_{30}H_{60}$	Solid	Melissene..........	Melissic.

420. **Homologues and Isologues.**—The members of a group of hydrocarbons which differ regularly by CH_2, as in this table, are said to be *homologues*, or to form a *homologous series.* Two or more *series*, on the other hand, differing from each other by H_2, are said to be *isologues*, or to form an *isologous series.* Thus the members of the Ethylene or Olefiant Gas Series are homologous among themselves, but isologous with respect to the Marsh Gas Series on page 324. Many of the hydrocarbons of such isologous series are rare bodies, mere chemical curiosities; but we will give you a table showing some of these, that you may the better understand the terms homologous and isologous, and that you may see at a glance the enormous number of compounds of hydrogen and carbon which are capable of ex-

HYDROCARBONS.

HOMOLOGUES AND ISOLOGUES AS FAR AS C_6.

PARAFFINS. C_nH_{2n+2}	OLEFINS. C_nH_{2n}	ACETYLENES. C_nH_{2n-2}	TEREBENES. C_nH_{2n-4}	BENZOL SERIES. C_nH_{2n-6}		
CH_4 Marsh gas, or Methane.	CH_2 Methylene, or Methene.					
C_2H_6 Ethyl hydride, or Ethane.	C_2H_4 Ethylene, or Ethene.	C_2H_2 Acetylene, or Ethine.				
C_3H_8 Propyl hydride, or Propane.	C_3H_6 Propylene, or Propene.	C_3H_4 Allylene, or Propine.	C_3H_2? Propone.			
C_4H_{10} Butyl hydride, or Quartane.	C_4H_8 Butylene, or Quartene.	C_4H_6 Crotonylene, or Quartine.	C_4H_4? Quartone.	C_4H_2? Quartune.		
C_5H_{12} Amyl hydride, or Quintane.	C_5H_{10} Amylene, or Quintene.	C_5H_8 Valerylene, or Quintine.	C_5H_6 Quintone.	C_5H_4? Quintune.	C_5H_2?	
C_6H_{14} Hexyl hydride, or Sextane.	C_6H_{12} Caproylene, or Sextene.	C_6H_{10} Sextine.	C_6H_8 Sextone.	C_6H_6 Benzol, or Sextune.	C_6H_4?	C_6H_2?

<·········HOMOLOGUES·········>

<·········ISOLOGUES·········>

isting. The bodies marked ? are not as yet known to chemists.

At the head of each column is placed an algebraic formula expressing the formula of the series in general terms. By making $n=1$, $n=2$, $n=3$, etc., each member of the homologous series can be obtained. Two sets of names are given: the first are in general use among chemists, and the second is a very ingenious plan proposed by Dr. A. W. Hofmann, where the vowels a, e, i, o, and u are successively used in the final syllable to indicate the position of any member of the isologous series. The Marsh Gas Series, or *Paraffin* Series, as it is called, and the Olefin Series, are of first importance, next comes the Benzol Series; of benzol itself you will learn more farther on.

421. **Substitution.**—Marsh gas, you know, is CH_4, but it may be considered as CHHHH, which is really the same thing. Each H represents one atom of hydrogen. Now certain bodies, as chlorine, bromine, cyanogen, etc. (provided they are monatomic; see § 44), may take the place of these atoms of H; or, as we say, may be *substituted*, by means of appropriate processes, for each atom of H in the compound CHHHH; this *substitution* may take place all at once or gradually, as shown below:

CHHHH or CH_4 (1)
CHHHCl or CH_3Cl (2)
CHHClCl or CH_2Cl_2 (3)
CHClClCl or $CHCl_3$ (4)
CClClClCl or CCl_4 (5)

thus giving rise to a large number of so-called substitution compounds. The bodies numbered (1), (2), (3), (4), and (5) really exist, one of them, (4), being the well-known and valuable substance chloroform. Thus you see how the theory of substitution is made use of to explain the formation of organic bodies. One more example, however, will be given.

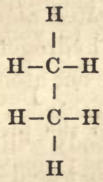
Ammonium, $(NH_4)'$, and cyanogen, $(CN)'$, you have learned, are called radicals, because they act like simple elements in certain cases. Now water is $H-O-H$; if you remove one H, you have left $-O-H$, or $(OH)'$, which acts also like a radical, taking an important part in the building up of organic bodies. This radical, called *hydroxyl*, is *monatomic*, or has one bond of affinity, as indicated above, and hence may take the place of one atom of hydrogen in any compound. Suppose, then, we substitute one atom of hydroxyl, $(HO)'$, for one atom of H in the hydrocarbon we have been studying, CHHHH, what kind of a body will result?

This question can of course be answered by experience only, and experience has taught the chemist that a body very closely resembling common alcohol is formed. Actually the substance is methylic alcohol, or $CH_3(OH)$. This leads us to the next subdivision of the scientific classification, which is that of alcohols.

422. **Alcohols.**—You are now prepared to understand the relation between alcohols and hydrocarbons; for common alcohol has become the type of a vast number of bodies, some of which resemble it in its physical properties, but many of which are crystalline solids, and have no apparent connection with it. This relation is not founded on resemblance in properties, but on similarity of constitution, which, indeed, is the key to this scheme of classification.

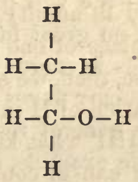
Alcohols, then, are substances derived from hydrocarbons by the substitution of one or more groups of *hydroxyl*, $(OH)'$, for hydrogen. Take the case of common alcohol: the formula of this body determined by analysis is C_2H_6O; certain facts show its relations to ethane, which is C_2H_6. Now follow carefully the following formulæ, and you will see how common alcohol is a derivative of ethane:

CCHHHHHH = ethane; remove one H and substitute one (OH), and you have CCHHHHH(OH), which is the same as $C_2H_5(OH)$ or C_2H_6O, the formula for common alcohol. This way of writing formulæ has a great disadvantage: it does not bring out the idea of atomicity, so we will repeat this explanation with *graphic formulæ.* (See § 417.)



$$\begin{array}{c} H \\ | \\ H-C-H \\ | \\ H-C-H \\ | \\ H \end{array}$$

Ethane.



$$\begin{array}{l} \quad\ H \\ \quad\ \ | \\ H-C-H \\ \quad\ \ | \\ H-C-O-H \\ \quad\ \ | \\ \quad\ H \end{array}$$

Common alcohol.

Of course it makes no difference which atom of H in the formula is replaced. This is a matter of theory solely, and is apt when thus briefly treated to leave rather crude notions, of which we must beg you to beware.

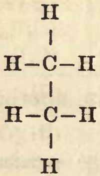
423. **Ethers.**—From what has been said it is evident that if we regard (C_2H_5) as a compound radical, alcohol may be regarded as a hydrate; this similarity to the hydrates of mineral chemistry is shown thus:

Radical..........K	Na	(NH_4)	(C_2H_5)
Hydrate.........KHO	NaHO	$(NH_4)HO$	$(C_2H_5)HO$

Alcohols may therefore be looked at in another light, viz., as hydrates of organic radicals.

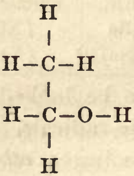
Now if alcohols are hydrates, *ethers* are *oxides.* Here again we must ask you to bear in mind that the term *ethers* is a general one, applied to a great number of bodies similar in constitution to common ether, though not at all alike in other respects. You have probably been in the habit of considering ether as a very mobile, volatile, odorous, inflammable liquid used in medicine and photography; it will therefore be difficult to conceive of ethers which are crystalline solids, some of them with a texture resembling organized bodies. And yet this is the case, the word ether having acquired a general meaning, just like oxide. Common ether, then, is oxide of *ethyl*, the name of the radical C_2H_5 just mentioned, and its formula is $(C_2H_5)_2O$, just like K_2O, or $(NH_4)_2O$.

424. **Acids.**—We will pass over aldehydes and ketones, as they are of no great importance to you. The number of organic acids is enormous. To print their names alone would require many pages of this book. But it is important to learn their general relations to the preceding bodies. Take the simple example, acetic acid; analysis shows it to be composed of $C_2H_4O_2$; now alcohol is $C_2H_5(OH)$; compare these two formulæ, and you will find one more atom of oxygen in the acid than in the alcohol, and two atoms less of hydrogen. This is the result of substitution, for one O atom, being a dyad, may replace two H atoms, being monads. This is indeed the way acids are regarded; they are derived from their corresponding alcohols by one atom of oxygen replacing two atoms of hydrogen. Let us have recourse once more to graphic formulæ:



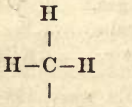
$$\begin{array}{ccccc} & & H & & \\ & & | & & \\ H & - & C & - & H \\ & & | & & \\ H & - & C & - & H \\ & & | & & \\ & & H & & \end{array}$$

or C_2H_6
Ethane.



$$\begin{array}{ccccccc} & & H & & & & \\ & & | & & & & \\ H & - & C & - & H & & \\ & & | & & & & \\ H & - & C & - & O & - & H \\ & & | & & & & \\ & & H & & & & \end{array}$$

or C_2H_6O
Alcohol.



$$\begin{array}{ccccccc} & & H & & & & \\ & & | & & & & \\ H & - & C & - & H & & \\ & & | & & & & \\ O & = & C & - & O & - & H \end{array}$$

or $C_2H_4O_2$
Acetic acid.

Observe that the two atoms of H in the lower left-hand corner of the formula of alcohol disappear in the formula of acetic acid, one atom of O taking their place, and held fast to the carbon by two strokes, signifying its diatomic power.

Now we have said that alcohols and ethers are names given to classes of bodies; this is also the case with acids. Acetic acid may be regarded as the type of one class of acids. We can not here go deeper into this abstruse subject; if you wish to learn about mono- and di-basic, monatomic and diatomic acids, we refer you to larger works, especially to *Fowne's Manual of Chemistry.* All the acids with which you will become familiar—citric (from lemons), tartaric (from grapes), malic (from apples), formic (from ants), and a host of others—belong to this division, and are regarded as similarly constituted, their basicity, etc., excepted. Examine also the table, page 303, giving acids and alcohols corresponding to the hydrocarbons of the Ethylene Series.

TABLE

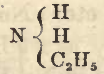
Showing the Chemical Relations of Hydrocarbons, Alcohols, Acids, and Ethers in the First Three Members of the Marsh Gas Series:

HYDROCARBONS.	ALCOHOLS.	ACIDS.	ETHERS.
$\begin{array}{l} H \\ \vert \\ CH_2 \end{array}$ (or CH_4) Marsh gas, or methane.	$\begin{array}{l} H \\ \vert \\ CH_2(OH) \end{array}$ Wood-spirit, or methylic alcohol.	$\begin{array}{l} H \\ \vert \\ CO(OH) \end{array}$ Formic acid.	$\begin{array}{l} H \\ \vert \\ CH_2(OCH_3) \end{array}$ Methylic ether.
$\begin{array}{l} CH_3 \\ \vert \\ CH_3 \end{array}$ (or C_2H_6) Ethane.	$\begin{array}{l} CH_3 \\ \vert \\ CH_2(OH) \end{array}$ Common, or ethylic alcohol.	$\begin{array}{l} CH_3 \\ \vert \\ CO(OH) \end{array}$ Acetic acid.	$\begin{array}{l} CH_3 \\ \vert \\ CH_2(OC_2H_5) \end{array}$ Common ether.
$\begin{array}{l} CH_3 \\ \vert \\ CH_2 \\ \vert \\ CH_3 \end{array}$ (or C_3H_8) Propane.	$\begin{array}{l} CH_3 \\ \vert \\ CH_2 \\ \vert \\ CH_2(OH) \end{array}$ Propylic alcohol.	$\begin{array}{l} CH_3 \\ \vert \\ CH_2 \\ \vert \\ CO(OH) \end{array}$ Propionic acid.	$\begin{array}{l} CH_3 \\ \vert \\ CH_2(OC_3H_7) \end{array}$ Propionic ether.

425. **Amines.**—These are bodies containing nitrogen, and patterned after ammonia. Up to this point carbon, a tetrad, has been the foundation on which the organic bodies are built up, but now we will assume that nitrogen takes this position. Ammonia is NH_3, NHHH, or $N\left\{\begin{matrix}H\\ H\\ H\end{matrix}\right.$; it matters not how it is written. Now the hydrogen atoms in ammonia are capable of being replaced by organic groups, which we have called radicals, either successively or all at once. Suppose we take, for example, the same radical C_2H_5 which is supposed to exist in alcohol, ether, etc. Now if we substitute C_2H_5 for one of the H atoms in $N\left\{\begin{matrix}H\\ H\\ H\end{matrix}\right.$, we get $N\left\{\begin{matrix}H\\ H\\ C_2H_5\end{matrix}\right.$, and this is called an *amine;* actually it is *ethylamine*, for the radical C_2H_5 is called *ethyl.* Now what do you suppose are the properties of ethylamine? They resemble those of ammonia very closely; it is a gas, with a pungent, not disagreeable odor, very soluble in water, unites with acids to form crystalline salts, etc., just like ammonia; so that the substitution of the group C_2H_5 for H has made but little change in the properties. Do you ask how this exchange is actually performed in a laboratory? We will tell you. A liquid called ethyl iodide, C_2H_5I, is put into a strong glass tube with a solution of ammonia; the tube is then sealed, and heated by immersion in boiling water. In a short time a new body is formed, having a very long name. The tube is then opened, and its contents heated in a retort with potassium hydrate, when the ethylamine distills over and dissolves out in the water, which condenses at the same time. We have explained roughly this operation in order to give you some idea how a chem-

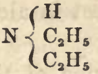
ical reaction of this nature is practically carried out, and to enable you to understand that the "substitution" is not merely a new arrangement of letters on paper, but an actual rearrangement of the atoms of tangible matter.

Now as a matter of fact, when the above operation is carried out the liquid which distills over, on heating with potassium hydrate, contains other bodies besides ethylamine. For not only is *one* atom of H replaced by C_2H_5, but *two*, and all *three* atoms are likewise replaced, yielding bodies having the composition shown in the formulæ following:



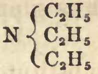
$$N\left\{\begin{matrix}H\\H\\C_2H_5\end{matrix}\right.$$

Ethylamine.



$$N\left\{\begin{matrix}H\\C_2H_5\\C_2H_5\end{matrix}\right.$$

Diethylamine.



$$N\left\{\begin{matrix}C_2H_5\\C_2H_5\\C_2H_5\end{matrix}\right.$$

Triethylamine.

These bodies are chemical curiosities; but we have explained their formation and constitution in order that you may have some idea of the group of *Amines*, for to this class of bodies it is believed that the *Alkaloids* belong; and the alkaloids you will learn are of immense importance, including as they do the valuable and interesting bodies quinine, strychnine, morphine, etc., occurring in plants. When the replacing radical contains oxygen, the new body formed is called an *amide*, but these are of less importance.

426. **Organo-metallic Compounds.**—These are compounds of hydrocarbon radicals with monad, dyad, and tetrad metals, but, being mere chemical rarities for the most part, do not interest us. One of them, called zinc-ethyl—$Zn(C_2H_5)_2$—is a volatile liquid with a disagreeable odor, and possesses the property of igniting spontaneously in contact with the air, like phosphoretted hydrogen. We will not return to this class of bodies.

427. **Organic Analysis.**—Analytical chemistry does not come within the scope of this work, but we will tell you

briefly how chemists determine the constitution of organic bodies. There are two kinds of organic analysis: first, *proximate* analysis separates the several definite compounds or *proximate elements* of which a complex substance is composed; second, *ultimate* analysis determines the number of atoms of the elementary bodies in the molecule of a *proximate* constituent. For example, starch, cellulose, gluten, sugar, coloring matters, alkaloids, etc., are *proximate principles* of plants, while carbon, oxygen, and hydrogen in certain ratios are the *ultimate* elements of starch, sugar, and other proximate principles.

The methods in use for separating *proximate* principles of vegetables and animals vary with nearly every substance examined; no scientific scheme has been yet devised, nor can be until our knowledge of this branch of organic chemistry is vastly increased.

On the other hand, *ultimate* organic analysis has been brought to great perfection. The principles on which the process is based are as follows: Organic bodies may be considered as mainly made up of carbon, hydrogen, and oxygen; now when such a body is completely burned, or oxidized (which is the same thing), the carbon, as you know, burns to form carbonic anhydride, the hydrogen burns to form water, and the oxygen escapes as such, or assists in the oxidation. By taking a weighed amount, therefore, of an organic substance, and oxidizing it carefully (by heating with an oxidizing agent, or in a current of pure dry oxygen) in a gas-tight apparatus, so arranged that all the carbonic anhydride and water formed can be collected and weighed, it is not difficult to calculate from the amounts of these products the actual amount of carbon and of hydrogen in the substance taken. How the operation is conducted, and how the calculation is made, is a matter foreign to the character of this work.

QUESTIONS.

418. What two methods of classifying organic bodies may be pursued? Give the scientific classification in seven groups.—419. What is said of the compounds of hydrogen and carbon as to number and variety? How do these isomeric bodies differ in constitution? Name some of the hydrocarbons of the Ethylene Series.—420. Explain the terms homologous and isologous.—421. Show how bodies are formed by substitution. What is $CHCl_3$? What is hydroxyl?—422. Show the relation between alcohols and hydrocarbons. Explain, taking common alcohol as an illustration.—423. What are ethers?—424. What are the relations of acids to alcohols? Illustrate with acetic acid.—425. Whence are amines derived? How? How is ethylamine practically prepared? How theoretically derived? What important constituents of plants belong to this class of bodies?—426. What is said of zinc-ethyl?—427. What are the divisions of organic analysis? Illustrate. Explain briefly the method of ultimate analysis.

CHAPTER XXV.

CONSTITUENTS OF PLANTS, ETC.

428. **Variety of Vegetable Substances.**—There is a great variety in the substances which are produced in plants. They are wood, starch, gums, gluten, fatty substances, volatile oils, coloring matters, alkaloids, etc. Then from many of these are developed other compounds. A very wide field is thus opened; and, numerous as are the valuable combinations already discovered, we know probably but little as yet of the extent of the discoveries which are to be made in this field. Stöckhardt says on this point: "Thousands of such new combinations have been discovered within the last twenty years; our posterity will probably count them by millions."

Of the products of vegetation, there are some which are so widely diffused that they can be considered essential constituents of plants every where; while others appear only in particular plants, and though essential, are not universally so. It is the former class, which may properly be called the constituents of plants, that we shall speak of now, reserving the consideration of the latter class for another chapter. In treating of them, we shall speak of the changes effected in them by the operations both of nature and of art.

429. **Wood.**—What is termed wood in chemistry is the vegetable tissue which makes the framework of all vegetable growths in all their parts, giving to them their shape and firmness. It is the solid part of all vegetable organs. It is to plants what bones, muscles, tendons, skin, etc., are to animals. Woody fibre is present even in the most delicate and tender fruits, holding in its interstices the juices. It is sometimes so exceedingly delicate that in crushing the fruit there seems to be almost nothing but juice. In some fruits, as the orange, the woody tissue is beautifully arranged in long and slender sacs or bottles containing the fluid for our use, the sacs being packed into several different compartments, and each compartment being made of woody tissue. This same tissue, which is so soft and finely divided in the pulp of fruits, in leaves, and flowers, is condensed and hard in what is ordinarily called wood, in bark, in straw, and the husks of grain, and especially in the shells of nuts and the stones of cherries, peaches, etc. The so-called vegetable ivory is chiefly condensed wood. In cork we have wood in a very light, porous, and elastic form.

430. **Cellulose.**—The essential part of woody fibre is called cellulose; this has the composition $C_6H_{10}O_5$; it is nearly pure in cotton, paper, and wood pulp, provided they are not colored with any thing and are not starched.

Pure cellulose may be obtained by washing white cotton, unsized paper or old linen with a warm solution of potassium hydrate, then with cold dilute hydrochloric acid, then with ammonia water and alcohol, repeating the process several times. Thus purified it is white, translucent, and unalterable in the air; it is insoluble in water, alcohol, ether, and oils, but is decomposed by strong acids. Nitric acid converts it into gun-cotton, as explained in § 433; sulphuric acid diluted with about one half its volume of water acts upon cellulose in a peculiar manner, converting it without change of composition into a tough substance resembling animal parchment and applicable to the same purposes. This so-called "vegetable parchment" is manufactured on a large scale.

431. **Linen and Cotton.**—These are composed of fibres of wood, long and pliant. Hemp is also another form of a similar kind. Linen is the inner bark of the flax plant. It is separated from the outer bark by *rotting* and *breaking*. In rotting there is long exposure to moisture and air, which rots the outer bark, and in the breaking this is beaten and rubbed off. Then follows the *hatcheling*, by which the fine fibres are separated from each other but left parallel, and the tangled ones are taken out, making what is called the tow. The flax thus obtained has a gray color, which is removed by bleaching and boiling with lye. Cotton is in the form of fine hollow hairs, which are beautifully arranged in the cotton-plant around the seeds. All cotton, except the Nankin cotton, which is yellow, is so white that it would need no bleaching were it not that in spinning and weaving it oil and dirt are necessarily gathered upon it.

432. **Uses of Wood.**—We put woody fibre to a great variety of uses. We build houses with it, and fill them with wooden furniture. Out of this fibre we make thread, twine, cordage, and fabrics of every variety. We clothe ourselves with it; we write and print upon it; we even eat it as a

part of much of our food. We burn it to keep ourselves warm and to do our cooking. We spread it out in huge sheets to the wind in our boats and ships.

433. **Gun-Cotton.**—If any form of cellulose in a divided state, as cotton, linen, saw-dust, etc., be submitted for a short time to the action of strong nitric acid, it becomes a more explosive substance than even gunpowder. When the discovery was first made it was proposed to use it in place of powder, but this was found impracticable on two accounts. First, it ignites so readily that it is very apt to explode when we do not wish it. Secondly, its explosion is too forcible and rapid, or, in other words, the gases produced expand too rapidly—four or five times more so than they do in the case of gunpowder. The consequence of this quick expansion is that there is danger that the gases will not have time to escape, as in the case of gunpowder, at the outlet of the gun-barrel, and therefore the barrel is very apt to burst. Gun-cotton can be prepared by immersing cotton for about five minutes in strong nitric acid, and then washing it thoroughly, and drying it. Care must be taken to use but a moderate heat in drying it, lest it should explode. The explanation of its explosiveness is that the cotton loses a portion of its hydrogen and takes in its place nitric peroxide, thereby increasing the number of atoms in the molecule and its consequent instability. § 413. The reaction is shown in the following equation:

Cellulose.		Nitric acid.		Gun-cotton.		Water.
$C_6H_{10}O_5$	$+$	$3(HNO_3)$	$=$	$C_6H_7(NO_2)_3O_5$	$+$	$3H_2O$

Gun-cotton is often called *trinitro-cellulose* on account of its composition, as shown in the formula just given. It contains much more both of oxygen and nitrogen than common cotton does. It is, then, like potassium chlorate, a substance highly charged with oxygen, and on that account explosive. It is the oxygen that produces the combustion when the heat is applied; and the nitrogen, being set free, expands with the other gases, and helps to give force to the explosion. Sulphuric acid is commonly used with the nitric acid in preparing gun-cotton. It is of use only in taking the water from the cotton, by virtue of its strong attraction for water (§ 244), thus making more room for nitric acid, and securing a larger combination of this acid with the cotton than it could otherwise obtain.

Collodion is a solution of gun-cotton in ether, making a sirupy liquid. It is often used for court-plaster, and also for making small air-balloons. If it be put upon any thing the exposure to the air causes an evaporation of the ether at once, and the cotton is left in the form of a transparent coating.

434. **Products from Wood by Heat.**—When wood is consumed with free access of air, it is decomposed, as you have already learned, into its elements—carbon, oxygen, and hydrogen; and these, together with some oxygen from the air, form carbonic anhydride and water in the condition of vapor. When, however, there is imperfect combustion from a restricted access of air, the products are different. They are four in number: 1. Charcoal; 2. Illuminating gas, which is a mixture of several hydrocarbons with some carbonic oxide and carbonic anhydride; 3. Pyroligneous acid, or wood-vinegar; 4. Wood-tar. In the common burning of wood the combustion is not perfect, and we have three of these products deposited in the form of soot, for this substance is composed of particles of carbon which have passed off unburned in the current of smoke, having united with them some of the pyroligneous acid and the wood-tar. In the case of the air-tight stoves, so called, soot forms which contains a much larger proportion of the acid and the tar than the soot of an open fire, because the current up the chimney is too sluggish to carry up much of the carbon.

435. Dry Distillation of Wood.—These products can be obtained separate from each other by a process called dry distillation, represented in Fig. 109. Some pieces of wood are heated in a retort, and the volatile matters pass over through the tube into a receiver. The illuminating gas passes on through the bent tube, and is collected in the usual manner. One of these, the wood-tar, is very thick; and the other, the wood-vinegar, is a thin, watery substance. Charcoal, not being at all volatile, is left behind in the retort. Wood is composed of the three elements, carbon, oxygen, and hydrogen; and it is out of these that the products above mentioned are formed by the incomplete combustion produced by the heat. They did not exist in the wood, and therefore may be properly called *products.* Even the carbon left in the retort may be called a product, for in the wood it does not exist *as carbon*, but is in combination with the other elements forming the compound, wood; just as oxygen does not exist in water as oxygen, but is in combination with hydrogen, forming the compound, water.

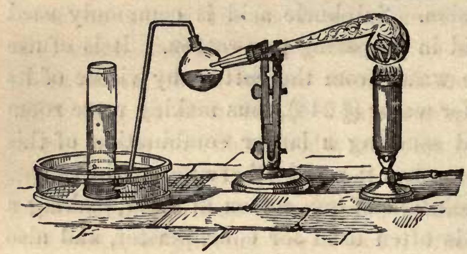


Fig. 109.

Two of the above products—charcoal and illuminating gas—have already been sufficiently described in other parts of this book, and therefore we will now notice only the other two.

436. Pyroligneous Acid.—The name of this acid is derived from a Greek word, *pur*, fire, and a Latin word, *lignum*, wood. Its acidity comes from acetic acid, and hence the propriety of calling this liquid wood-vinegar. Its peculiar strong smell comes from creosote, wood-naphtha, and other bodies. The same smell we have in smoke, and from the presence of the same substances. It is the creosote which makes smoke so irritating to the eyes. It is this substance which, both in smoke and in pyroligneous acid, acts upon meat as an antiseptic. Creosote is a liquid of an oily consistency, and colorless when freshly prepared, but it gradually becomes brown by age. It is a very powerful substance when obtained pure, and is an irritating poison. If taken into the mouth it has a very burning taste, and destroys the tender membrane which lines the tongue and mouth. Great care, therefore, should be exercised when it is employed, as it often is, as a remedy for the toothache.

437. **Wood-Naphtha.**—The liquid portion of the products of the distillation of wood contains, besides acetic acid and creosote, eight or ten other substances; one of these, wood-naphtha, is of considerable importance. It is a volatile, odorous, mobile liquid, resembling alcohol, and yet having a different composition. If it be purified by treatment with lime to remove acetic acid, etc., and then by distillation, a pure substance is obtained, known as *methylic alcohol.* This is the first of a series of bodies called alcohols, with one member of which you are familiar, viz., common alcohol. Its composition is CH_3HO, while common or *ethylic* alcohol is C_2H_5HO. Methylic alcohol burns with a flame much like that of common alcohol, is a good solvent of resinous substances, and, being cheaper than ethylic alcohol, is of great use in the arts.

438. **Wood-Tar.**—This is a resinous substance, and is therefore soluble in alcohol, but not in water. If it be distilled, a volatile oil passes over, called oil of tar, and there is left behind a black pitch. This separation takes place gradually when wood is besmeared with tar, the volatile oil flying off into the air, and the pitch becoming, there-

fore, solid on the wood and in its pores. There is always some creosote in the tar, and this preserves the wood from decay or putrefaction. You see, then, the object of applying tar in the calking of ships.

439. **Coals found in the Earth.**—These are conveniently divided into three classes: lignites, bituminous coals, and anthracites. The first named has more nearly the composition of wood; the second is an intermediate state; and the last, anthracite, is nearly pure carbon, having under the combined influence of heat and pressure lost most of its hydrogen and nearly all of its oxygen.

Lignite is of a browner color than the others, and retains in some degree its woody structure. Bituminous or soft coal burns with a smoky flame containing some hydrocarbons, and hard coal burns with scarcely any flame at all.

All three were made from woody substance, and were brought into their present state by an imperfect combustion. We see the same process essentially going on at the present time, to a certain extent, in the formation of peat. This substance is formed from marsh plants. There is a growth of these every year, which, rotting in the water, sink to the bottom. There occurs, therefore, in the course of time, a large accumulation of vegetable substance, mostly woody fibre, in the form of a brown net-work, in which the separate parts of the plants are discoverable. By the partial decay—that is, incomplete combustion—of this mass it is converted into peat, which is a half-formed coal, being mostly carbon, having some oxygen and hydrogen combined with it.

The formation of coal in the earth will be particularly noticed in Part III.

440. **Imperfect Combustion of Bituminous Coal.**—When bituminous coal is heated with the air excluded, products are obtained very similar to those which result from wood

when subjected to this process. They are these: 1. Coke, which is nearly pure carbon; 2. Illuminating gas; 3. Tar-water, a watery empyreumatic liquid containing some ammonia; 4. Coal-tar, a dark, viscid liquid. This process of dry distillation of bituminous coal is employed for the production of the gas so much used for illumination. The coke which is left in the retorts of the gas-works is a valuable article of fuel. The ammonia in the tar-water is the chief source of the commercial article; it is derived from the nitrogen, which is always present in coal in small quantities, uniting with the hydrogen during the distillation.

Coal-tar is used for covering roofs, to protect them from moisture, and, mixed with chalk and other substances, it is employed as a cement. A great variety of products can be obtained from it. By distilling it we can obtain two oils, one of them a light oil, called benzol, which can be used for many purposes in place of spirits of turpentine; the other a heavy oil, used in the arts for lubrication and for dissolving India rubber, and also sometimes for illumination.

Benzol is one of the large class of bodies called *hydrocarbons*, so many of which are found in petroleum. Its formula is C_6H_6. It is a colorless, volatile liquid, having a low boiling-point. By treating it with nitric acid it is converted into *nitro-benzol*—$C_6H_5(NO_2)$—commonly called artificial oil of almonds, from its odor, which resembles bitter almonds. It is much used in perfumery. Aniline is made from benzol, and is the basis of many of the beautiful dye-stuffs which have been introduced of late years. These dyes are called aniline colors, or simply coal-tar colors; their manufacture is interesting, but too complicated to give here. Aniline is also a constituent of the heavy oil mentioned above. This heavy oil also contains naphthaline, a solid hydrocarbon also yielding dye-stuffs, and carbolic acid (phénol), a substance of great value as a disinfectant. By acting on phenol with nitric acid, a beautiful yellow dye is obtained called *picric* acid. The pitch which is left after distilling off these oils is much used in Europe as a cement for refuse coal-dust. The mixture thus made is cut up into cakes for fuel.

441. **Nature's Products from Bituminous Coal.**—The results of the dry distillation of bituminous coal by art have their counterpart in nature. Volcanic heat is the agent. The anthracite coal is very much like the coke formed in the retorts of the gas-works, except that immense pressure has condensed and hardened it during the action of the heat. Then we have inflammable gases issuing from crevices of rocks, answering to the illuminating gas produced by art. The oil of coal-tar has its representatives in nature in the naphtha that oozes out of the ground in Persia, and in the mineral tar found in France as well as in Persia. Then, to compare with the pitch, the artificial asphaltum obtained from the coal-tar, we have the natural asphaltum of the Dead Sea of Judea, found also in other seas in Asia.

442. **Petroleum.**—Petroleum has been known from a very early period in the history of the earth, but it was reserved for American enterprise to discover the inexhaustible supply beneath the surface. Evidences of the use of petroleum are found near the ruins of Nineveh and Babylon; the springs of Rangoon, in India, have been worked for ages; and in our own country the Indians collected petroleum for various purposes, chiefly medicinal. In 1854 a company was formed for collecting "rock oil" at Oil Creek, Pennsylvania; but the process of gathering it from ditches in blankets and squeezing it into tubs was too expensive. In 1858 Colonel Drake began to bore an artesian well for oil, believing that that which oozed out of the

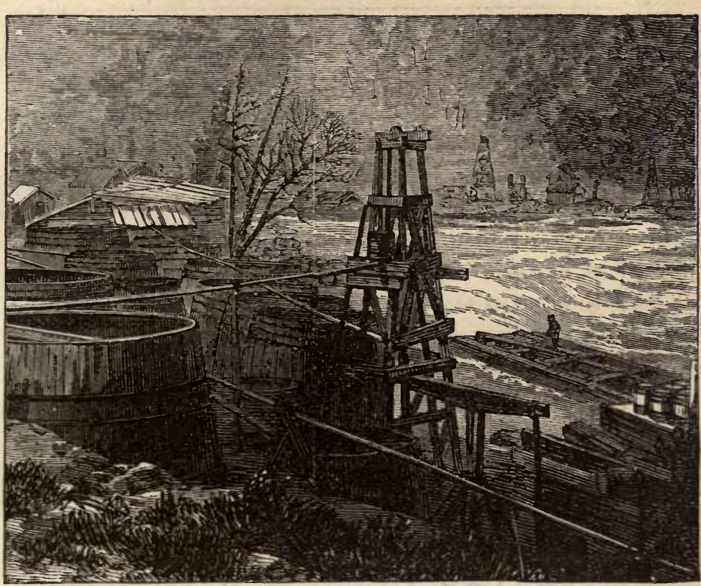


Fig. 110.—A View on Oil Creek, Penn., showing Oil-Wells, Derricks, etc.

ground and ran along the surface might be obtained in great quantity by digging down to its source. His expectations were more than realized; and a well which yielded 400 gallons of oil a day, worth at the time 55 cents per gallon, rewarded his exertions, and successfully answered the ridicule of his neighbors. The eleven years succeeding this discovery produced more than thirty-five million barrels of this useful article.

443. **Composition of Petroleum.**—Petroleum is a mixture of a great number of hydrocarbons, differing from each other in volatility and density. These hydrocarbons belong to two series, one called the Marsh Gas Series and the other the Olefiant Gas Series, because these bodies are the first members of their respective series. The table

HYDROCARBONS IN PETROLEUM.

MARSH GAS SERIES.			OLEFIANT GAS SERIES.		
Name.	Formula.	Boiling Point.	Name.	Formula.	Boiling Point.
Ethane	C_2H_6	Gaseous at ordinary temperatures.			
Propane	C_3H_8				
Quartane	C_4H_{10}	1° C.			
Quintane	C_5H_{12}	30			
Sextane	C_6H_{14}	68			
Septane	C_7H_{16}	93			
Octane	C_8H_{18}	117			
Nonane	C_9H_{20}	137			
Decane	$C_{10}H_{22}$	161	Decene	$C_{10}H_{20}$	160° C.
Undecane	$C_{11}H_{24}$	182	Undecene	$C_{11}H_{22}$	195
Duodecane	$C_{12}H_{26}$	198	Duodecene	$C_{12}H_{24}$	216
Tridecane	$C_{13}H_{28}$	217			
Quatuordecane	$C_{14}H_{30}$	238	(And probably many more of this series; see table on page 303.)		
Quindecane	$C_{15}H_{32}$	258			
⋮	⋮	⋮			
Paraffin	C_nH_{2n+2}	Solid.			

on page 324 gives the names, formulæ, and boiling points of the chief hydrocarbons occurring in American petroleum.

444. **Refining Petroleum.**—Petroleum as it issues from the earth is dark colored and ill-smelling; some of its constituent hydrocarbons are too volatile for burning in lamps, others are too heavy, consequently the petroleum is subjected to a process of refining. The chief point in the refining process is called fractional distillation, whereby the bodies having different boiling points are separated; the lighter portions boiling the lowest distill over first, and the successive portions are denser and less volatile. This process furnishes various products, which are still mixtures of hydrocarbons, and which have no definite composition, but they have received names for commercial uses; the following table shows these bodies and their uses:

PRODUCTS OF THE DISTILLATION OF CRUDE PETROLEUM.*

NAME.	PERCENTAGE YIELDED.	SPECIFIC GRAVITY.	BOILING POINT.	CHIEF USES.
Cymogene.....			0° C.	Generally uncondensed—used in ice-machines.
Rhigolene......		.625	18.3	Condensed by ice and salt—used as an anæsthetic.
Gasolene.......	1½	.665	48.8	Used in making "air-gas."
C Naphtha.....	10	.706	82.2	Used for oil-cloths, cleaning, adulterating kerosene, etc. For paints and varnishes.
B Naphtha.....		.724	104.4	
A Naphtha		.742	148.8	
Benzine	4			Used to adulterate kerosene oil.
Kerosene oil...	55	.804	176.6	Ordinary oil for lamps.
Mineral sperm.		.847	218.3	
Lubricating oil.		.833	301.6	Lubricating machinery.
Paraffin........	19½	Solid.		Manufacture of candles.

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* Rearranged from Dr. C. F. Chandler's Report on Petroleum, presented to the Board of Health of the City of New York, 1870.

445. **Unsafe Kerosene.**—The cheapness of kerosene oil, the brilliancy of its light, the freedom of its flame from smoke when burned in suitable lamps, makes it universally used for illuminating purposes. Unfortunately many accidents occur by explosion of lamps, but this is only because the kerosene oil contains too much of the lighter oils, benzine and naphtha. This makes the oil too readily inflammable, for the vapors of the lighter oils are driven out by heating (as when a lamp is burning), and these mixed with the oxygen of the air form a dangerous explosive mixture. There is a law requiring manufacturers to keep kerosene oil free from these lighter oils; but since the latter are not worth so much, the wicked avarice of some manufacturers causes them to break the law and run the risk of detection. Hence so many fatal accidents.

446. **White Rotten Wood.**—There is a decay of wood in the hollow trunks of trees which produces a singular substance when there is no opening in the trunk to permit the access of air. This substance differs from that which ordinarily results from the decay of wood, very much as a hydrate does from an anhydrous oxide. For example, it is as iron rust differs from common oxide of iron. This rotten wood can be prepared artificially. If you put some moistened saw-dust into a closed vessel in summer, and let it stand for some months, you will find it converted into a white friable substance, which is perfectly dry because the water has chemically united with it. White rotten wood is sometimes luminous from some chemical change which is going on in it.

447. **Chlorophyll.**—This substance, leaf-green, giving the green color to leaves and twigs and stalks, is one of the most widely diffused of vegetable substances. It is not one single substance, but is a mixture of several coloring substances, the character of which has not been fully ascer-

tained; it is known, however, that the green color is due to the mixture of a blue with a yellow substance. Chlorophyll is not soluble in water, but is easily soluble in alcohol and ether, which are used to extract it from green leaves. Light is necessary for its formation, as we know by the white color of plants that grow in darkness.

QUESTIONS.

428. What is said of the variety of vegetable substances?—429. What is wood, chemically speaking?—430. What is the essential part of woody fibre?—431. What is said of linen and cotton?—432. What of the uses of wood?—433. How is gun-cotton made? Why is it explosive? What is its chemical constitution? What is collodion? For what is it used?—434. What are the chief products of the distillation of wood?—435. Describe them.—436. Of what is pyroligneous acid composed? What are the properties of creosote?—437. What is said of wood-naphtha?—438. What of wood-tar and its uses?—439. What coals are found in the earth? Wherein do they differ? How are they formed?—440. What are the chief products of the imperfect combustion of coal? For what is coal-tar used? What is benzol? What is nitro-benzol? What is aniline?—441. What is said of nature's products from bituminous coal? What is asphaltum? Whence comes it?—442. Give the history of petroleum.—443. What is its composition? Name some of the hydrocarbons occurring in petroleum.—444. What is said of refining petroleum? Name some of the products of distillation of petroleum?—445. What makes kerosene unsafe?—446. What is said of white rotten wood?—447. What is chlorophyll? What is necessary to its formation?

CHAPTER XXVI.

CONSTITUENTS OF PLANTS (CONTINUED).

448. **Starch.**—This vegetable constituent, while it is present to some extent in all plants, is especially abundant in particular parts of some of them. It is one of the principal

ingredients in all cereal grains and other seeds, and in the tubers and roots of various plants. It is also in the bark and pith of many trees. It is abundant in all unripe fruits, and some of it changes into sugar as they ripen. All vegetable substances which are used as food contain more or less of starch. Thus in bread, so prominent an article of food as to be called the staff of life, about four fifths of the substance (that is, exclusive of the water) is starch. Arrowroot is a starchy meal which is prepared in the West and East Indies from the roots of marshy plants. Sago is prepared by heat and water from starch extracted from the pith of palm-trees.

449. **How Starch is Obtained.**—Make some dough by moistening flour, and work it with the hand on a sieve or on muslin (Fig. 111), pouring some water continually upon it, until it ceases to pass through milky. There will be a substance left on the muslin which we will speak of soon. That which is in the water below, giving it a milky appearance, is starch, which will settle in a little while as a white powder. In a similar way it can be obtained from rasped potato, and from other substances that contain it.

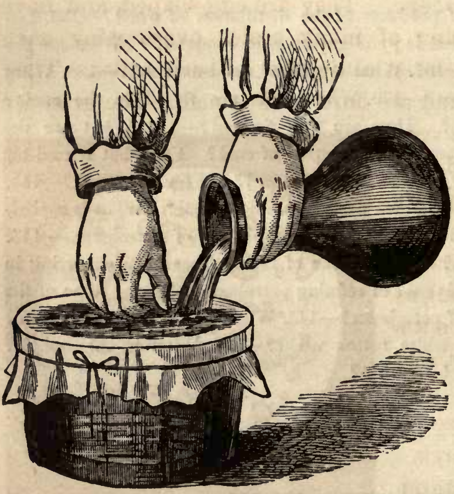

Fig. 111.

450. **The Grains of Starch.**—Starch appears to the naked

eye as if composed of particles of a mealy substance. But if we examine it with a powerful microscope we find that it is made up of grains which are generally regular in their form. They are of different forms and sizes in different plants. In Fig. 112 you see a representation of the granules of potato starch as seen through the microscope. They are egg-shaped, and have a covering consisting of many scales overlapping each other, or perhaps consist altogether of such scales. They glisten in the sun and are hard to the touch. The granules of wheat starch are very different; they are shown in Fig. 113. They are flattened and dull. The granules of rice starch are not rounded at all, as those of wheat and potato, but are angular, and are only about one twelfth of the size of those of potato starch.

Fig. 112.

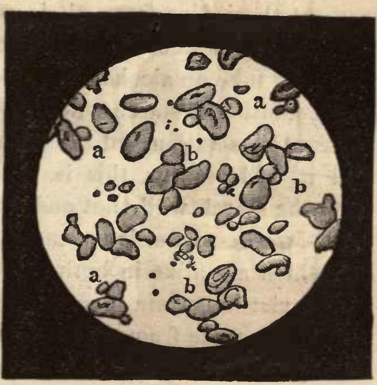

Fig. 113.

We have in starch grains an example of a body with an *organized* structure. The exact composition of starch is not known, but is $C_6H_{10}O_5$ or some multiple of these numbers. Probably the multiple is 3; if so, starch is $C_{18}H_{30}O_{15}$.

451. **Properties of Starch.**—Starch is not soluble in cold water. But while cold water produces no effect at all upon it, a very peculiar effect is produced upon it by boiling water. The hot water is absorbed by the granules, swelling them up and uniting them together, so that the mixture becomes at first mucilaginous, and at length is as thick as jelly. If this jelly be boiled with water for some time the starch is rendered soluble. It is this swollen starch that is so much used in giving stiffness and smoothness to linen and cotton clothing, and in thickening the colors used in printing cloth. The swelling of beans, pease, rice, etc., when they are cooked, is owing to this absorption of the hot water by the starch granules, which compose so large a part of these vegetables.

452. **Iodide of Starch.**—You remember that in § 64 we told you how to test for ozone by means of iodide of potassium and starch paper. Ozone, however, is not necessary to the production of the blue color; any thing will do which can set the iodine free—nitric acid, for example. Instead of taking potassium iodide to get the blue iodide of starch, you may take an alcoholic solution of free iodine. A very weak solution of starch will give you a beautiful blue color. Warm this solution and the color will disappear, let it cool and it will return; this is because the iodine separates from the starch while hot and returns on cooling.

453. **Gums.**—Gum is a generic term for various substances which are alike in both constitution and in properties. They exist in certain plants, and sometimes so abundantly that they exude from the bark as a thick liquid, and harden on exposure to the air. We have familiar examples of this in our peach and cherry trees. The most widely known of the gums is gum-arabic, which exudes from several of the species of acacia in Africa. Most of the gums dissolve readily in water, forming a *mucilage*. The mucilage of gum-arabic is quite adhesive, and therefore is much used

instead of paste and glue; and, as it can be made of a thick consistency, it is used in calico-printing to thicken colors and mordants. Some of the gums, as gum-tragacanth, do not dissolve in water, but only swell up, forming a jelly. The juices of many fruits and roots—as currants, cherries, apples, carrots, etc.—contain a peculiar kind of gum, which gives to the juices the property of hardening into a gelatinous mass on cooling, especially when they have been boiled with sugar. This is called *pectin*.

454. **Dextrin.**—Starch, by certain processes, may be converted into a gum called dextrin, $C_6H_{10}O_5$. The change can be produced simply by the action of heat. If starch be roasted, being kept in motion all the while to prevent its burning, it becomes at length of a brownish-yellow color, and then has the property of being soluble in either cold or hot water. This dextrin, or starch-gum, as it is commonly called, is much used in calico-printing for thickening colors and mordants, and is prepared for this purpose in large quantities by roasting it in the same way that coffee is roasted. This gum is also used in making "fig-paste" and other kinds of confectionery.

Dextrin can be made with a less degree of heat by the agency of either sulphuric or nitric acid. Let a paste of potato starch be made, and while it is yet hot drop a few drops of sulphuric acid upon it in a saucer, and stir it in well. You will find that the swollen starch soon becomes liquid. Now place the saucer upon a jar in which water is simmering, and let it remain over the steam until the liquid is nearly transparent. You have now a solution of dextrin, with the sulphuric acid in it unaltered. To rid it of the acid you add prepared chalk until effervescence ceases. There is gypsum now in the solution in place of the sulphuric acid, for the acid has united with the lime of the chalk, setting free its carbonic acid, which, decomposing into water and carbonic anhydride, occasioned the effervescence. The gypsum, being insoluble, is easily got rid of by filtering, and then by evaporating the solution you obtain the dextrin in solid form.

455. **Explanation.**—In this conversion of starch into dextrin the acid employed does not itself change in the least, but acts only by its presence in some manner not comprehended. Starch has the composition $C_{18}H_{30}O_{15}$, and it takes to itself one molecule of water, and then breaks up into dextrin and glucose, a sugar about which you will learn very soon. The reaction is then probably as follows:

$$\begin{array}{ccccccc} \text{Starch.} & & \text{Water.} & & \text{Glucose.} & & \text{Dextrin.} \\ C_{18}H_{30}O_{15} & + & H_2O & = & C_6H_{12}O_6 & + & 2C_6H_{10}O_5 \end{array}$$

456. **Sugar.**—This substance is widely diffused in the vegetable kingdom, though not as widely as starch. It is abundant in all sweet fruits and vegetables. The Creator has ordained certain plants to be great sugar-makers for man, so that annually large stores of this article are laid up in them for his use. The principal of these are the sugar-cane, the sugar-beet, and the sugar-maple. In many fruits we have an agreeable mixture of sugar with acids, the chemistry of nature being competent to produce these two results at the same time and in the same locality—a thing impossible to the chemist in his laboratory, who can only obtain sugar by one process and an acid by another, and then bring them together in mixture, as we so often do in making lemonade.

457. **Different Kinds of Sugar.**—Sugar is not, like starch, always one thing. There are different kinds of sugar, all agreeing in being composed of the same elements—carbon, oxygen, and hydrogen—but differing in the proportions of these elements. The four most prominent kinds are as follows: 1. Cane-sugar, or sucrose—$C_{12}H_{22}O_{11}$—found chiefly in the juice of the cane, maple, and sugar-beet; 2. Milk-

sugar, or lactose, an important constituent of milk, having the composition $C_{12}H_{22}O_{11}.H_2O$, which differs from cane-sugar only by one molecule of water; 3. Grape-sugar, or glucose—$C_6H_{12}O_6$—which is especially abundant in fruits, as grapes, prunes, figs, etc., and occurs solid and crystallized in dried fruits—raisins, for instance; 4. Fruit-sugar, or cellulose, which occurs in honey and many fruits, together with glucose, and possesses the same composition, but differs in its optical properties. The last kind can not be crystallized.

458. **Cane-Sugar.**—This kind of sugar is obtained more largely from the sugar-cane than from other plants, and hence comes its name. The amount of sugar extracted annually from the sugar-cane in all parts of the world is many millions of pounds, the largest portion coming from the East and West Indies. Cane-sugar is obtained largely from the sugar-beet on the continent of Europe, and from the sugar-maple in the northern parts of this country. In obtaining sugar from the cane the juice is first pressed out by passing the cane between large iron rollers. The juice is then clarified, and boiled down to such a point that it will crystallize as it cools. The raw sugar is thus formed, and the drainings which come from this make the common molasses. The sugar thus obtained is refined by various means and processes, by which it is prepared in different forms for the market. The crystals which sugar is disposed to form are of the shape seen in Fig. 114, an oblique six-sided prism, as you may observe in what is called rock-candy.

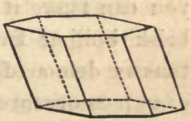

Fig. 114.

459. **Milk-Sugar.**—The sweetness of milk depends upon a peculiar kind of sugar. When the curd is separated from milk in the making of cheese, the sugar remains dissolved in the whey. It can be obtained from this by boiling it

down considerably, and then cooling it. This sugar is so hard as to appear gritty when crushed between the teeth, and is both less soluble and less sweet than cane-sugar. In Switzerland and some other countries, where great quantities of cheese are made, there is some trade in this sugar; but very little of it is sold in the markets of the world in comparison with other kinds of sugar. Milk-sugar is used in pharmacy.

460. **Grape-Sugar.**—This is by no means as sweet as cane-sugar, as you can readily see by comparing the taste of a candied raisin with that of common sugar. A gramme of common sugar has as much sweetening power as two and a half grammes of grape-sugar. Cane-sugar is also twice as soluble in water as grape-sugar, consequently the sirup made with cane-sugar has a more tenacious consistency. Their difference in composition may be shown thus:

$$\overset{\substack{\text{Two molecules of}\\ \text{glucose.}}}{2(C_6H_{12}O_6)} = \overset{\substack{\text{One molecule of}\\ \text{sucrose.}}}{C_{12}H_{22}O_{11}} + \overset{\substack{\text{One molecule of}\\ \text{water.}}}{H_2O}$$

461. **Sugar made from Starch and Wood.** — Grape-sugar can be made from either starch or wood by the agency of heat and sulphuric acid. You saw in § 454 that sulphuric acid with a certain degree of heat converts starch into the gum called dextrin. Now with a higher degree of heat you can make it convert the starch into sugar. Bring to brisk boiling five tablespoonfuls of water, in which are twenty drops of sulphuric acid, and add gradually thirty grammes of starch made into a paste, keeping the water all the while boiling. Let the boiling continue about half an hour, and the requisite change is effected — you have a sirup, that is, sugar dissolved in water. But the sulphuric acid, which is not at all changed in the operation, is in the sirup. This you can get rid of in the way described in § 454, and then on evaporating the sirup you have the

sugar. An infusion of brewer's malt can be used in this process in place of the dilute sulphuric acid.

The process by which wood or cellulose is converted into sugar is a little different. The wood must be in the form of saw-dust. This is moistened with a little over its own weight of sulphuric acid, and is left to stand for twelve hours. The mass becomes very nearly dry in that time; but on being pounded in a mortar it becomes liquid. Water is added to it, and boiling completes the transformation, giving you a sirup which is to be treated in the same way as that obtained from starch. Some kinds of wood yield more sugar than others. Poplar wood is found to be the best, every five pounds of the wood yielding four of sugar. As the fibre of cotton and of linen is really cellulose, sugar can be made by the above process from cotton and linen rags.

The explanation of this reaction has been anticipated in § 455, in explaining the formation of dextrin. We need hardly say that no way has yet been discovered of converting cellulose or starch into cane-sugar. If such a discovery could be made it would be a vast mine of wealth to the discoverer.

462. **Cheating in Sugar.**—Cane-sugar is often adulterated in England and on the continent of Europe with this grape-sugar made from starch and wood. Stöckhardt states that the white sugar sold in Germany "is frequently found to be composed partly or entirely of starch-sugar." In England the manufacture of it has been prohibited by law. The profit on such adulteration must be very great, for the materials used are all cheap, especially if an infusion of malt be used instead of sulphuric acid in effecting the conversion. Grape-sugar is used extensively by brewers, being cheap and easily undergoing fermentation.

463. **Starch and Wood changed into Sugar in Plants.**—We

have beautiful examples of the change of starch and even of wood into sugar in different plants. Fruits that become sweet as they ripen have their starch converted into sugar. This can be proved by the application of the iodine test (§ 452). If tincture of iodine be applied to the fruit when green, you will have the characteristic blue color of iodide of starch; but if it be applied when the fruit is fully ripe, no such color appears. When sugar forms so abundantly in the sugar-maple in the early spring it comes partly from the conversion of the starch in the tree, and probably some of its wood, into sugar.

464. **Wood and Starch made from Sugar.**—Wonderful as are the changes effected by art, as described in § 461, still more wonderful are those which are effected by nature. The chemist can only produce one of the sugars from wood and starch, and that of a poorer kind, while nature can not only produce all kinds, but can change them back as occasion requires into starch and wood. For example, the sap of the maple loses its abundant sweetness as the leaves put forth, the sugar in it being converted into wood in the annual growth of the tree. So, also, in the case of the sugar-beet, if left too long in the ground much of the sugar changes into wood, making the beet tough and fibrous. If grass be not cut soon enough, the hay is deficient in sweetness, and is too coarse and strong, because much of the sugar in its juice has been turned into wood. In cutting the sugar-cane the tops are rejected, because they have so little sugar in them. The reason of this is, that as the plant grows upward the sugar is used up in making the woody structure, but as soon as any of the structure is completed the cells in it are filled with the sugary juice. The lower part, therefore, being complete, is fully charged, while the upper part, which is growing, is not.

465. **Honey.**—The bee gathers sugar in the form of honey

from the nectaries of flowers and deposits it in its honey-bag, which is really a crop connected with the gullet. During the time that it remains there it is probably acted upon by the secretions of the mouth and the crop; so that when the bee, on its return, disgorges it into some honey-cell in the hive, it is probably not exactly of the same chemical composition as when it was first collected from the flowers. Honey varies much in its qualities, from the coloring and odoriferous substances of different plants, which become intimately combined with the honey as the bee gathers it. Some honeys are for this reason much more highly valued than others.

466. **Manna.**—There are various trees from which substances called manna are obtained. In these substances there is a peculiar sugar called mannite—$C_6H_{14}O_6$—which is less sweet than even the grape-sugar. There is also in them some sugar which appears to be like grape-sugar, and also some other matters. The composition of the ordinary manna of commerce may be stated thus:

	Per Cent.
Mannite	40
Grape-sugar	10
Gum and other matters	40
Water	10
	100

The large proportion of gum and other matters in the manna lessens, of course, its sweetening capacity. When freshly gathered it is very agreeable to the taste, and is a valuable article of food. But after it has been kept for some time it has a laxative quality which unfits it for use as food. This medicinal quality is not owing to the sugar, but to some chemical change in the other substances. A manna obtained from a tree in the neighborhood of Mount Sinai is supposed by some learned men to be the same as that on which the Israelites were fed in passing through the wilderness. But this opinion is obviously incorrect, and is not generally received. Besides the want of correspondence in taste, general appearance, etc., there is a chemical difference indicated in the following passage from Exodus: "And Moses said, Let no man leave of it till the morning. Notwithstanding they harkened not unto Moses; but some of them left of it till the morning, and it bred worms and stank: and Moses was wroth with them." No such change as this occurs in the manna now obtained near Mount Sinai, and it shows, therefore, that the manna which was furnished miraculously to the millions of Israelites was of a different chemical composition.

467. **Gluten.**—The constituents of plants thus far noticed are composed of carbon, oxygen, and hydrogen. But these alone could not sustain and nourish animals, for there is no nitrogen in them. There are other constituents, therefore, which contain this element, in addition to the three of which sugar and starch are composed. The principal of these is gluten, so called because it is a glutinous or sticky substance like glue. You will recollect that in the process of obtaining starch from wheat flour a substance was left on the cloth. This was gluten. It is this in the flour which gives cohesion to bread. Without this the bread would crumble to pieces, for the cells in it, if made of starch alone, would be easily broken down. Though gluten is so important a part of grains as food for man and animals, it bears but a small proportion to the starch. In the bread that we commonly eat—wheat bread—there is about eight times as much starch as gluten. Gluten is analogous to a substance largely existing in animals called fibrin, and for this reason it is often denominated *vegetable fibrin.*

468. **Albumen.**—If in the process for obtaining starch detailed in § 449, after the starch is settled you decant the water from the vessel and boil it, it will become turbid, and on standing will deposit a flocculent precipitate. This is vegetable albumen, which has properties similar to those of animal albumen, a common specimen of which we have in white of egg. The precipitate above spoken of is essentially the same as the white of egg coagulated by heat. This albumen, which is thus found to be present in a small amount in the grain of wheat, is very widely diffused in the vegetable world. It is this substance in the sap of wood which renders it so liable to decay.

469. **Casein.**—Vegetable casein is so called from its resemblance to the cheese contained in milk. It is found chiefly in the seeds of leguminous plants, and therefore is sometimes called legumin. Like gluten and albumen, it contains nitrogen. It differs from albumen in not being coagulated by heat; but it is coagulated by acids, as is the case with the cheesy matter or casein in milk. It may be obtained from pease by the following process: Put a handful of pease into a vessel containing considerable water, and let it stand for several days in a warm place. A great part of the water will be absorbed by the pease, so that they will become large and soft. Mash them, and add sufficient water to make a thin paste. By treating this as the paste of flour was treated in § 449, you obtain the same substances, viz., the gluten on the cloth, the starch deposited from the liquid, and the albumen coagulated in the boiling of the decanted liquid. If now, after separating the albumen from the liquid by filtering, you add to the liquid a little acid of some kind, a flaky white substance will be precipitated, which is casein.

470. **Protein Substances.** — The three nitrogenous substances which we have thus briefly noticed—albumen, fibrin,

and casein—have nearly the same chemical composition, and are convertible into each other. The name, *protein compounds*, has been given to them because they were supposed to have a common base, which, from its importance in the chemistry of life, was called protein, from the Greek word *protos*, first. This supposition has been abandoned, but the name has been retained, and these substances are often spoken of still as the protein compounds. They are often also spoken of as the *albuminoids*, especially in relation to the nutrition of animals. Then, again, they are styled the *plăstic* elements or constituents, because they are used in building up structure in animals, this word being derived from a Greek word meaning to form. Another term still is often applied to them—*azotized*—because they contain, unlike starch, gum, sugar, etc., nitrogen, or azote. There is always in these substances a small amount of both sulphur and phosphorus. It varies much, however, in different cases.

QUESTIONS.

448. What is starch? What proportion of bread is starch? What is arrow-root? What is sago?—449. How can starch be obtained?—450. Describe the grains of various kinds of starch. What is the composition of starch?—451. What are the properties of starch? What causes the swelling of rice when boiled?—452. What curious property has iodide of starch?—453. What are gums? What is a mucilage? What is pectine? —454. How is dextrin made from starch? To what uses is dextrin applied? Describe another way of making dextrin.—455. Explain the chemistry of this change.—456. What is said of the production of sugar in nature? What of the mingling of sugar and acids in fruits?—457. What are the different kinds of sugar?—458. What is the source of cane-sugar? How is it obtained from the cane? What is rock-candy?—459. What is said of milk-sugar?—460. How does grape-sugar differ from cane-sugar in properties? How in composition?—461. How can sugar be made from starch and wood? Explain the change.—462. What is said of the adulteration of cane-sugar?—463. What of the conversion of starch and wood

into sugar in plants?—464. What is the difference between the artificial and the natural production of sugar?—465. How does the bee form honey?—466. What is manna? What are its ingredients? Its properties? What is said of the manna of the Israelites?—467. What is the use of gluten in plants? How may gluten be obtained from wheat flour? Why is gluten called vegetable fibrin?—468. What is said of vegetable albumen?—469. What of casein? How may it be obtained?—470. What is said of protein substances? Why are they called plastic elements? What is the meaning of the term azotized?

CHAPTER XXVII.

VEGETATION.

471. **The Seed.**—The beginning of the formation or building up of a plant is in certain operations in the seed. The chemical forces remain dormant in the seed until awakened to action by heat and light. These, in the presence of moisture and air, operate upon the seed when it is put into the ground. With these stimuli wholly shut out seeds may be kept a very long time in their dormant state, their living power being preserved in the sleep. Thus seeds which were found buried in the ruins of Herculaneum were proved to be alive by growing when they were planted, like the fresh seeds of the previous year.

On the whole our knowledge of the chemical operations taking place in the plant is very slight; only here and there have we glimpses of wonderful processes which produce such an immense variety of vegetable bodies.

472. **Growth from the Seed.**—A seed is composed chiefly of starch, with some gluten. Both of these are insoluble in water, and therefore can not be used in growth until they are so changed as to be rendered soluble. Accordingly the first thing which is done by the forces men-

tioned is the production of a substance which so acts upon these materials as to make them soluble. This substance is formed by the union of the oxygen of the air with some of the gluten, and is therefore oxidized gluten. This union will not take place unless there be moisture, just as iron will not rust or oxidize in perfectly dry air. The substance thus produced is called *diastase.* It has the power of converting the starch into dextrin, and also into sugar, and both of these substances are soluble. It also in some way renders the gluten soluble. But little diastase is required to produce these changes, and therefore but little of the gluten is converted into diastase. There are some very familiar examples of these changes. The malt of the brewer is sweet and mucilaginous to the taste, because in the germination of the barley the diastase converted some of the starch into sugar and dextrin, the latter giving the malt its mucilaginous character. For the same reason when potatoes sprout they become soft, mucilaginous, and sweet.

473. **Root and Germ.**—From the materials contained in the seed, thus rendered soluble, the root is formed downward and the germ upward. These are solid formations. Observe how they are made. It is not by chemical power, as particles are arranged in various crystalline forms. The branching germ and root are not formed as the lead-tree is, noticed in § 373. In this latter case particles are deposited on each crystal in regular layers, each layer outside of that deposited before it. But in the formation of the germ and root life is ever pushing along, making channels for the materials of the seed to flow in. By the time that these materials are used up in the formation of the plant it becomes fitted to go on in its growth by absorbing materials from the earth and from the air, for the same living power which constructs the channels for it

forms in the minute roots absorbent mouths to take materials from the earth, and other mouths in all the leaves to absorb material from the air. This absorption from earth and air begins indeed as soon as the root and germ are at all formed, but it is not established in full until all the nutriment of the seed is taken into the plant.

474. **Source of Carbon in Plants.**—You have already seen, in § 408, the source of a large part of the carbon in plants. Then there is some carbon introduced by the root, for there is always carbonic anhydride in the soil, as the product of decompositions going on there, and this is absorbed with other materials by the innumerable mouths in the minute fibres of the root. What proportion of the carbon comes from the air is not known, but it is probably by no means always the same. It is supposed that generally more is taken in by the leaves than by the roots.

475. **Sources of the Oxygen and Hydrogen.**—With the carbon there must be united oxygen and hydrogen to form the various structures of the plant—the wood, bark, leaves, etc., and also the substances contained in the plant—the starch, sugar, gum, etc. From whence, then, does it get the oxygen and hydrogen? Probably mostly, and sometimes wholly, from water. As this fluid, absorbed by the root, carries up in the channels which life has constituted various materials gathered from the earth, some of it is decomposed in order to furnish oxygen and hydrogen to unite with carbon in forming the various compounds alluded to. It is not a union, you observe, of water and carbon, but of the elements of water and carbon, and to effect this the water must be decomposed into its elements. This is done by the vital force which alone can build up organized structures. Man can-not effect this decomposition except by applying strong heat, and at the same time presenting some substance to the water which has a decided affinity

for the oxygen, as you saw in § 142. But in the plant the decomposition is effected in the most quiet manner, and the two elements thus separated are united with carbon in the production of a great variety of substances.

476. **Plants Growing Without Earth.**—You can now understand how it is that plants often grow in water only. It is because the air furnishes the carbon, while the water furnishes the oxygen and hydrogen, and these are all the elements which are absolutely necessary for the structure of the plant. We have familiar examples in the hyacinths raised in bulb glasses, in oats growing from seeds on cotton floating in water, and in canary-seed throwing up delicate shoots from all parts of a pine-cone which stands immersed in water in a glass. There is, it is true, in all these cases some nitrogenous matter in the seeds, and also in the water, unless it be freed from its impurities by distillation. But this is too small in amount to satisfy the natural demands of the plant, and therefore, though there be growth, there is by no means that vigorous and productive growth that there would be if all the materials naturally belonging to the plant were at hand. The oats and canary-seed, therefore, produce no seeds, or very defective ones, and the hyacinth produces no additional bulb. And, farther than this, in the case of the oats and canary-seed the growth is very manifestly deficient, because the plants are naturally rich in nitrogen, and therefore especially require that article of diet, as we may express it, which is not true of the hyacinth.

477. **Sources of the Nitrogen in Plants.**—Although nitrogen is not needed, so far as the structure of plants is concerned, it is generally present in some amount; and it is essential to the formation of the fruits of many plants, as the grains, beans, pease, etc. From whence does it come? There is an abundance of it in the air, for four fifths of the atmosphere is nitrogen. And it is not combined with any

other element, but is free; and as it bathes the leaves it would seem that it might be absorbed as the carbonic anhydride is. But not a particle of the nitrogen, so far as we know, is absorbed by them. How, then, the question returns, does the plant get its nitrogen? It comes from the soil. But how? There is no free nitrogen in the soil, so that the mouths of the roots may drink it up as they do carbonic anhydride. But there are substances in the soil which contain nitrogen in combination, and furnish it to the plant. The principal of these is ammonia, which, as you learned in § 160, is composed of nitrogen and hydrogen. In the process of decay always going on in the soil there are produced ammonia, by the union of nitrogen and hydrogen, and carbonic anhydride by the union of carbon and oxygen. Then the ammonia and carbonic anhydride unite with the elements of water to form carbonate of ammonium. As this salt is volatile, much of it escapes into the air; but it is brought down to the earth again by the dew and the rain. The existence of ammonia in rain-water has been proved by Liebig. The amount is indeed very small in any one quantity of water subjected to examination; but the aggregate for the year is so large an amount that we may say that the land receives great quantities of one of its most valuable fertilizers from the rains of heaven. This is but returning, however, to the ground what is first generated there by decay. The value of manures containing ammonia will be spoken of hereafter.

478. **Summary.**—You see, then, that from carbonic anhydride, water, and ammonia all the constituents of plants can be furnished, for we have in these all the elements which compose these constituents. We may state it thus:

Carbonic anhydride	gives carbon, oxygen,	from which are formed	wood, starch, gum, gluten, sugar, etc.
Water	" hydrogen, oxygen,		
Ammonia	" nitrogen, hydrogen,		

The materials of growth, then, are produced by decay, which is really not destruction, but a set of chemical changes for the purpose of a recombination of the elements in new forms of life and beauty. It is thus that life continually springs out of what we call death.

479. **Nitrogen from Nitric Acid.** — Considerable nitrogen is furnished to plants from the nitric acid, which we have stated is formed in the air and brought down in the rain. As long ago as 1785, Cavendish, an English chemist, discovered that by passing a succession of electric sparks through a mixture of nitrogen and oxygen in presence of aqueous vapor in a glass tube, a little nitric acid is formed. This is a small representation of what takes place on a large scale in the atmosphere, for traces of nitric acid have been found in samples of rain collected during and after thunder-storms. As one of the elements of nitric acid is nitrogen, its decomposition furnishes this element to plants to be used in their growth.

480. **Green Manuring.** — Land which has been impoverished is often rendered fertile by raising some crop upon it, as buckwheat, barley, rye, etc., and plowing it in while green. The manner in which this process, called green manuring, enriches the soil will be clear to you by referring to what we have said of the sources of the materials for growth. In the first place, all the ammonia and nitric acid which are washed down by the rain are used by the plants, and as these are plowed in there is really a store of nitrogen laid up in the ground for the next crop. Then, again, every leaf of the plants is gathering in, by its multitude of open mouths, carbon from the air; and this carbon is plowed in, therefore, with the nitrogen. But, besides all this, the roots as they are pushed down by the living power of the plant break up the mass, and then thoroughly mix with it in their decay. We have, therefore, a loosen-

ing and rearrangement of the soil which are favorable to fertility.

481. **Inorganic Food of Plants.**—The materials of which we have spoken as ministering to the growth of plants are said to be their *organic food.* They are composed of the four grand elements—carbon, oxygen, hydrogen, and nitrogen. But there are other substances which are absorbed in various quantities in different plants, as silica, potash, lime, phosphorus, etc. These are said to be their *inorganic food.* Although the inorganic are not as essential to the growth of plants as the organic substances, still the fact that the most important of them are present to some extent in all plants shows that every plant requires some amount of them for its full development. If a plant fails to find them its growth is feeble, and it withers before attaining maturity.

482. **Ashes of Plants.**—If a plant be burned, we obtain in the ashes the inorganic portion of it. The organic part has flown off in the form of gas, the carbon having formed carbonic anhydride with oxygen, the hydrogen water with oxygen, and ammonia with nitrogen. The ashes show how small a proportion of the substance of plants is inorganic. Ordinarily every hundred grammes of wood affords but two of ashes, the other ninety-eight grammes having been dissipated in the air.

483. **Mineral Classification of Plants.**—The ashes of different plants differ very much in their inorganic constituents. A knowledge, therefore, of their composition in this respect, derived from a chemical examination of their ashes, is very important for an intelligent application of manures in raising different crops. The inorganic substances which are found to predominate in the ashes of a plant must be considered as indispensable to its nourishment; and if the soil be deficient in them they must be supplied by the culti-

vator. If the soil be destitute of potash, neither turnips nor grape-vines will grow well in it. If it be destitute of lime, it will not answer for clover or pease. Liebig divides all cultivated plants into three classes, according to the chemical character of their ashes: 1. *Potash plants*, the ashes of which contain more than half their weight of salts, having alkaline bases (potassium and sodium), soluble in cold water. The beet, mangel-wurzel, and turnip belong to this class. 2. *Lime plants*, the ingredients of which are salts of lime and magnesia, soluble in acids. In this class we have clover, beans, pease, tobacco, etc. 3. *Silica plants*, in which silica predominates in the ashes. Wheat, barley, rye, and oats are in this class.

484. **Water in Plants.**—In the processes of vegetation water not only furnishes some of the material, but it is the common carrier, as we may say, of all the other materials. What is taken in by the roots and the leaves is carried to all parts of the plant by the water. In doing this work the water courses through the plant in larger quantity than is commonly supposed. We can get some idea of this by looking at the amount which is exhaled from the leaves of plants into the air. Some investigations have been made on this point. It was found that from the leaves of a single cabbage there passed into the air nearly a quart of water in twenty-four hours. With this great exhalation from plants there must be a large amount of water passing up from the earth through them in a rapid but quiet circulation.

485. **Annual Changes in Plants.**—When annual plants have stored up in their seeds a sufficient quantity of starch and albuminous substance for the germs of a new race of plants their work is done, and they fall to decay. But in perennial plants, such as shrubs, fruit and forest trees, after their fruit or seed has ripened, the woody fibre which has

been formed in the spring becomes harder by continued woody deposit. At length, however, there ceases to be any formation of wood, and in its stead starch is made, and diffused through every part of the plant by the autumnal sap, the buds of the next year being formed at the same time. In the following spring this starch thus stored up is converted into dextrine and sugar, from which the leaves and tender branches are constructed, and the whole plant increased in bulk.

QUESTIONS.

471. What is said of the dormant seed, and of its stimuli? What are the constituents of the seed? What changes do the stimuli effect in these?—472. What familiar examples have we of such changes?—473. State the contrast between the formation of the lead-tree and that of the root and germ of the plant. From whence are the materials for their growth derived?—474. What is said of the supply of carbon to plants?—475. What of the sources of their oxygen and hydrogen? What is said of the decomposition of water in plants and in the laboratory of the chemist?—476. Explain how plants can grow without earth. In what respects is their growth defective, and why?—477. What is said of the nitrogen in the air in relation to the supply of plants with it? From what source is it supplied, and how? What is said of the presence of carbonate of ammonium in the air?—478. Give the summary in regard to growth and decay.—479. What is said of nitric acid as supplying nitrogen to plants?—480. What is green manuring? How does it fertilize land?—481. What is said of the inorganic food of plants?—482. What of the ashes of plants?—483. Of what use is the chemical examination of the ashes of plants to the cultivator? What are Liebig's three classes of plants?—484. What are the offices of water in plants? What is said of the quantity of water that circulates in them?—485. What provision is made by annual plants for the following year? What is the provision in perennial plants?

CHAPTER XXVIII.

SOILS AND MANURES.

486. **Soil the Food of Plants.**—There is a striking analogy between the root of a plant and the stomach of an animal. In both there are minute absorbents which take up the material for growth. As the food put into the stomach is not all nutritious, and the absorbents take from it that which is so, so also the soil, the food of plants, as it is mingled with the fine branches of the roots, has its nutritious portion absorbed by the little mouths which are there ever open to receive it. The root, therefore, may be regarded as the stomach of the plant. The proportion of nutritious substance is much greater in the food of the animal than in that of the plant, and therefore the stomach of the latter is a much more extensive organ than that of the animal.

487. **Loosening the Soil.**—As food put into the stomach of an animal more readily furnishes its nutritious part to the absorbents if it be well masticated, so it is with the food of the plant. Hence the necessity of preparing the ground for plants by plowing, digging, etc.; and hence, also, the usefulness of loosening the ground about plants so well known to the gardener. One of the evils of an abundance of clay in a soil is the close, compact character which the clay gives to it. The cold of winter has much influence in preparing the soil for the coming growth of spring, for, as the ground freezes, the expansion of the water, which is mingled up with its particles as it changes into ice, separates these particles from each other, and thus

loosens the compact soil. It is thought that earth-worms are more beneficial than injurious, because the benefit which they confer by loosening the soil is greater than the damage which they do by extracting nutriment from it.

488. **Water in the Soil.**—Food for either plant or animal needs to be dissolved to be available, and the great solvent is water. If a drought prevail plants languish, not because there is a deficiency of nourishment in the soil, but because there is not sufficient water to present the nutritious matter in good quantity to the absorbents, and to carry it up in the tubes of the plants. You saw in § 484 that a large amount of water is required for this. The solid matter of nutrition must be carried along on a full tide in the channels made for it.

489. **Soil as Generally Constituted.**—Soil is commonly made up of many substances mingled together, but derived from two sources. The first is the rocks. The great bulk of the soil comes from this source. This is very manifest in gravelly and sandy soils, for in them a mere glance shows you the broken pieces and grains which came from the rocks. But it is true even of fine rich earth that the most of it is mineral, and therefore that the rocks furnished it. You can see this to be so if you take some earth in your hand and examine it after it is dry. You will find that the grains of stone predominate over the other materials. An analysis of the earth will develop the fact more thoroughly, for two reasons. First, some of the ingredients from the rocks are dissolved in the water of the earth; and, secondly, some of them are very finely divided, and therefore their mineral character is not manifest to the naked eye. The second source of soil is the decay of vegetable and animal matters. All wood, leaves, bones, flesh, etc., as they decay form a part of the soil.

490. **Humus.**—This second part of the soil is called *hu-*

mus. It is of a dark color, and hence fertile earth has a darker color than sand. The substances forming humus are chiefly those that are composed of carbon, oxygen, and hydrogen, vegetable fibre as contained in wood, bark, leaves, etc., being the principal. There is some nitrogen, of course, in humus, from the juices of plants and the seeds, and also from the decomposition of animal substances. The immediate products of the decomposition of humus are humic acid, so called, humic acid salts, carbonic acid, water, ammonia, etc. The decomposition produces a good effect mechanically upon the whole body of the soil, loosening it, and so making it mellow, as it is commonly termed. Humus is also a great absorbent of water, swelling up as a sponge, and this helps the mechanical effect produced by the generation of gases by decay. Heat also is developed by the chemical changes, which is often of very material benefit when the soil is naturally a cold one.

491. **How Soil was Originally Made.**—All the soil, with the exception of that portion of the carbon which has been supplied from the air, and also the water which is diffused in it, came originally from the rocks. There was a time when there was nothing but rocks and water and air. Some of the rocks became at length broken and ground up by processes which the geologist describes, and thus was furnished the soil on which the plants first grew. Soil being thus prepared, seeds were supplied by the Creator, the plants from which, sending down their roots into the powdered rock, took up there the soluble matters, and sending up branches and leaves into the air, collected carbon there with their outspread nets. And now the plants, decaying, added humus to the soil, which, increasing year after year, at length made the soil a fertile one. Besides those agitations which break up and scatter fragments of rocks and grind them to powder, there is another process, called

weathering, which is necessary in preparing the soil for vegetation. This consists in the action of chemical forces, in connection with heat and moisture, which not only aid in the pulverization, but also render some of the materials soluble, and therefore available for vegetation.

492. **The Process Seen in Volcanic Countries.**—The formation of soil is continually going on in all parts of the earth in the manner indicated. It can be best seen in the neighborhood of volcanoes. The lava that has issued from a volcano lies barren for years; but the varying temperature, the water, and the oxygen of the air at length produce sufficient disintegration and chemical change to make a soil for lichens. These succeed each other year after year for generations, from which there is a gradual accumulation of humus. This by its decay assists the other agencies of disintegration, and so there is a yearly addition to the soil on the rocky lava. Thus is preparation made for other plants, and so the accumulation goes on till at length, perhaps in the lapse of centuries, the soil becomes deep enough for shrubs and afterward trees. The various steps of this process, thus briefly described, may often be observed in deposits of lava of different ages in the neighborhood of volcanoes.

493. **Different Kinds of Soil.**—In the agitations by which rocks were broken up there was so wide a scattering of the broken materials that the varied mineral ingredients of soil are well mixed up in all parts of the earth. Still there are peculiarities in soils here and there, owing to the predominance sometimes of one and sometimes of another mineral ingredient. For example, in the regions of limestone formations there is apt to be a predominance of lime in the soil. The three chief mineral ingredients of soil are these: 1, *Silica*, in the shape of *sand;* 2, *Alumina*, mixed or combined with sand, as *clay;* and 3, *Lime*, in the form

of carbonate, as *limestone*, *chalk*, etc. Soils are named according to the proportions of these ingredients. Thus if an ordinary soil, dried, is found to contain but 10 per cent. of clay, it is a *sandy soil;* if from 10 to 40 per cent., a *sandy loam;* if from 40 to 70, a *loamy soil;* if from 70 to 85, a *clay loam;* and if from 85 to 95, a *strong clay*, fitted for making bricks. If a soil contains from 5 to 20 per cent. of carbonate of lime it is called a *marl*, and if more than 20 per cent., a *calcareous soil.* Sometimes the only difference in the character of two soils may be mechanical, while the one is barren and the other fertile. Thus there are sandy soils in Ohio which for fifty years have yielded, without manuring, eighty bushels of corn to the acre, and yet they do not differ in chemical character, so far as inorganic matters are concerned, from sandy soils in the Eastern States which are nearly barren. The only difference discovered between the two soils is that the barren consists mostly of coarse grains, while the other is a very fine powder. Commonly, however, when there is a marked difference in fertility, there is a considerable difference in chemical composition.

494. **Rotation in Crops.**—The differences in soil are affected by the crops which we raise. If, for example, a crop be raised year after year upon a soil which contains in due quantity a chemical ingredient particularly adapted to that crop, the ingredient will be at length exhausted. Hence comes the good policy of rotation of crops. Potassium compounds are particularly needed in the raising of turnips, but if turnips be cultivated on the same field year after year, the potassium salts will finally become deficient, and you will have poor crops of turnips. So, also, if pease be raised successively on the same land, the soluble lime in the soil will be at length exhausted. But change these two crops on the two fields, and there will be no difficulty.

The turnips will flourish in the pea-field, because there is plenty of potash there; and the pease will flourish in the turnip-field, because the turnips have not used up the lime.

495. **Manures.**—You have seen in § 486 what analogy there is between the stomach of the animal and the root of the plant. Let us follow out this analogy a little farther. If we give an abundance of proper food to the animal it grows well, but with scanty and improper food it becomes lean and languishing. So it is with the plant. If its root be supplied in the soil with a proper amount of those substances which are fitted for its nutrition, it grows vigorously, and its leaves, flowers, and fruit are abundant. The object of manures is to supply to the soil whatever of these substances are deficient. In doing this we must have regard to the kinds of food which different kinds of plants need. There are certain substances the presence of which in the soil is required by all plants in order to secure vigorous growth. But then in regard to many substances the wants of plants are very different. A potash-plant, for example, must have a soil that has considerable potash in it; while a lime-plant must have one that contains considerable lime. If lime or potash be deficient where it is wanted, it must be supplied in the form of manure. And the same can be said of other substances.

The term manure is applied to any substance which acts as a fertilizer. Sometimes such substances act indirectly by producing some mechanical effect upon the soil, or by modifying the action of other substances, instead of affording a direct supply of nutriment, as is generally done by manures.

496. **Chemical Knowledge Requisite.**—In order to apply manures appropriately we must know something of the chemical characters of the soils, of the plants, and of the

manures. From a deficiency of this knowledge mistakes are made continually by farmers. For example, lime has been often applied where there was already enough of it, as might be shown by a chemical analysis of the soil, and so has proved, not merely a waste, but a positive injury to the land. A very simple test will often give valuable information. Suppose, for instance, we take a pound of earth, and after boiling it for some time in about a pint of water, so that the lumps may be all destroyed, and the earth uniformly diffused in the water, introduce into the mass a strip of blue litmus paper. If this after a little time turns red it shows that the soil is sour, and that the humic acid in it requires the application of lime to neutralize it. Chemistry may be made use of often by the farmer in discovering rich materials for fertilizing his land. Beds of marl have been found here and there which have proved of great value as furnishing a fertilizer for certain soils. We will quote here some remarks of Stöckhardt on these discoveries: "Probably such treasure still lies hidden in the ground in many other places; it appears only to require the divining-rod to indicate where it lies, and the touchstone by which it can be ascertained whether it really is what it appears to be. Yet both are close at hand: the divining-rod is called 'look for it,' and a wine-glass of 'hydrochloric acid' serves as a touch-stone. How many accidental opportunities the farmer has of penetrating a little deeper than usual into the earth! Here a well is dug, or a ditch; there a hill is leveled or cut through in road-making; in other spots a stone-quarry, a sand or loam pit, is opened. These are all excellent opportunities—and even deep-plowing and ordinary work with the subsoil plow not unfrequently furnish others—to make acquaintance with the kind of earth lying beneath the cultivated soil. If an earth of different character is met with under the surface soil, a few drops of hydrochloric acid should be poured upon a specimen of it; if this produces an effervescence, it is a sure sign of the presence of carbonate of lime, and the earth probably belongs to the useful kinds of marl, which may then readily be ascertained more exactly by a chemical examination."

497. **Volatile Substances in Manures.** — There are some valuable substances in some manures which are volatile, and the skill of the farmer is called in requisition to prevent their flying off, or to *fix* them, as it is expressed. If he carelessly leave his manure heaps to putrefaction, he will lose a large part of some of their most valuable material. He will lose, for example, much of the ammonia. It will pass off into the air, and so will be lost to him, though it will not be lost to the earth, for it will be brought down by the rain. By losing it he will unwittingly benefit other farmers over a wide extent of territory, for the volatile matter will be largely diffused. There are means of fixing the ammonia, which are applied sometimes in the manure heap, and sometimes in the field with the manure as it is scattered. These means will be noticed hereafter.

498. **Animal Manures.**—These are of two kinds—the substances composing the body of the animal, and the excretions. They are generally the most valuable manures that we have, for they contain, besides other ingredients, a considerable amount of that very important element, nitrogen. The excretions of different animals vary much according to the kinds of food upon which they live. This is of course to be taken into consideration by the farmer in the application of these manures, and in the mixture of other manures with them.

499. **Guano.**—This is the manure of sea-birds, which has been accumulated during a long period of time in deep layers upon uninhabited islands and rocks. There are im-

mense quantities of it in different parts of the earth. It is calculated that the deposits of it in South and Middle Peru amount to more than twenty millions of tons. The value of this manure, when it is good, is very great. Its goodness depends upon the amount of nitrogen it contains locked up in its ammonia. Next to nitrogen, phosphoric acid, contained in phosphate of lime, must be considered as the most valuable constituent of guano; but of so much more value is the nitrogen than this, that we may lay it down as a rule that the more of ammoniacal salts and the less of phosphate of lime guano contains, the higher is its value. Peruvian guano is better on this account than the guano of Patagonia and that of Africa. The reason that these latter have so small a proportion of ammoniacal salts in them is that by exposure to the action of air and water these salts have been to a great extent washed out. Guano is deficient in potash, and therefore in its application wood-ashes make a useful addition.

500. **Tests of Guano.**—Guano varies much in its character, and on account of its pecuniary value is often adulterated, hence it is well that certain plain tests of its chemical composition should be known, that they may be applied by buyers of the article. We will mention some of them. 1. *Test by Combustion.*—Put fifteen grammes of the guano to be examined in an iron spoon, and hold it over some red-hot coals until a white or grayish ash is left. The weight of the ash, subtracted from that of the guano, gives you the proportion of nitrogenous substance, for this has been burned up and volatilized, while the phosphate of lime makes the ash. In this application of heat the odor differs according to the character of the guano. That from a good specimen is pungent, like the vapor from spirits of hartshorn, while the odor from a poor specimen is like that of singed hair. 2. *Lime Test.*—Put a teaspoonful of guano

into a wine-glass, and upon this a teaspoonful of slaked lime, and, adding a few teaspoonfuls of water, shake the mixture briskly. The stronger the smell of ammonia the better is the guano, for the lime, by taking away the acids that are united with the ammonia, sets that pungent substance free. 3. *Vinegar Test.*—If on pouring vinegar upon guano a strong effervescence ensues, we infer that there has been an intentional adulteration with carbonate of lime. 4. *Test with Hot Water.* — Make a filter of blotting-paper, folded together in the form of a cone, and put it into a common funnel. Put into this fifteen grammes of guano well dried, and pour upon it hot water as long as it passes through of a yellow color. Now dry the filter, and, weighing the dried powder which is upon it, you find what proportion of the guano is dissolved, or, in other words, what proportion of ammoniacal salts it contains, for it is this part of the guano alone that is soluble.

501. **Ammoniacal Salts.**—The salts of ammonium, some of which, as you have seen, are the principal source of the fertilizing power of guano, are chiefly the chloride, or sal ammoniac, the sulphate, the nitrate, the humate (formed with the acid of humus), and the carbonate or salt of hartshorn. These salts are present in stable manure, and in other fertilizing substances which furnish nitrogen to plants. There is considerable ammonia in the gas-liquor which is formed in the process of cooling and purifying the gas. This liquor is very valuable for manure. There also is considerable ammonia in soot, and hence this substance is a good fertilizer.

502. **Bone-Dust.**—The powder of bones is an exceedingly valuable manure, as you can readily see it would be from observing the composition of bone. A bone is composed of an animal part, gelatin, and a mineral part, nine tenths of which is phosphate of lime, and one tenth the carbonate.

These two parts can be obtained separate from each other by processes which are described in the first chapter of Hooker's "First Book in Physiology." The gelatin is of great value as a fertilizer for any crop because of the nitrogen which it contains; and the phosphate of lime is especially favorable to the development of seeds, and therefore bone-dust is peculiarly appropriate as a manure for grain-fields. It is on account of this phosphate of lime that bone-dust is so beneficial to dairy lands. Milk and cheese both contain this substance. There is about half a pound of it in ten gallons of milk. Bone-dust is also an excellent manure for wheat; for though this is a silica plant (§ 483), the presence of phosphates in the soil is essential to the formation of the seeds. If the soil be rich in silicates but deficient in phosphates, excellent straw will be obtained, but the grain will be small in amount: it will be a crop better calculated to make bonnets than bread. It is calculated that 1 cwt. of bone-dust is equal to 25 or 30 cwt. of stable-manure. Although bones contain such fertilizing materials, they must be well pulverized in order that they may be immediately available for the nutrition of plants. It often takes even twenty or more years for the soil to disintegrate fragments of bone of the size of a hazel-nut or a pea, and yet such fragments are frequently seen in the bone-dust of commerce.

503. **Lime.**—While guano, bone-dust, stable-manure, etc., act as direct nutrients, giving actual substance to the plant, the action of lime is for the most part indirect. It acts in many ways. In some cases its chief effect upon the soil is mechanical, rendering it loose and porous. In other cases, as stated in § 496, it neutralizes the acidity of the soil, and thus makes it fertile. In still other cases it excites a more rapid decay of the humus, and thus provides more nutritious matter in the soil for the plants. And still again it

does good service often in aiding the weathering (§ 491) of the mineral substances in the soil, and thus acts as a solvent for matters which the plants need but can not get unless they are dissolved. The direct manures, you observe, act with their own power, and furnish some of their own material to plants; but lime, on the other hand, does not work with its own material, but at the expense of other matters in the soil. Lime, therefore, tends eventually to make the soil poorer unless other manures are applied at the same time, and hence the maxim current among the Belgian farmers:

> "Much lime and no manure
> Makes both farm and farmer poor."

504. **Marl.**—We have alluded to this manure in § 493. Marl is a lime mud which was deposited in the last overflowings of the surface of the earth in its preparation for man. It is sometimes tolerably pure, but is commonly mingled with clay, stones, shells, etc. The lime in it is in the form of carbonate. Its effects upon soils are very similar to those of quick-lime, just described. There are, however, other substances mingled with the carbonate of lime, which modify its effects, and render the marl more valuable as a fertilizer than it otherwise would be. Yet these are so small in amount that the Belgian proverb is nearly as true of marl as it is of lime.

505. **Gypsum.**—The fertilizing properties of sulphate of lime were known in Europe long before they were in this country. Franklin, when abroad, was struck with the richness of the crops raised in fields manured with gypsum, and endeavored to persuade American farmers to use it, but in vain. To convince them of the truth of his statements he resorted to the following expedient: He strewed gypsum on a sloping field in such a way as to form in enormous letters the words *Effects of Gypsum*. The abundant growth

on the part so prepared, making the letters legible to every passer-by, brought the new manure at once into popular favor. There has been much dispute as to the manner in which gypsum acts as a fertilizer. One thing is quite settled about it—it answers a good purpose in *fixing* the ammonia in the soil. This is effected by a double decomposition between the sulphate of lime and the carbonate of ammonium, the result being carbonate of lime and sulphate of ammonium. In this connection we will mention that sulphuric acid is often used for fixing ammonia in manures, forming with it a sulphate, which is not volatile like the carbonate.

506. **Vegetable Refuse.**—In every garden and on every farm all vegetable matter which is useless should, so far as it can be done, be made to add to the stock of humus by its decay. It is convenient to have in a garden a pit into which all weeds, small trimmings, etc., can be thrown, where, covered up, they may be left to decay, forming rich humus. The decay may be hastened by the occasional addition of some lime. On most farms there is a large quantity of vegetable matter left to decay on the surface of the ground, and thus waste by volatilization a part of its fertilizing material. This refuse might be of great value if gathered up and mingled in a compost heap with other materials.

507. **Sewer-Water.**—This always contains a great variety of fertilizing substances, and therefore is one of our most valuable manures. Yet it is very generally wasted. Vast quantities of it in our towns and cities run off into the water, where it is not only lost, but sometimes does much harm. The water of the River Thames is becoming more impure every year from this cause. It is calculated that the London sewers pour into it fertilizing materials of the annual value of over half a million pounds sterling. Great

attention has been attracted to this subject, and plans have been broached for avoiding this enormous waste.

QUESTIONS.

486. State the analogy between the stomach of an animal and the root of a plant. What is said of the difference in the proportion of nutritious substance?—487. State the analogy in regard to loosening the soil. What influence has clay upon soil? What effect has the cold of winter upon it? What is said of earth-worms?—488. What of water in the soil?—489. From what source comes the principal part of the soil? In what two ways can you see what its chief source is?—490. What is the second source of the soil? What name is given to the product from this source? What is said of its chemical character? What are the products of its decomposition? What mechanical effect does this decomposition produce? What other effect is mentioned?—491. State in full how soil was originally made. What is weathering?—492. Describe the process of making soil as seen in volcanic countries.—493. How are peculiarities in soil produced? What are the three chief mineral ingredients in soil? What are some of the different soils made by different proportions of these ingredients? What is said of the mechanical differences of soils?—494. What is said of the rotation of crops?—495. Follow out the analogy between stomachs and roots in regard to amount of food. What is the object of manures? What circumstances should govern the selection of the kind of manure? What is said of the term manure, and of the modes in which manures act?—496. Illustrate the truth that a knowledge of chemistry is necessary to a suitable application of manures. What opportunities often offer for ascertaining the chemical character of subsoils? What is said of hydrochloric acid as a test of the character of soils?—497. What of the management of volatile substances in manures?—498. What of animal manures?—499. What is guano? What is said of its abundance? What are the chemical ingredients that give it its value? Why is the guano of Peru better than that of Africa and Patagonia? Why are wood-ashes a good addition to guano when used?—500. State the test of guano by combustion. State the lime test. The vinegar test. The test with hot water.—501. What are the ammoniacal salts present in various manures? What is said of gas-liquor?—502. What is the composition of bone? What is said of the fertilizing powers of the ingredients? What of their use in regard to different crops? What of the value of bone-dust? What of its degree of

pulverization?—503. How does lime differ from most other manures in its action? Give the maxim in regard to lime, and the ground for it.—504. What is marl? What is said of its effects on soils?—505. Give the anecdote of Franklin in regard to gypsum. What is said of the manner in which gypsum acts as a fertilizer?—506. What is said of vegetable refuse?—507. What of sewer-water?

CHAPTER XXIX.

OILS AND FATS.

508. **Acids.**—The common idea that acids are sour bodies must now be given up, for under this head are included many oily and fatty substances which do not react acid at all. The sources of organic acids are exceedingly various; thus formic acids can be extracted both from red ants and from nettles; acetic acid is a product of fermentation, as you will learn in the next chapter; butyric acid is contained in rancid butter, palmitic acid in palm-oil, stearic acid in tallow, and melissic acid in beeswax. These form part of a series called the Fatty Acid Series.* The first one is a liquid, with a low boiling-point; the rest increase in density, becoming oily and finally solid. The first acids of this series mix with water, but the last acids are quite insoluble in water; thus a gradual transition of properties is noticeable, and their formulæ become heavier and more complex as you ascend the series. Formic acid is CH_2O_2, acetic acid $C_2H_4O_2$, etc., while the last named, melissic acid, has the formula $C_{30}H_{60}O_2$.

There are many other acids which do not belong in this series, also derived from various sources; thus tartaric acid

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* See last column in Table on page 303.

is found in grapes, citric acid in lemons and some other fruits, malic acid in apples, lactic acid in sour milk, etc.

These organic acids form salts by replacement of hydrogen with a base just like the mineral acids. In fact the acids mentioned as found in fruits do not exist as such, but combined with potassium, sodium, or possibly calcium. Thus in the case of tartaric acid it is combined with potassium in the plant. Acid potassium tartrate, or so-called cream of tartar, is gradually deposited in wine-casks from the wine, and this is one cause of the improvement of wine by age. Rochelle salt is a double salt—a tartrate of potassium and sodium. So tartar emetic is a tartrate of potassium and antimony. Then there is a double tartrate of potassium and iron, which is a valuable medicine.

Many of the organic acids char on heating, owing to the imperfect combustion of the carbon. If they are heated more strongly complete decomposition ensues, just as in the case of wood, sugar, etc. This distinguishes them in their reactions from the mineral acids.

509. **Tannic Acid.**—This body is not a true acid, and strictly belongs to another group of bodies called glucosides, but it is of so much importance in many ways in the arts that it should not be passed by. It exists extensively in the bark of many trees, as the oak, horse-chestnut, hemlock, birch, etc., and is also found in some roots, and in the leaves of roses and pomegranates. It exists most abundantly in the gall-nut of the oak. Here we have a valuable vegetable product as the result of disease, for the gall-nut is a morbid growth which comes from the wound of an insect made in the oak for the purpose of depositing its eggs.* Tannin, as this body is commonly called, is a very astringent substance. By the decomposition of tannic acid another

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* See Hooker's "Natural History," page 270, for further particulars.

acid called gallic acid is obtained, and then by the decomposition of this latter several other acids can be produced.

510. **How Obtained.**—The mode of obtaining tannin is as follows: Into a globular funnel, *b*, Fig. 115, which can be closed at the top by a stopper, is introduced a quantity of powdered nut-galls after the tube of the funnel, *c*, has been stopped with a little cotton. The funnel is then placed in the bottle, *a*, and is filled up with the ether of the shops, which is about one tenth water. The apparatus being allowed to stand several days, there appear two layers of liquid. The lower one, which is as thick as sirup, is a concentrated solution of the tannin in water, with very little ether in it, while the upper is ether containing a mere trace of tannic and gallic acids. The theory of this process is that the tannin has such a greedy affinity for water that, as the liquid passes through the powder, the tannin in it seizes the water, withdrawing it from the ether. The tannin is obtained from this sirup-like solution by evaporation.

Fig. 115.

511. **Tanning.**—In the common process of tanning the tannic acid in the bark is the effective agent. It is a chemical union of this acid with the gelatin of the skin that converts the skin into leather. This combination prevents the decay or putrefaction which would otherwise take place in the skin, just as the chemical union of corrosive sublimate with the albumen of the wood in kyanizing prevents the decay of the wood. A black color is given to the leather by washing it with a solution of iron, the tannin of the leather uniting with the iron to form a tannate of iron. The reason that drops of tea upon a knife-blade become of a dark color is that the tannic acid in the tea forms a tannate with the iron.

512. **Writing-Ink.**—Common writing-ink is prepared from nut-galls and ferrous sulphate. A solution of the tannic acid is obtained by boiling the galls in water, and this is mixed with a solution of ferrous sulphate. A ferr*ous* tannate results, which makes a very pale solution; but by exposure to the air the tannate becomes more highly oxidized, and thus changes to a ferr*ic* tannate, which is of a very dark color. It is desirable, for the permanency of the writing, that this change should take place in part in the fibres of the paper, and not wholly in the ink before it is used. The ink is, therefore, bottled, and thus shut in from the air before the change is completed, so that when used in writing it may be rather pale, and become gradually dark on the paper. To keep the tannate from settling gum is added to the ink, and to prevent moulding oil of cloves or creosote is introduced in small quantity. Corrosive sublimate is a very effective preventive of moulding, but it is obviously dangerous to employ it with the ordinary careless habits of people in using ink. It is from the action of tannin on ferrous sulphate and other salts of iron that it is used in dyeing.

513. **Oils and Fats.**—These substances are found widely distributed in both the vegetable and the animal kingdoms, and are constituted very much alike in both. In plants they are generally contained in the investing membranes of seeds or in the cellular substance of fruits. There is seldom any fatty matter in leaves or in roots. The principal vegetable oils and fats are as follows: *Linseed-oil*, which is pressed out from flax-seed; *Olive-oil*, from the pulp of the fruit of the olive-tree; *Palm-oil*, a yellow fat, similar to butter, from the fruit of a species of palm-tree; *Castor-oil*, from the seeds of the castor-oil plant; *Butter of Cacao*, the tallow-like fat of the cacoa-nut, the cause of the fat particles which rise on boiled chocolate; *Hemp-oil*, from hemp-seed, etc. Oils can also be obtained from pumpkin-

seeds, walnuts, sunflower-seeds, hazel-nuts, even apple-seeds, plum and cherry stones, etc.

514. **Composition.**—The oils and fats are composed mostly of three ingredients, called stearin, palmitin, and olein. The stearin, when separated from the others, is a solid at all ordinary temperatures, while the olein is a liquid; the palmitin is midway between the other two. In very cold weather, when a portion of lamp-oil becomes solidified, we have a partial separation between the stearin and the olein. The consistency of fatty substances depends upon the proportions of olein and stearin in them, the former predominating in the liquid, and the latter in the more solid bodies. But these constituents of fats are far from being simple substances. They are compounds formed by the union of acids with a certain base or radical called glyceryl. Thus stearin is a combination of stearic acid with this base, a glyceryl stearate, just as pearlash is potassium carbonate. Likewise olein is glyceryl oleate. Bodies formed after this pattern are called salts in organic chemistry just as in mineral chemistry, the only real difference being that the radicals and the acids in one instance are far more complex than in the other. This the formulæ for stearin, palmitin, and olein show:

Glyceryl, a hydrocarbon radical,	$(C_3H_5)'''$
Stearin, or glyceryl stearate,	$(C_3H_5)'''(C_{18}H_{35}O_2)_3$
Palmitin, or glyceryl palmitate,	$(C_3H_5)'''(C_{16}H_{31}O_2)_3$
Olein, or glyceryl oleate,	$(C_3H_5)'''(C_{18}H_{33}O_2)_3$

515. **Glycerin.**—This is a colorless, sirupy liquid, of a sweet taste; this latter quality gives it its name, which is derived from a Greek word—*glukus*, sweet. It belongs to the class of bodies called alcohols, but is described in this connection because it is a product of the decomposition of oils and fats. It is a hydrate of glyceryl, and has the formula $C_3H_5(HO)_3$.

Glycerin is soluble both in water and alcohol. It can be obtained by boiling stearin and olein with a solution of potassium hydrate. The fat (or stearin) is decomposed by the substitution of potassium for glyceryl, and the resulting products are potassium stearate and glyceryl hydrate or glycerin. We will explain this further in the section on soaps. Glycerin has remarkable solvent powers, dissolving readily the greatest variety of substances, mineral and organic. *Nitroglycerin* is a powerfully explosive oily liquid, made by the action of nitric acid on glycerin, much as in the case of gun-cotton. It is very dangerous to manufacture and to handle, and at the same time very useful for blasting rocks. Mixed with porous silica and some other substances it is called *Dynamite.*

516. **Candles made of Stearin and Stearic Acid.**—Stearin may be obtained from lard and tallow by a simple process. If the fat be melted, as it cools it hardens, forming a mass from which the fluid olein can be pressed out, leaving the stearin alone by itself. The stearin is used for making candles, while the expressed olein is the well-known lard-oil. But a better material for candles can be obtained by decomposing the stearin with lime, thus forming a stearate of lime, and then decomposing this with sulphuric acid. In this way we obtain stearic acid, for the sulphuric acid takes the lime away from the stearate of lime, and thus sets the stearic acid free. This acid is a white, crystalline, translucent substance with a brilliant lustre. It is a better material for candles than stearin, because it is not so readily softened by heat, its melting point being about ten degrees higher than that of stearin.

517. **Soaps.**—In the preparation of glycerin, described in § 515, we did not tell you any thing about the potassium stearate which was produced along with the glycerin; this substance is *soap.* Soap, then, as well as oils and fats, is a

true chemical *salt.* In the manufacture of soap, lime, sodium hydrate, or potassium hydrate may be used; calcium, sodium, or potassium stearate being formed. Natural fats, however, are composed of stearin, palmitin, and olein, consequently the soaps are mixtures of stearates, palmitates, and oleates of the bases named, and not pure stearates. If we consider the formation of only one of these bodies, it can be expressed in a rather complex equation, thus:

$$\overset{\substack{\text{Caustic soda or}\\ \text{Sodium hydrate.}}}{3(NaHO)} + \overset{\substack{\text{Olive-oil or}\\ \text{Glyceryl oleate.}}}{(C_3H_5)'''(C_{18}H_{33}O_2)_3} = \overset{\text{Sodium oleate.}}{3(NaC_{18}H_{33}O_2)} + \overset{\text{Glycerin.}}{(C_3H_5)'''(HO)_3}$$

518. **Hard and Soft Soap.**—Hard soaps are formed by soda, and soft by potash. A potash soap can be converted into a soda soap by means of common salt. This is often done by soap-makers on a large scale. The soft soap is dissolved in boiling water, and salt is thrown into it. There is a collection of soda soap on the surface of the water, which on cooling becomes hard. The chemical change is this: The chlorine of the salt goes to the potassium of the soap, forming potassium chloride, while its sodium goes to the stearic and oleic acids to form stearate and oleate of sodium.

The cleansing power of soap in washing depends chiefly upon the fact that the water used with them sets free some of the alkali from its combination with the fatty acids, so that we have a mixture of caustic alkali and fat-salts, the alkali by its union with the greasy matters in the cloth cleansing it, and the salts—the stearate and oleate—by their lubrication, keeping the cloth pliant, and thus making the operation easy. The alkali would not answer alone, because it would by shrinking the fibre of the cloth render it rigid, and thus prevent its perfect cleansing, and at the same time would injure it by its too great causticity.

Alcohol dissolves soaps, and the common soap liniment is a solution of soap in alcohol. Camphor added to this makes the liquid opodeldoc. Volatile liniment is a sort of soapy mixture made of oil and the volatile alkali ammonia. Equal parts of lime-water and sweet-oil make a soapy mixture which is one of our best applications for a burn. A solution of ammonia in alcohol is very effective in removing grease spots from woolen clothes, because it unites with the grease to form a soap, which readily washes out with the application of a little water.

519. **Properties of Fats.** — Fatty or oily substances have some peculiar properties which fit them for many valuable uses. They spread readily in the pores of substances, and as they are not volatile they answer a valuable purpose in keeping leathern and other articles soft and pliable for a long time. As the fats float upon water, they can be used for excluding air from various substances, thus preserving them from chemical change. Thus a layer of oil is sometimes poured over preserved fruits. As the fats are not only insoluble in water, but have a sort of repulsion for it, they are extensively used for preserving substances from being penetrated by water. Shoe-leather is rendered impervious to water by greasing. Iron is oiled to protect it from the damp air, and thus keep it from rusting. Timbers saturated with oil will be preserved a long time from rotting in the damp earth.

520. **Varnish Oils.**—All fatty substances on exposure to the air gradually absorb oxygen and evolve carbonic acid; and as there is always a certain amount of nitrogenous substance in them, a sort of fermentation occurs, producing acids, and thus making the fats rancid. There are some oils, however, that instead of changing thus gradually in the air, absorb oxygen rapidly and become dry and hard. These drying oils are called varnish oils, because they are so much used in mixing varnish. Linseed-oil is one of the most important of them. It is prepared for varnishing by freeing it from all mucilaginous matter by heating it with litharge or oxide of lead in it, and mixing it, after this clarifying, with some coloring substance.

Oil-cloth is cotton cloth covered with colored varnish, and oil-silk is varnished silk. Drying oils are used in painting, and mixed with lampblack they constitute printers' ink.

521. **Spontaneous Combustion.**—It is because of the rapid absorption of oxygen from the air that the drying oils are sometimes the cause of spontaneous combustion. This commonly occurs in waste thrown together in a heap. The heat produced by the absorption of the oxygen sets fire to the combustible substance—cotton or linen or woolen—that is impregnated with the oil, and the oil, being itself combustible, burns also. The reason that the heat is adequate to produce this effect is that it is so shut in among the parts of the heap where it is generated that it accumulates, reaching at length the point of combustion. The oil in drying always produces heat; for condensation of a gas, as it combines with a fluid or solid substance, can not take place without this effect; but the heat in all ordinary circumstances quietly escapes into the air as fast as it is produced. In the drying of paint upon any surface heat is formed at every point of it, but it produces no combustion because it escapes instead of accumulating.

522. **Combustion of Fats.**—As both the fat acids and their base, glyceryl, are compounds of carbon, oxygen, and hydrogen, we have in them the same elements as in wood and coal, and therefore their combustion is attended with the same phenomena and the same results. The facts stated in Chapter X. fully illustrate this, and we need not dwell upon the point here.

523. **Wax.**—This substance has so decided a resemblance in some respects to the fats that it may be classed with them. It is a mixture of two substances—*cerin* and *myricin.* A soap can be formed with cerin by boiling it in a solution of potassium hydrate. Wax occurs in small quantity in all plants. It gives a shining appearance to leaves,

stalks, and fruits, which in some cases is very decided. Some plants in South America and China contain so much wax that it is obtained from them by boiling and pressure, and is sold under the name of vegetable or Chinese wax. But most of the wax in use in the world is made by bees. It has been supposed that the bees simply gathered the wax from flowers as it exists in the pollen; but this is certainly not true in regard to all of it, for it has been satisfactorily proved that the bees actually convert the sugary substance into wax in their abdominal sacs.

524. **Volatile Oils.**—The oils which we have already noticed are called *fixed* oils, because they have no tendency to pass off into the air. The volatile oils, of which oil of turpentine, oil of peppermint, and oil of lemons are familiar examples, nearly all possess the same chemical composition —$C_{10}H_{16}$; they differ from the fixed oils in three important respects: 1. As their name imports, they are readily dissipated in the air. Some of them are exceedingly volatile. Sometimes a volatile oil is adulterated with some fixed oil; but this can be readily detected by dropping some of the specimen on paper, for if it be adulterated it will leave a grease spot upon it. 2. Volatile oils dissolve in alcohol. Such solutions form the bases of essences and cordials and perfumed waters, such as the *Eau de Cologne*. 3. They are hydrocarbons, and not salts of fatty acids like the fixed oils. The volatile oils are very numerous, as you may readily see from the fact that all the varied odors of plants are due to their presence. They are most frequently produced in flowers and seeds, sometimes in the stalks and leaves, and in some plants in the roots. Sometimes there are several sorts of oil in the same plant. Thus there are three different kinds of oil in the orange-tree—one in the leaves, another in the blossom, and still another in the peel of the fruit.

525. **Composition.**—The volatile oils are divided into three classes, according to their composition: 1. *Oxygenated* oils. These, which are by far the most numerous class, are composed of carbon, hydrogen, and oxygen. 2. *Non-oxygenated* oils, which are composed only of carbon and hydrogen, and are therefore called hydrocarbons. The principal of these are the oils of turpentine, savin, juniper, lemons, etc. 3. *Sulphuretted* oils, which are composed of carbon, hydrogen, and sulphur. Nitrogen is a component of some of them. These oils exist in mustard, horseradish, garlic, onions, hops, etc. They have a very pungent smell, causing lachrymation, and are so acrid that they raise blisters when applied to the skin.

526. **Camphor.**—Camphor is obtained by distilling with water the wood of the *laurus camphora.* This forms when pure a white, crystalline, translucent solid, having a peculiar odor which is familiar to every one. It gradually sublimes at ordinary temperatures, and often forms beautiful crystals on the sides of the bottles in which it is kept.

527. **Resins.**—Where an essential or volatile oil is exposed to the air, a part of it evaporates, diffusing an odor, but a part combines with the oxygen of the air, forming a resin. The pure rosin, or colophony, is thus produced from the oil of turpentine. It is really a mixture of two acids. This oxidation is, however, only partial, so that the turpentine when gathered is a mixture of the oil and the resin. Some of the resins are called balsams. The resins are very indestructible, and have also the power of preserving other substances from decay. The mummies found in the pyramids of Egypt are bodies which were embalmed with resins. *Amber* furnishes the most striking illustration of this indestructibility. This resin was formed in the early ages of the world, it having survived the destruction of the trees from which it exuded. Insects are often seen inclosed in

pieces of it, embalmed, as we may say, centuries upon centuries before the Egyptians lived whose mummies are found in the pyramids.

528. **Uses of the Resins.**—The resins are chiefly used for making varnishes. In *spirit varnishes* the solvent is alcohol; in *oil varnishes* it is some drying oil. As the resins are soluble in fat oils, they enter into the composition of many ointments and plasters. Sealing-wax is mostly the resin called shellac, with a little turpentine to make it melt and burn more readily, and some cinnabar, lampblack, or other substance to color it.

529. **Caoutchouc and Gutta-Percha.**—These are mixtures of several hydrocarbons, and are in their composition very much like turpentine oil. The caoutchouc is the milky juice which exudes from incisions made in several kinds of large trees in South America. This, when left to dry in the air, becomes a white elastic mass. The drying is more rapid when the exuded substance is spread upon moulds of clay and suspended over a fire, as is commonly done. The soot, which thus becomes incorporated with it, gives it a dark color. Gutta-percha is obtained from certain trees in the East Indies. Like the caoutchouc, it exudes as a milky juice. It differs from caoutchouc in three respects —it is very tough, has little elasticity, and becomes soft and plastic with a moderate heat, hardening again as it grows cool. This difference in properties fits these two substances for different uses in the arts.

530. **Vulcanized India-Rubber.**—This substance is a compound of sulphur and caoutchouc, which has received peculiar qualities from being subjected to a certain degree of heat. Unless this be done it is too soft for use. Shoes and other articles of this material are therefore, after being made, brought up to the required temperature, and on cooling they have the two qualities of firmness and pliability.

The discovery of this effect of heat, so important in the manufacture of India-rubber goods, is said to have been made by our countryman, Goodyear, in consequence of an accidental circumstance. As he was talking earnestly with a friend, in making a gesture he threw into the fire a bit of the compound of sulphur and caoutchouc. On taking it out of the fire he observed that its properties were essentially altered, and this observation led to experiments which resulted in the discovery alluded to, and to its wide application in the India-rubber manufacture.

531. **Vegetable Alkaloids.** — There are certain organic bases, that is, bases which are extracted from the seeds, bark, roots, and other parts of plants. They are called alkaloids, because, like the alkalies, they produce a basic reaction on red litmus paper. We will mention a few of the most prominent of them. There is *morphine*, which we get from opium, and *quinine*, which we get from the cinchona bark. *Caffeine*, or *theine*, is the alkaloid found both in the leaves of the tea-plant and the berries of the coffee-plant. *Strychnine*, which is so exceedingly poisonous, is obtained from the seeds of the strychnos nux vomica. *Nicotine* is found in tobacco. It is an oily, colorless substance, which is so poisonous that a fourth part of a drop will kill a rabbit. Most of these bases are crystalline, and the crystals of some of them are beautifully delicate. Thus the crystals of caffeine are fine white prisms of a silky lustre; and those of piperine, the active principle alike of white, black, and long pepper, are white and needle-shaped. Most of the organic bases, like the inorganic, unite with acids to form salts. Thus morphine and quinine unite with sulphuric acid to form sulphates.

The formulæ of these bodies are very complex. They all contain nitrogen, however, besides C, H, and O, and belong to the class of bodies called Amines, as mentioned in § 425.

What the organic radicals are of which these alkaloids are composed is not definitely known. When the exact constitution of quinine, for instance, is discovered, it will be possible to prepare it artificially, instead of extracting it from cinchona bark. This discovery will be of immense importance, and will doubtless prove a fortune to the happy discoverer.

532. **Coloring Matters.**—There is a great variety of these in the vegetable world. A portion of them are composed of C, H, O, and N, but some of them contain no N. The former are called nitrogenous because they contain nitrogen, and the latter non-nitrogenous. The principal of the latter class are madder, hematoxyline, which is the coloring principle in logwood, Brazil-wood, and camwood, gamboge, etc. Indigo is the most important of the nitrogenous class. This is derived from the juice of several species of the plants called indigofera. The indigo is not, however, of a blue color in the plants, but is almost colorless. It acquires the brilliant blue color that we see it have by a fermentation, to which the leaves of the plants are subjected in the extraction of the indigo. Blue indigo is, therefore, oxidized indigo, and by depriving it of its oxygen we can restore it to its colorless state. When thus deoxidized it is soluble, as it is in its natural state in the plant; but by exposure to the air it absorbs oxygen rapidly, and so becomes blue and insoluble. The blue litmus, so much used by the chemist in testing acids and bases, is a nitrogenous coloring matter which is derived from certain lichens. Almost the only coloring matter of animal origin is cochineal —an insect. The color from this insect is called carmine.

533. **Mordants.** — Some coloring matters have such an affinity for the substance of cloth that they will unite intimately and firmly with the fibres, and so make fast colors. But some have not this power. In order to fix the colors

in such cases, some substance must be employed which has a strong attraction for both the coloring matter and the substance of the cloth, and can therefore unite the two firmly together. Such a substance is called a *mordant*, for reasons already given. The cloth to be dyed is first charged with the mordant, and then is immersed in the dye.

534. **Colors Modified by Mordants.**—The mordant not only fixes the color, but modifies it, so that with different mordants different colors can be produced with the same dye. Thus, by using with madder the acetate of aluminium, produced by mixing common alum with acetate of lead, a red color is obtained; but if ferrous sulphate be mixed with the acetate of lead instead of the alum, a deep black color is the result. Then, again, if some arsenious acid be added, together with the ferrous sulphate, the madder gives a rich purple color. Now all of these madder colors can be produced upon the same piece of calico by printing the different figures with different mordants before introducing it into the dye. The printing is done by rollers, between which the calico is passed. These rollers are engraved with the figures, and the pastes containing the mordants are each put upon its appropriate set of rollers. The calico is passed through the several sets successively. After all the mordants are thus printed upon the cloth it is immersed in the dye. The process is not finished yet, for the common color of the madder is in all those parts of the cloth not touched by the mordants. But the color is not fast, and is easily washed out, leaving a white ground, the washing out not affecting at all the colors fastened by the mordants.

QUESTIONS.

508. Why must the common idea that acids are sour be abandoned? Name some of the sources of organic acids. What is said of the properties of the members of the fatty acid series? In what conditions do the

acids of fruits, etc., exist in the plant? How may some organic acids be distinguished from mineral acids?—509. From what sources is tannic acid obtained? What is its character? What is said of the products of its decomposition?—510. Describe the mode of obtaining it.—511. What is tannin? To what is it compared? Give the chemical explanation of the black color of leather. Why do drops of tea on a knife-blade become dark?—512. Explain the common mode of making writing-ink. What is said of securing permanency in writing? What substances are added to ink, and for what purposes?—513. In what parts of plants are oils and fats formed? Name some of the principal ones, with their sources.—514. What is said of their composition? What is stearin? Olein?—515. What are the properties of glycerin? To what class of bodies does it belong? What is nitroglycerin? What is dynamite?—516. How can stearic acid be obtained? Of what are candles best made?—517. What is soap, chemically considered? Explain the action of caustic soda on olive-oil. Of what are natural fats composed?—518. What is the difference between hard and soft soaps? Upon what does the cleansing power of soap depend? Mention some of the uses of soap. What is the best application for burns?—519. What is said of the properties of fats, and of the uses to which they are accordingly applied?—520. How do fats become rancid? What are varnish oils? How is linseed-oil prepared for varnishing? What are oil-cloth and oil-silk?—521. State in full what is said of spontaneous combustion.—522. What is said of the combustion of fats?—523. What are the nature and composition of wax? What is said of its occurrence in plants? What of its preparation by bees?—524. How do volatile oils differ from fixed? How can adulteration of a volatile with a fixed oil be detected? In what parts of plants are the volatile oils found?—525. Give the three classes of volatile oils, and what is said of them.—526. What is said of camphor?—527. What are resins? What is said of their indestructibility?—528. What of their uses?—529. What is said of caoutchouc? What of gutta-percha?—530. What of vulcanized India-rubber.—531. What are vegetable alkaloids? Mention some of them, and the sources from which they are obtained. What is said of their crystals? What of their composition?—532. What are the two classes of coloring matters? What is said of indigo?—533. What is said of mordants?—534. What is said of modifying color by mordants? In what way can different colors be put upon the same piece of calico?

CHAPTER XXX.

FERMENTATION.

535. **Different Kinds of Fermentation.**—The word fermentation is applied to various decompositions and changes which occur in organic substances. We have the alcoholic fermentation, producing alcohol; the acetous, producing vinegar, etc. It is of these two kinds that we shall speak in this chapter. By the alcoholic fermentation sugar is converted into alcohol, and by the acetous alcohol is converted into acetic acid, the sour principle of vinegar; or, strictly speaking, alcohol is made from sugar, and acetic acid from alcohol.

Putrefaction and fermentation are really the same thing, only the former name is given to the decomposition when accompanied by an offensive odor. Some fermentations give rise to evolution of gases, derived from the constituents of the decomposing substance; when these gases have a disagreeable odor, as sulphuretted hydrogen, certain hydrocarbons, and ammonia, for example, produced in the decomposition of animal matter, the term putrefaction is used. Nitrogenous bodies are the most disposed to this kind of decomposition. Substances which arrest fermentation already begun, or deprive bodies of the power of fermenting, are called *antiseptics.* Such are ferric chloride, arsenious anhydride, carbolic acid, etc.

536. **Ferments.** — There must always be a fermenting agent to produce the change. Neither sugar nor alcohol has any tendency to ferment of itself, but they very readily

do so on the application of a small amount of some ferment. This ferment may be either of the albuminous substances gluten, albumen, or casein.

The manner in which these bodies act in exciting fermentation is very imperfectly understood; "they neither add any thing to the fermenting body nor take any thing away from it, but the motion or disturbance of their particles, while undergoing putrefaction, is supposed to be communicated to the particles of the fermenting body with which they are in contact, and thus induce decomposition." Fermentation is always accompanied by the growth of organized bodies—called fungi when vegetable, and infusoria when animal. In fact, their development is regarded as the exciting cause of fermentation and putrefaction.

537. **The Chemical Change in Alcoholic Fermentation.**—Alcohol is composed of the same elements as sugar, but in different proportions. The production of alcohol by the fermentation of sugar is not really a conversion of sugar into this substance, but a splitting up of the sugar into alcohol and carbonic anhydride. Cane-sugar does not thus break up, but is converted first into glucose, or grape-sugar, and this is decomposed in the following manner:

$$\underset{\text{Grape-sugar.}}{C_6H_{12}O_6} = \underset{\text{Alcohol.}}{2C_2H_6O} + \underset{\text{Carbonic anhydride.}}{2CO_2}$$

Some other substances are formed at the same time, but only in small quantity; and their production has been disregarded in the equation.

538. **Yeast.**—What is commonly called yeast is really a growth, for yeast is a collection of very minute plants; so minute that it is estimated that a cubic inch contains twelve hundred millions of them. This plant, revealed to us by the microscope, multiplies itself with exceedingly great rapidity, and will continue to do so as long as there is nitrogenized matter to supply it with the means of growth.

Thus in a brewery the quantity of yeast continually increases, and it is sold largely for the raising of bread, a fermenting process to be noticed soon. There is a difference of opinion as to the mode in which yeast causes fermentation. Some suppose that it is the yeast-plants that produce this effect, while others suppose it is their decomposition.

539. **Wines, Cider, etc.**—In making these no addition of yeast is required, for there is nitrogenous matter in the juices from which they are made, which by exposure to the air becomes a ferment. In making Champagne and other sparkling wines, the wine is bottled before the fermentation is finished. Of course the process goes on in the bottle, and the carbonic acid produced is pent up in the liquid, ready to expand and escape the moment the way is opened. Sweet wines are those in which there is some sugar that has not been decomposed in the fermentation. Wines are called *dry* when they contain very little sugar. Wines are made from other fruits as well as the grape, as, for example, the currant, the gooseberry, the elderberry, etc. Cider is essentially a wine made from apples. Much of the so-called Champagne wine is really cider, to which a peculiar flavor is given. Other wines are counterfeited, and there is probably no class of men more often cheated than wine-drinkers.

540. **Flavor of Wines.**—The flavor which distinguishes grape wines as a class from other spirituous drinks is produced by a very small amount of an ethereal substance called œnanthic ether. When obtained in a separate state it is a very fluid liquid, having a sharp, disagreeable taste, and a vinous odor so powerful as to be almost intoxicating. It does not exist in the grape, but is one of the products of the fermentation, and increases with the age of the wine. You can have some idea of the power of this substance from the fact that in few wines does it constitute more than the one four-thousandth part of their bulk. It is often obtained by manufacturers of wines from grain spirit and cheap wines, and is used by them for producing imitations of wines of higher prices with such cheap articles as potato

whisky. Besides the general wine flavor given by the œnanthic ether, there are other flavors imparted by other substances giving to the various wines individual characteristics.

541. **Acidity of Wines.**—The acidity of grape wines is owing to the presence of tartaric acid in combination with potassium, forming the acid tartrate of potassium, or cream of tartar. As this gradually separates from the wine, and collects as a crust on the sides of the casks and bottles, the longer wines are kept the less acid they become, and hence in part the value which age gives to them. The acid which is present in small amount in malt beer is acetic acid, the acid of vinegar; and that which we have in cider is lactic acid, the acid which is present in sour milk; so that wine, malt beer, and cider each has a different acid. When, however, the fermentation goes in either of these beyond the production of alcohol, acetic acid results, for then we have the acetous fermentation.

542. **Amount of Alcohol in Wines.**—The proportion of alcohol varies very much in different wines. Even in the strongest wines more than three fourths of the liquid is water. The proportion, by measure, of alcohol in the most prominent wines is as follows:

	Per Cent.		Per Cent.
Port	21 to 23	Tokay	9
Sherry	15 to 25	Rhenish	8 to 13
Madeira	18 to 22	Moselle	8 to 9
Marsala	14 to 21	Champagne	5 to 15
Malmsey	16	Burgundy	7 to 13
Claret	9 to 15		

543. **Production of Alcohol from Starchy Substances.**—In the production of alcoholic liquors from barley, rye, potatoes, etc., in which starch is the chief ingredient, and sugar is only present in very small amount, a preliminary process is necessary in order to change the starch into sugar. In making beer from barley this is done in the following manner: The grain is first moistened in heaps, and spread upon a floor in a dark room. It sprouts, and in doing this some of the starch in it is turned into sugar by the action of the diastase (§ 472), so that the barley has quite a sweet taste. The process is arrested by drying in the kiln just as the germs are about to burst from the seed, for if it be left to

go on beyond this some of the sugar will be lost by being converted into vegetable fibre. The malt—for so this sugared barley is called—after being dried, is bruised and put into the mash-tun with water in the requisite quantity, which is gently warmed. Here the sugar and diastase are dissolved, the latter at the same time converting the remaining starch of the seeds into grape-sugar. The liquor, or wort, as it is called, is now put into the boiler, and boiled with the hops, which not only give to the liquor its bitter taste, but also help to clarify it. The boiled liquor is run off into shallow vats, where it is cooled, and then it is poured into the fermenting tun, where, with the addition of yeast, the requisite fermentation is produced. In like manner in making whisky from the potato the starch must first be converted into sugar to prepare for the alcoholic fermentation.

544. **Distillation.** — In the operations of which we have spoken alcohol is obtained mingled with a large amount of water. By the process of distillation this amount of water can be much diminished, giving us the stronger spirituous liquors called by the common names of distilled liquors and ardent spirits. Brandy, for example, is distilled from wine, and has from 50 to 54 per cent. of alcohol, while the strongest wine has but 25 per cent. In rum, distilled from fermented molasses, there is from 72 to 77 per cent. of alcohol. A common form of apparatus for distilling brandy and spirits of wine is represented in Fig. 116 (p. 385). It consists of a copper still, A, having a dome-shaped head, B, which by a tube, C, communicates with the worm, D. Heat being applied to the still by the Bunsen burner, the alcohol passes over to the worm more freely than the water because it is more volatile. For the purpose of condensing the vapor as it passes into the worm, the worm is inclosed in a cylindrical vessel, E, which is full

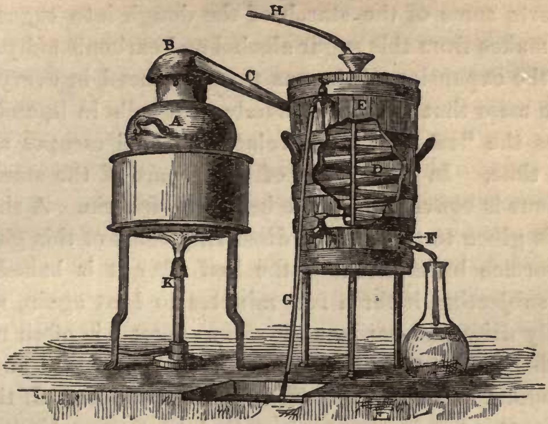

Fig. 116.

of water. To prevent the water from becoming hot a constant supply of cold water flows in by the tube H to the bottom of the vessel, the heated water rising and flowing out by the tube G. The condensed liquor, passing out at F, drops into the receiver.

545. **Fusel-Oil.**—This oily substance, which is very poisonous, was first discovered in the distillation of liquor made from potatoes, and hence has sometimes been called potato-oil. In reality it is amylic alcohol, one of the large class of alcohols mentioned in the fourth column of the table on page 303. Amylic alcohol is produced in the distillation of liquors made from the grains, and occasionally at least in other distillations also. It may be separated from the spirit by filtration through charcoal, this substance absorbing the poison into its pores. But not only is this process often omitted, thus leaving this poison to aggravate the deleterious effects of the alcohol itself, but the fusel-oil is made use of to a large extent by unprincipled manufacturers, of whom there are a great number, in getting up factitious liquors, wines, and cordials. The enormous cheating and destructive poisoning to which the drinkers of spirituous liquors are thus subjected, though extensively known, seem to be little heeded.

546. **Fermentation in Bread.**—The "raising" is ordinarily accomplished by alcoholic fermentation. The yeast first

converts some of the starch of the dough into sugar, and then makes from this sugar alcohol and carbonic anhydride. It is the expansion of the gas thus produced in every part of the mass that makes the numberless cells in it, and thus causes the "raising;" the volatile alcohol escapes at the same time. In the baking of bread part of the starch of the flour is converted by the heat into dextrin. A shining coat is given to the loaf by dissolving some of this gum on the surface by moistening the loaf after it is baked, and then subjecting it for a few minutes to heat again, which quickly dries and hardens the gum. Bread is often raised by other means than fermentation. Tartaric acid and hydro-sodium carbonate are used for this purpose. If the bicarbonate, as it is commonly called, be thoroughly mixed with the dough, and the tartaric acid be then added, it will seize the soda, and the released carbonic anhydride, as it expands into its gaseous state, raises the bread, as it does when generated by yeast. Bakers sometimes use ammonium carbonate to raise their light, spongy cakes. There is no need of any acid in this case, for the heat volatilizes the carbonate, and as it escapes it makes the cakes porous. Rum and alcohol have sometimes been employed, the vapor produced by the heat answering the purpose. There is considerable water in bread. In every 100 pounds of flour there are 16 of water. Then in the making of the flour into bread there are added 50 pounds more of water, so that there are 66 pounds of water in 150 pounds of bread. When bread becomes "stale," its dryness is not owing to an escape of water, but to a more thorough incorporation of the water with the bread.

547. **Ether.**—This singular fluid, so different from alcohol in its properties, is prepared from alcohol, and differs from it but little in its composition—having the same ingredients, though not in the same proportions. Alcohol being

$C_2H_5(HO)$, ether is $(C_2H_5)_2O$. As stated in § 423, if we regard alcohol as a hydrate of the radical ethyl C_2H_5, ether may be regarded as the oxide of this radical. Ether is a very light liquid. If exposed to a heat of 35.6°, two degrees less than blood heat, it boils, and it has never yet been frozen. It is exceedingly volatile. On account of its volatility and the effect of heat upon it, it must be kept in a cool place and in tightly closed bottles. If the hand be moistened with it, there ensues a sensation of great cold, owing to the rapid evaporation. It is very combustible, and its vapor mingled with the air forms an explosive mixture. The inhalation of it in considerable amount produces insensibility, and it is therefore much used in surgery to prevent the patient from suffering while undergoing an operation, and also to some extent in medicine to relieve the pain of disease. It is also used to dissolve gun-cotton, or *pyroxyline;* the solution is largely employed by photographers to form the collodion films of the glass plates on which the negative pictures are produced.

548. **Compound Ethers.**—As ether is an oxide it unites with acids to form compounds which may properly be termed salts. That very common medicine, the sweet spirits of nitre, is one of these salts diluted with alcohol. The essences used in flavoring wines, cordials, and in cooking food, are really compound ethers, artificially prepared on a large scale. In the following table (p. 388) you have a list of some of these perfume ethers, their formulæ, and the flavors they imitate. By mixing these ethers with each other, and with essential oils in various proportions, the odor and flavor of nearly every fruit may be imitated. Dilution with alcohol best develops the flavor.

Salicylol is not an ether, but finds a place in this table for obvious reasons.

549. **How Ether is Obtained.**—It is by the action of sul-

PERFUME ETHERS; FRUIT ESSENCES.

NAME.	FORMULA.	FLAVOR.
Ethyl butyrate......	$C_2H_5.C_4H_7O_2$	Pine-apple.
Ethyl œnanthylate..	$C_2H_5.C_7H_{13}O_2$	Greengage.
Ethyl pelargonate..	$C_2H_5.C_9H_{17}O_2$	Quince.
Ethyl suberate......	$C_2H_5.C_8H_{12}O_4$	Mulberry.
Amyl acetate.......	$C_5H_{11}.C_2H_3O_2$	Pear.
Amyl valerate......	$C_5H_{11}.C_5H_9O_2$	Apple.
Salicylol...........	$H.C_7H_4O.HO$	Meadow-sweet.
Methyl salicylate...	$C_7H_4O.CH_3.H.O_2$	Winter-green.

phuric acid upon alcohol that ether is generally obtained. The process is represented in Fig. 117. Equal quantities by weight of alcohol and the acid are introduced into a retort, A, to which heat is applied by a ring-burner, or, better, by means of a sand-bath. The retort is connected with an apparatus for condensing the vapor of the ether, known as Liebig's Condenser, and consisting essentially of two glass tubes, C and D, one fitted into the other by means of corks; water entering the space between these tubes through the

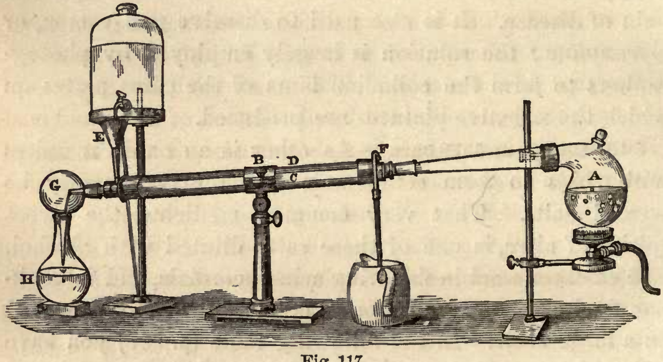

Fig. 117.

funnel, E, cools the vapor of the ether, and passes off through the outlet, F. The ether condensing in the inner tube flows into the two-necked receiver, G, and thence into a flask, H. The Liebig condenser is supported by a stand, B; the outer tube of the condenser is often made of metal. The stopper in the tubulure of the retort, A, may be removed, and more alcohol added as may be needed for the continuance of the formation of the ether to any considerable amount. The chemical process here is this: Sulphuric acid takes away the elements of water from the alcohol and leaves ether, thus: $2(C_2H_6O) - H_2O = (C_2H_5)_2O$. At least this is the simplest explanation which we can give you. Ether is very commonly called sulphuric ether, but the name is improper, as it contains neither sulphuric acid nor sulphur. By managing the alcohol and sulphuric acid differently a gas may be produced which is a very different substance from ether. The amount of sulphuric acid used for this purpose is five times that of the alcohol. This gas is olefiant gas, one of the hydrocarbons obtained by distillation of wood and coal. The reaction in this case is a *dehydration* or abstraction of water from the alcohol:

$$\underset{\text{Alcohol.}}{C_2H_6O} = \underset{\text{Olefiant gas.}}{C_2H_4} + \underset{\text{Water.}}{H_2O}$$

550. **Chloroform.**—This valuable substance can be obtained in various ways. It is commonly produced by distilling alcohol with water and chloride of lime. Its molecule contains one atom of carbon, one of hydrogen, and three of chlorine, and its composition is therefore expressed thus: $CHCl_3$. We have seen in § 421 how it may be regarded as a substitution product of marsh gas. It is, like ether, a colorless and very volatile liquid, having a peculiar sweetish smell. Its inhalation produces insensibility more readily than ether.

551. **Vinegar.**—This is a mixture of acetic acid with wa-

ter, there being diffused through the water also more or less of some other matters. But a small percentage of the whole is acetic acid. Common table vinegar contains but from two to five per cent. As acetic acid is little if any more volatile than water, it can not be obtained pure from vinegar by distillation. The only way in which the chemist can obtain it is to decompose some of the acetates, as acetate of lead—the common sugar of lead—by an acid which is strong enough to seize the base, and thus release the acetic acid.

552. **The Acetous Fermentation.**—Vinegar is commonly made by the exposure of some spirituous liquor, as cider or wine, to the air. This occasions what is called the acetous fermentation. This, like the alcoholic fermentation, can not take place without the presence of a ferment. For this reason, if a solution of alcohol in perfectly pure water be exposed to the air, there will not be the least fermentation. In the case of cider, wine, etc., there is no need of adding any ferment, for there is one already present in the liquid, the same which acted in its alcoholic fermentation. It is the decomposition of this which produces that gelatinous mass called the *mother*. As one of the results of this decomposition we have the generation of infusoria, or *vinegar eels*, as they are commonly called, which can often be seen by the naked eye when a glass of vinegar is held up to the light of the sun. When the acetous fermentation takes place in liquids containing starch and sugar, it is always really preceded by the alcoholic fermentation. For example, when preserved fruits become acid there is first an alcoholic fermentation, which passes into the acetous, producing vinegar. The effervescence which occurs, causing bubbles on the surface, is occasioned by the carbonic anhydride generated by the preliminary alcoholic fermentation. The more thoroughly the air is shut out from preserves the

less apt will they be to ferment. Exposure to heat favors fermentation, and hence preserves should be kept in a cool place. A high degree of heat will, however, destroy the power of the ferment, and hence preserves are scalded when there is a suspicion that fermentation is commencing in them. For the same reason vinegar is boiled to arrest the formation of the mother in it.

553. **Sour Bread.**—When bread is sour it is because the vinous fermentation has been followed by the acetous. This may arise from two causes. Either the fermentation has been allowed to go on too long before the bread was baked, or the ferment used has been kept so long as to enter into that state which makes it capable of producing the acetous fermentation. If a flour paste stand in a vessel covered with a board for six or eight days, it acquires a pleasant smell in the change which has taken place in it, and is now fit to act as an alcoholic ferment. Bread raised by it will be sweet. But if this paste or dough be left to stand a little longer, it acquires an acid taste, and will now, indeed, excite an alcoholic fermentation in sugared water or in bread, but this will at once pass on to the acetous fermentation.

554. **Explanation of Acetous Fermentation.**—The change which alcohol undergoes on conversion into acetic acid is not strictly a result of fermentation, because this conversion may be effected in various ways which exclude the idea of any vegetable or animal growth. It is rather a case of oxidation, for alcohol contains more oxygen and less hydrogen than acetic acid, as shown in the following equation:

$$\begin{array}{ccccccc} \text{Alcohol.} & & \text{Oxygen.} & & \text{Acetic acid.} & & \text{Water.} \\ C_2H_6O & + & O_2 & = & C_2H_4O_2 & + & HO_2 \end{array}$$

Since, however, pure alcohol may be exposed to the air, either alone or mixed with water, for any period without suffering oxidation, and the change is induced by the presence of unstable organic substances, the conversion may be regarded as a sort of fermentation.

Actually the change is not so simple as represented in the equation just given. It has two stages. As when starch is converted into sugar there is an intermediate substance—dextrin—into which it is changed preparatory to its conversion into sugar, so also, in the formation of acetic acid, the alcohol is first changed into an intermediate substance called aldehyde. The two changes may be expressed thus:

$$\begin{array}{ccccccc} \text{Alcohol.} & & \text{Oxygen.} & & \text{Aldehyde.} & & \text{Water.} \\ C_2H_6O & + & O & = & C_2H_4O & + & H_2O \end{array}$$

$$\begin{array}{ccccc} \text{Aldehyde.} & & \text{Oxygen.} & & \text{Acetic acid.} \\ C_2H_4O & + & O & = & C_2H_4O_2 \end{array}$$

Compare the equations in § 537 explaining alcoholic fermentation.

555. **Quick Mode of Making Vinegar.** — Alcohol can be converted into acetic acid in a very short time by providing for a very free exposure of it to the air, so that the oxygen may act upon every drop of it at once. This is done in the manner represented in Fig. 118. A barrel is filled with shavings which have been steeped in vinegar. Near the top of the barrel is a shelf, perforated with holes, in which there are fastened either bits of string or straw, that the liquid poured in, which is alcohol and water with a little yeast, may trickle down upon the shavings. A free access of air is secured to the whole surface of the shavings by holes made in the side of the barrel, and some holes in the perforated shelf large enough to admit glass tubes of considerable size. Now as the fermentation creates heat, the cold air admitted in

Fig. 118.

the holes becomes expanded by the heat, and so rises to pass out through the glass tubes; and in this way quite a brisk circulation of air is kept up, bringing, therefore, oxygen to the whole surface of the shavings with considerable rapidity. The fluid as it runs out below passes into the receiver. Of course the barrel is whole as used; in the figure a portion of it is represented as cut away, merely that you may see the interior arrangement.

556. **Adulteration of Vinegar.** — Even vinegar is sometimes adulterated. When a manufacturer desires to sell poor vinegar as good he gives the requisite sharpness to it by adding some substance, as, for example, sulphuric acid. Adulteration with this article can be very easily detected. Fill a jar or mug half full of water, and set upon it a cup containing some of the vinegar with grape-sugar in it. If you set the mug upon a hot stove the vinegar in a little time will be all evaporated. If now what is left in the cup be of a black color, there is proof of the presence of free sulphuric acid. The explanation is this: As the vinegar evaporates, the sulphuric acid, not being volatile, remains in the cup, and at length, when all the water is gone, is so concentrated that it carbonizes the non-volatile organic matter. (See § 244.)

Great care must be taken not to heat the contents of the mug too hot, or the organic matter may be charred by the heat alone.

QUESTIONS.

535. What is said of different kinds of fermentation? What is the difference between fermentation and putrefaction? What are antiseptics? —536. Explain the nature and action of ferments. What is said of the growth of organized bodies?—537. Explain the chemical change in alcoholic fermentation. Give the equation.—538. What is yeast?—539. What is said of the fermentation of wines? When are wines dry?—540. What

gives peculiar flavor to grape wines? How much of this ether do wines contain?—541. To what is the acidity of grape wines due?—542. What is said of the amount of alcohol in wines?—543. What is the first step in making alcohol of starchy substances? What is malt? How is it made? —544. Describe the process of distillation.—545. What is fusel-oil? How produced?—546. Explain the raising of bread by yeast. What other means are employed to raise bread? How much water is there in bread? What makes bread stale?—547. What is ether? What are its properties? For what is it used?—548. How may compound ethers be regarded? Give the names and flavors of some of the so-called fruit essences.—549. Describe the process of making ether. Explain the chemical reaction which ensues. What is obtained by managing the alcohol and sulphuric acid differently? — 550. How is chloroform made? Of what composed? — 551. What is vinegar? Why can not acetic acid be obtained from it by distillation? How is it obtained by the chemist?—552. What is said of the common mode of making vinegar? What is the *mother* of vinegar? What are *vinegar eels*, and how are they produced? State in full what is said of the acetous fermentation in preserves.—553. Explain the chemistry of sour bread.—554. Explain in full the chemical changes of the acetous fermentation. In what two stages does this change take place?—555. Describe and explain the quick mode of making vinegar.—556. How is vinegar commonly adulterated, and how can the adulteration be detected?

CHAPTER XXXI.

ANIMAL CHEMISTRY.

557. **Materials.**—The elements which enter into the composition of the various substances found in animals are the same with those which compose vegetable substances. We have first the four grand elements—carbon, oxygen, hydrogen, and nitrogen. There are also chlorine, sulphur, and phosphorus, and also the metals calcium, potassium, sodium, and iron. As in vegetables, so in animals, these elements never appear as elements, but always in combination. Thus we never have chlorine alone, but it exists in

combination chiefly with sodium, forming the chloride or common salt, which, as you will soon see, plays quite a part in the animal economy. So phosphorus is mostly united with oxygen and calcium, so as to form a phosphate of calcium, and is never found as phosphorus. The combinations of the four grand elements are very various in their character, for out of them are built animal structures of every kind. It is not commonly the elements themselves, but the combinations of the elements, derived from various sources—vegetable, animal, and mineral—that animal chemistry works upon as materials in evolving animal substances, both liquid and solid. Thus phosphorus and oxygen and calcium are not introduced into the animal system separately, and there united to form phosphate of calcium; but this salt is introduced as such in both vegetable and animal food. So the carbon, oxygen, hydrogen, nitrogen, and sulphur which compose albumen do not unite in the animal to produce this substance, but it is formed in the vegetable for use in the animal.

558. **How Animal and Vegetable Chemistry are Alike.**— They are alike, as you have just seen, in the elements which are employed. They are also alike in many of the combinations of these elements. The chloride of sodium and the phosphate of lime found in animals are also present in vegetables. One of the principal constituents in animals is like vegetable gluten. Then there are albumen and casein, corresponding with substances of the same name in vegetables. This resemblance between animal and vegetable chemistry comes in consequence of the fact that the vegetable world is so largely engaged in preparing for the animal world what it gathers up from the mineral world. It not only transfers, but prepares, and many of its preparations are combinations which enter with little or no alteration into the composition of animal substances.

559. **How they Differ.**—Animal and vegetable chemistry differ in several important particulars. The former is much more complex and mysterious than the latter. Certain substances, as starch and sugar, found in such abundance in some vegetables, are not present in animals in their normal state. When taken into the animal they are changed into fat and other substances. Then there is not only difference but opposition between the chemical action of leaves and that of lungs, carbon being given out by lungs and taken in by leaves, and oxygen being given out by leaves and taken in by lungs, as stated in § 128. Besides all this, the plant lives upon unorganized materials, while the animal lives upon organized materials built up by the plant.

560. **The Blood.**—This universal building material of the animal contains all the constituents needed for the construction and repair of every part. There is fibrin, out of which chiefly the various textures of the body are formed. This is the firm part of the coagulum or clot that separates when blood is left standing, there being incorporated with it the coloring matter of the blood. The clot swims in a watery fluid called serum, which contains albumen in solution. Besides these there is a variety of materials in small amounts in the blood. There is iron, which is contained in the matter which gives the blood its red color. Then there are mineral materials for the manufacture of bones, teeth, etc., and various other substances. Water constitutes about four fifths of the blood. Without this the materials which we have mentioned could not be carried to all parts of the body. In this they are sent to their destination through innumerable tubes by the heart, the great central pump of the circulation.

561. **How the Blood is Made.**—The blood is made mostly from our food. We say mostly, because that important sub-

stance, oxygen, is partly furnished from the air that enters the lungs. The process of digestion, by which the blood is made from the food, we shall not particularly describe here, but will refer you to Hooker's two works on Physiology. It is sufficient to speak of it here very briefly and generally. The food on being ground up by the teeth is at the same time mixed with the saliva, which is poured into the mouth by several glands, or saliva factories, as they may be called. In the stomach the ground and moistened mass is acted upon by the gastric juice, a fluid which oozes out from myriads of minute glands set into the inner surface of the organ. This is a chemical operation, and it is promoted by a constant motion which is kept up in the stomach, thus stirring up the food so that the gastric juice may be well mixed with it. After the proper chemical change is effected the nutritious part of the mass is absorbed and poured into the blood, and becomes a part of it.

562. **Albumen.**—The protein compounds, or albuminoids, are very nearly identical in composition, as you have already learned, and they are convertible into each other. In the animal the various tissues or structures, as we have stated in § 560, are made chiefly of fibrin. Exactly how fibrin is formed in the animal economy is an unsettled question. It was formerly supposed that albumen was transformed into fibrin, and that all other protein bodies were first converted into albumen in the stomach, but this lacks demonstration. Albumen is held in solution in the blood by means of chloride of sodium associated with it. It does not occur in the animal in the free state, but as an *alkaline albuminate.* It forms about seven per cent. of blood, and occurs in the brain, in the juice of the flesh, and in a greater or smaller quantity in all the liquids effused from the blood-vessels into different parts of the system.

563. **Formation of the Bird in the Egg.**—In the formation of the bird in the egg we have a marked illustration of the prominent part which albumen plays in nutrition. Both the yolk and the white are composed chiefly of albumen dissolved in water. The white is seven eighths water, and only one eighth albumen. In the yolk we have the same solution of albumen holding yellow globules of oily matter suspended in it. There are in both the yolk and the white minute amounts of various mineral substances, as common salt, phosphate of lime, carbonate of soda, etc. These form the ash of the egg when it is burned. It is the albumen of the egg from which all the varied structures of the bird are formed—the muscles, the skin, the feathers, etc. The oily matter of the yolk, it is true, is diffused in the interstices of many of the tissues, but it does not really form a part of them, unless it be in the case of the brain. The phosphate of lime also is deposited in the texture of the bones, but it is the albumen that first forms that texture. As we look at the white of an egg, so simple is it that we can hardly believe that such a variety of tissues can be evolved from it by the chemistry of life. And yet the evidence is clear that it is so; for shut up in the shell nothing can gain admission to it but the oxygen of the air, which acts upon it through the pores of the shell, and thus materially aids in the process, as may be proved by the interruption of it by a coat of varnish shutting up the pores.

564. **Gelatin.**—There is considerable doubt as to the nature of this substance, which enters largely into the structure of some portions of animals. It is supposed that it is formed from albumen and fibrin, as the gelatinous structures are well developed in animals which are fed upon these substances alone. Its composition is nearly the same as theirs, although its properties are very different. It forms

about one third of the substance of the bones, phosphate of lime being almost all of the remaining two thirds. It is the gelatin in the skin that tannin so firmly unites with, converting it into leather. What is commonly called glue is gelatin. This substance dissolves readily in water. The various jellies that we use prepared from animal substances are gelatin. The gelatin is first separated from them and dissolved by hot water, and then the solution on cooling leaves a jelly. Isinglass, so called, is chiefly gelatin prepared from the sounds or air-bladders of certain fresh-water fishes, particularly one of the sturgeon class found in the rivers of Russia.

565. **Two Kinds of Food.**—All the varieties of food are divided into two classes according to the purpose which they serve, the one class serving to build up the tissues, and the other to maintain the animal heat. To the former class belong those substances that contain nitrogen, as the gluten of bread, the fibrin of meat, the casein of milk, etc. The other class comprises those substances that have no nitrogen in them, as starch, sugar, and oily substances. These all serve to maintain the warmth of the body, and it is supposed have little or nothing to do with building its structures. They are burned up, as we may express it, in creating heat, which is just as essential to the maintenance of life as nutrition is. This food is called *respiratory* food, because it is supposed that the oxygen introduced by the respiration is employed in consuming or burning it. The products of this flameless combustion are the same with those of ordinary combustion with flame, water, and carbonic anhydride. The heat-making food is often called *carbonaceous* from the predominance of carbon in it, while the building food is called *nitrogenous* because it is distinguished from the other by containing nitrogen.

While the view thus presented is generally true, there is ground for doubt whether the distinction can be as strictly carried out as is attempted by Liebig and others. The reasons for this doubt will be noticed soon.

566. **Climate and Food.**—If the view above presented be substantially correct, climate must have a great influence upon the choice of food, the necessities of the case influencing that choice to a considerable extent through the instincts. Accordingly we find that oily and fatty food is largely used by the inhabitants of the arctic regions, from the great demand of the system for heat-making food amid the surrounding cold. And provision is made by the Creator for this want; for the animals from which the Esquimaux, the Greenlanders, etc., obtain their chief nutriment—as bears, seals, and whales—are loaded with fat, while there is but little of this substance in those animals which furnish meat to the inhabitants of hot climates.

567. **Warmth in Hibernation.**—It is observed that the woodchuck and other warm-blooded animals that are in a torpid state in the winter months are lean when they come out of this state in the spring, though they were very fat when they went into it. This is because the fat is burned up during the winter in maintaining the warmth requisite for the continuance of life in this torpid state. So, also, in disease, the fat previously accumulated in the system is often used in the production of animal heat, the other sources being in part cut off by the impaired ability to appropriate food.

568. **Corpulency.**—In this state of body there is an accumulation to a larger degree than usual of fatty matters in all quarters of the system. This is supposed to arise from the fact that the heat-making food is provided in so great amount that the oxygen introduced into the system is far from being sufficient to burn it up. In this case the

accumulation of fat does not come from oily food alone, for starch and sugar can be converted into fat by the chemistry of life. It is on account of this conversion that potatoes increase the butter or fatty part of the milk in the cow. For the same reason the butter in milk is greater in amount in the morning milk than in that of the evening, when in cold weather the cow is kept in a warm stall through the night, there being more starchy and sugary matters converted into fat when there is less necessity for their consumption in the production of heat. For the same reason, also, in the fattening of animals in cold weather, the more comfortably they are housed the less food will it take to fatten them.

569. **Heat in Carnivorous and Herbivorous Animals.**—It is obvious that carnivorous animals do not eat as much heat-making food as herbivorous animals do, while they eat more of building-food; and yet they have as much heat as the herbivorous animals, and do not have any greater development of structure. This seems to be in contradiction to the views presented of the purposes of food; but the apparent discrepancy, for it is only apparent, can be easily explained. There are two sources of the fuel used in maintaining animal heat, viz., the food and the waste of the tissues of the body. Now the heat in carnivorous animals is derived almost wholly from the latter source, for they are so active in their habits that there is much greater wear and tear of the tissues than in herbivorous animals. You can realize this difference in activity if you observe the constant restlessness which lions, tigers, hyenas, etc., manifest in their cages in a menagerie. Herbivorous animals are so inactive that when they are left to their natural habits they can live on food which contains but very little nitrogenous substance, as common grass, potatoes, etc. But when they are worked by man, if they are not fed in part on some of the grains, they will lose flesh for want of building-food. But there is another difference between carnivorous and herbivorous animals, which accounts for the absence of that overheating that we might reasonably expect from such an amount of heat-food as is commonly eaten by herbivorous animals. They perspire freely, much more so than carnivorous animals, and a large part of the heat made by their food passes off therefore as latent heat in the vaporization of the perspired matter.

570. Relation of Food to Labor.—This topic, incidentally touched upon in § 569, merits a more particular notice. If a horse is not worked he will retain his good condition on such food as hay and potatoes. If oats or corn be added he will gain in flesh; that is, the tissues will be more fully developed by this addition of plastic food, and at the same time the fat will be increased, as his heat-making food is not used up freely in producing heat. If now with this mixed diet he is put to work, he will retain from day to day his usual bulk both in respect to fat and muscular fibre. Laboring men require a larger proportion of nitrogenous food than those who are inactive. It is for this reason that when men live almost wholly on such articles as potatoes or rice or plantains there is the same failure both in bulk and power as in the working horse that is fed on hay alone. The Israelites could not have endured their journey if their manna had been like the article now called by that name. They needed food which was in part nitrogenous, and such was the manna miraculously furnished to them, as the change in it when it was kept for any length of time clearly showed (§ 466). It is calculated by Liebig that the proportion of nitrogenous to non-nitrogenous food most suitable to the wants of a laboring man is about as one to four. If he eat too much of the former, like the savage hunter who lives almost wholly on meat, there is deficiency of heat-making food, and he is obliged to eat a larger amount of nitrogenous food than is needed for nutrition, in order to get a sufficiency of that non-nitrogenous food which is combined with it, unless he pursue, like carnivorous animals (§ 569), so active a life that the waste of the tissues shall supply the requisite amount of fuel. The use of so large a quantity of animal food by no means proportionally develops the tissues, for it burdens the digestive and other organs with too much labor, and therefore produces disease in spite of the invigorating influences of an outdoor life.

571. Mingling of Heat-Food and Building-Food. — Generally in articles which are eaten the two kinds of food are mingled together. Thus even in the lean part of meat there is always some fat in addition to that which is deposited in masses in the neighborhood of the muscles; and gluten and starch are mingled in the grains. That mixture of nitrogenous and non-nitrogenous food which we have in bread is so especially suited to man that this article of diet has from remote antiquity been styled "the staff of life." The instincts of men seem to lead them to mingle the two kinds of food together. Thus the Irishman eats with his potatoes buttermilk for the casein it contains, or cabbage, which is one of the vegetables that is rich in nitrogen. The Italian for the same reason adds cheese to his macaroni, and the wayfaring Spaniard eats with his bread an onion or two, this vegetable containing much nitrogen, like the cabbage of the Irishman.* So pork, which is only heat-food, is eaten with cabbage or beans, butter with bread, and oil with salad. Experiments which have been tried show decidedly that life can be sustained only on *mixtures* of food. Animals have been fed on various single substances extracted from articles of food, and the results have always been bad, even to the destruction of life. This is true of the nitrogenous constituents as well as the carbonaceous. The fibrin extracted from meat is far from answering the same purpose as the meat itself. The juices of the meat are needed in combination with the fibrin to accomplish the full purposes of nutrition. It may be laid down as a general truth that no separated principles of food answer the same end as the mixtures which are produced in nature. The gluten of wheat does better than any other one thing, but this alone is by no means as good food as its mixture in the grain with starch and albumen.

572. **Milk.**—It is worthy of remark here that milk, the only mixture of food which nature has provided as the sole means of nutrition for some animals—the mammalia—in their infancy, has the two kinds of food combined, the

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* The dish so common in Ireland called *Kol-cannon* is prepared by beating potatoes and boiled cabbage together, putting in a little pork-fat, salt, and pepper. Johnston says of this, "Take a pot-bellied potato-eater and feed him on this dish, and he will become not only stronger and more active, but he will cease to carry before him an advertisement of the kind of food he lives upon, and his stomach will fall to the dimensions of the same organ in other men."

cheesy matter or casein being the nitrogenous part, and the oily matter or butter the non-nitrogenous part. And the proportions of the two, being as one of the former to four of the latter, furnish a clear indication of what they should be in food generally, making allowances, of course, for varying circumstances. Milk must contain, besides the casein and the oily matter, all the other materials required in both the solids and fluids of the body, else there would be some defect in the nutrition of an animal that lives entirely upon milk. We have therefore in this liquid iron for the blood, salt for this and various other fluids in the body, phosphate and carbonate of lime for the bones, etc. The milk, though of a white color, contains in fact all the elements that are present in the red blood of the animal, and in the same proportions, with the exception of that portion of the oxygen which is added to the blood in the lungs. A great error is often committed in confining a child too exclusively to starchy articles of food, such as arrow-root, thus depriving it not only of the albuminous substances, but also of the iron, the phosphate of lime, etc., which are all contained in the complex food furnished it by nature.

573. **Proportions of Heat-Food and Building-Food in Different Articles.**—In the following articles to every 10 parts of nitrogenous substance there are the parts named of non-nitrogenous substance: Cow's milk, 30; pease, 23; beef, 17; veal, 1; eggs, 15; wheat flour, 46; oatmeal, 50; rye flour, 57; potatoes, 86; rice, 123; buckwheat flour, 130. There are some variations according to circumstances, but these are the average proportions. The percentage of nitrogenous and non-nitrogenous substance, in three forms of food used largely in three different quarters of the world, may be thus stated:

	Rice.	Potato.	Plantain.
Gluten	7½	8	5¼
Starch, etc.	92½	92	94¾
	100	100	100

The percentage is reckoned here upon the *dry* food, that is, the substance freed from the water which is naturally in it. The albuminous material in cabbage is much greater than in these articles, being from 30 to 35 per cent., and in cauliflower it is still greater. In the onion it is from 25 to 30 per cent. In tea-leaves it is 25 per cent., so that if they were eaten they would prove good building-food. Figs as imported, that is, partially dried, are thus compared with wheat bread:

	Figs.	Wheat bread.
Water	21	48
Gluten	6	5¾
Starch, sugar, etc	73	46¼
	100	100

Figs, therefore, have less water than the bread, a little more gluten, and 27 per cent. more of starch and sugar. There is a larger proportion of gluten in the covering or husk of the wheat than in the grain itself, and therefore the separation of the bran from the flour by bolting impairs the nutritive power of the bread, that is, so far as the building of structure is concerned.

574. **Is the Division of Food into Two Kinds Correct?**—The classification of food given in § 565, which is that of Liebig, though generally received, is considered by some as without foundation. One of the chief objections to it is that the large proportion of heat-food which is used in warm climates in the form of starch, in such articles as rice and the plantain, is in opposition to it. But the objector forgets that man is always throwing off heat freely into the air even in hot climates; for when in such climates the atmosphere is at a higher degree of temperature than 36.6° C., the animal heat passes off in the abundant perspiration, both sensible and insensible. If it were not for this, disastrous consequences would result from exposure to excessive heat, either in a hot climate or in the

heated apartments in which some manufactures are carried on. There are other objections to Liebig's classification, but we will not dwell on them. The division is probably in the main correct, and yet there are some facts that seem to show that plastic food is sometimes used for the production of heat, and that fuel-food is sometimes used for building. If so, it is an exception to a general rule, and indicates that the chemistry of life is not bound by such strict lines as is inorganic chemistry.

575. **Amount of Animal Heat.**—At first thought it seems strange that so much of the food, ordinarily four fifths, should be expended as fuel in producing heat, because we are in the habit of thinking of food as doing good only in building up and repairing the system. This is the common popular view of nourishment, and it is only the investigations of the chemical physiologist that make us realize of what importance heat is in the maintenance of living action. It is calculated that the amount of heat produced in the body of an adult man in one year would suffice to raise from twenty to twenty-five thousand pounds of water from the freezing to the boiling point. The heat, then, required to run the animal machine, as we may express it, is very great, and therefore there must be a large provision of fuel.

576. **Uses of Fat in the System.**—There is one form of heat-food—fatty matter—which is used quite extensively in building up the structures of the system, though in the wear and tear of these structures it may eventually serve as fuel. But it is Liebig's idea that the fat which is so largely present in many tissues is not really a part of them, but is contained in them very much as water is contained in the interstices of a sponge. The combination, however, is certainly more intimate than this; perhaps it may be considered like that of phosphate of lime with gelatin in bone. And in the case of the brain there seems to be even a chemical combination of fatty matter with phosphoric

acid. More than one fifth of the solid matter of the brain is fat, and this substance constitutes more than a sixth part of the solid matter of muscle. It is present in considerable quantity, also, in other structures. It must, then, have other uses besides heat-making. Besides its usefulness in the textures of organs, it is of some local benefit as deposited in masses. Thus the eyeball rests in its socket upon a cushion of fat.

577. **Phosphorus and Sulphur.**—Phosphorus does not exist as such in animals, but is in combination with soda and lime. The phosphate of lime is present in large quantity in the bones. In the body of an adult man there is in the bones from 2 to 3 kilogrammes of this salt, and the phosphorus in it amounts to from 500 to 800 grammes. Phosphorus forms one of the most important constituents of certain complex fatty bodies in the brain. It is extensively provided for animals in their articles of food, mostly in the form of phosphate of lime. Phosphorus exists in eggs, and in all animal food. It is one of the components of milk, the universal and sole food of the mammalia in their infancy. It is also present in many seeds. So abundant is it in oats that the horse is liable to an earthy concretion in the bowels, of which phosphorus is a chief ingredient. Sulphur also occurs in combination in animals, chiefly in the albuminous or protein substances, and in some of the tissues. It comes from both animal and vegetable sources. Like phosphorus, it exists in flesh, eggs, and milk. It is also in the nitrogenous compounds of plants, gluten, albumen, and casein; and, combined with lime in the form of a sulphate, it is in most of the water that we drink.

578. **Lime.**—This is one of the most widely diffused mineral substances both in the animal and vegetable kingdoms. It exists largely in the seeds of most grasses, especially in the grains of wheat. Beans and pease have more nitroge-

nous matter than wheat, and therefore would be more nutritious were they not deficient in a salt of lime, the phosphate. There is considerable lime supplied to plants and animals from water in the forms of the carbonate and the sulphate, these salts being present in all hard water. The thickness of the shells of aquatic mollusks depends very much upon the amount of carbonate of lime in the water. Those which live in the sea have as much as they need, and their shells have considerable thickness; but those which are found in fresh-water lakes, where there is but little lime, have thin shells. There are some lakes, however, where, from local causes, the water is greatly impregnated with calcareous matter, and the mollusks that inhabit them have shells of uncommon thickness. Hens require more lime than usual when they are laying eggs, and they therefore instinctively at such times eat chalk, mortar, or any substance they can find which contains carbonate of lime. If they are shut up where they can not obtain this they lay eggs without shells, and if they obtain it sparingly the shells are thin.

579. **Iron.**—This metal is absolutely essential to the blood, and is present in all the pigments of the body, in the bile, and in various tissues, especially the hair. The quantity of iron in the blood is very small, it being only about the one four-hundredth part of its solid matter. It varies in different persons, being greater in the sanguineous than the lymphatic, in the well-fed than those who live on a poor diet. It is found more or less in most articles of food. It is in the yolk of eggs and in milk, as well as in animal flesh. It is present in most of the vegetable substances used as food by man, such as potatoes, cabbage, pease, mustard, etc. We have said that iron is essential to the blood. It is there not so much to be supplied to the tissues as to execute certain offices in the blood itself.

These offices we will indicate so far as they are ascertained. The blood, examined by the microscope, is seen to consist of two parts, an almost colorless liquid called *liquor sanguinis*, or liquor of the blood, and floating in this are multitudes of rounded particles called globules of the blood, or blood-disks. These are little sacs or vesicles containing a fluid, and the iron forms one of the constituents of certain crystalline principles suspended in this fluid. These globules convey the oxygen received in the lungs to all parts of the body, and the liquor sanguinis probably brings back to the lungs the carbonic acid which is to be discharged there. The crystalline bodies containing iron act as common carriers for oxygen. When iron is deficient in the blood some form of iron medicine is administered by the physician.

580. **Salt.**—The amount of salt in the blood is about three times that of iron. Though it is nowhere present as a part of any tissue, it is of much service in the formative processes, both as salt and by its elements, it being to some extent decomposed in the body. There is no salt found in the juices of muscles, but one of its elements, chlorine, is found there combined with potassium, and this element is undoubtedly derived from the salt in the blood. In the bile of land animals there is soda, derived from the same source. Then there is hydrochloric acid, an efficient part of the gastric juice in the process of digestion, which is furnished in some way from the decomposition of salt. We use salt instinctively with our food with some articles, as potatoes, more than with others. As it is not as abundant in plants as it is in animal food, considerable pains are taken to supply our domestic herbivorous animals with a sufficiency of this important article of diet. And, to meet the instinctive desire of the wild animals for it, there are places where it exists in the soil, to which they can resort for it.

Such are the "buffalo-licks" of this country. The results of some experiments which have been tried with cattle in relation to salt as an article of food are interesting and instructive. The salt had no influence on the flesh or on the amount of milk obtained; but the set which had salt mixed with their fodder had a much better coat, and were much more lively than the set from which salt was withheld.

581. **Water.** — This is the largest ingredient in animal bodies. It constitutes nearly 80 per cent. of the blood, and the same of the brain, and nearly 75 per cent. of the muscles. The body of a human being is about three fourths water. One great use of this abundant substance in the animal is to furnish a proper vehicle for the solid substances in their circulation. The materials for growth are carried every where in it, and the worn-out particles are conveyed to their natural outlets. It also serves various purposes in the tissues, giving transparency to some, as the cornea, the beautiful clear front-covering of the eye, and giving to the muscles and the membranes their softness, flexibility, and elasticity. Water is in these respects as essential to life as any other substance. Being thus needed in the animal, it is largely present in all the vegetable substances which are used as food; and as in vegetables it furnishes in its decomposition its elements for the formation of the compounds which they contain, so it may do to some extent in animals.

582. **Endosmose and Exosmose.**—In connection with water, it is proper to notice an agency which has a wide influence on the circulation of matter, both in vegetable and animal substances. This agency is exhibited in the following experiment: B C (Fig. 119, p. 411) is a glass tube expanded at its lower end, which has a piece of moist membrane, as fresh bladder, tied over it. If we pour some water into the vessel, and also so much into the tube as will make it at the same level with that in the vessel, there will be no change in the levels, however long the apparatus may be left

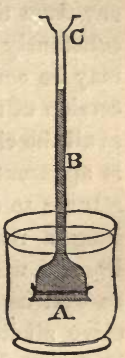


Fig. 119.

to stand. But if we add salt to the water in the tube, the solution thus made will in a few minutes rise in the tube, while the water in the vessel will fall. This is because some of the water, attracted by the solution of salt, passes through the pores of the bladder. The salt has given the water in the tube something like a power of suction. We can vary this experiment in several ways. If the salt be put into the vessel, the contrary effect will be produced—the water in the tube will fall below the level of the fluid in the vessel. If salt be put into both vessel and tube in equal proportions, no change will follow; but if in unequal proportions, the suction will be toward the strongest solution. Suppose now that instead of salt you put a solution of gum or sugar into the tube, holding it so that the level shall be the same with that of the water in the vessel. Here the fluid in the tube will rise, because the water from without presses in through the bladder. This passing inward is called by Dutrochet, who first developed this subject, *endosmose*, from two Greek words—*endon*, inward, and *osmos*, impulsion, or pressure. But some of the gum or sugar is found, after a time, in the water outside. There is, therefore, also a transmission from within outward, though less than that from without inward, and this he called *exosmose*, *ex* meaning from or outward. The membrane used in such experiments is called the *septum*. Similar phenomena are seen with other substances; as, for example, albumen, a substance which is largely present in animals. You can readily see, then, that the agency which we have described must have a very wide influence on the circulation of fluids in both the animal and vegetable world, for salt, gum, sugar, albumen, etc., are common substances in these fluids, and there are soft and porous membranes every where ready for this endosmotic and exosmotic action. And we may remark, in passing, that the influence of this agency is very considerable, also, in the mineral world, for gases as well as liquids are affected by it, and it may act through almost any porous substance.

583. **Circulation of Matter.**—You have seen in this book that in the ministration of nature to the wants of man and other animals there is a constant circulation and interchange of matter between the three kingdoms of nature. First there is a circulation in the strict sense of that word, for there is a movement in a circle. As the vegetable re-

ceives its materials from the mineral world, and the animal from the vegetable, there is a continual return in decay from the animal to the mineral world. Death is thus constantly ministering to life, and life to death; and life may be considered as being maintained by a constant succession of resurrections, not a particle of matter being lost in all the changes that take place, even in those where there is apparent destruction. As that which is made of dust returns to dust, a new life rises up out of that dust, exhibiting a reality more wonderful than that of the fabled Phœnix which shadows it forth. But there is interchange as well as circulation. The animal kingdom does not receive all its material through the vegetable, but some of it comes directly from the mineral kingdom. And then the vegetable, standing as it does between the animal and mineral kingdoms, receives from both, and gives to them in return. It yields back to the mineral world in decay what it receives from it; and while it receives from the lungs of animals carbonic acid, it gives back to them the oxygen which they need every moment for the maintenance of life. It is thus that the earth, with all its stability, has vast changes going on continually and every where upon its surface, in which air and water and heat and light and electricity and chemical and vital agencies are ever busy; and yet, extensive as these changes are, and accompanied with disturbance, conflict, and decay, the Creator, who seeth the end from the beginning, preserves amid it all a wonderful balancing and harmony, so that from age to age we see the impress which he put upon creation at the first, and bear witness that it is all "very good."

QUESTIONS.

557. What is said of the elements which come into play in animal chemistry? Give examples of the combinations of elements that are introduced into animals.—558. Indicate some of the points in which animal and vegetable chemistry are alike.—559. Indicate some in which they differ.—560. Give in full what is said of the composition of the blood.—561. Describe in full the way in which the blood is made.—562. What is said of the occurrence of albumen in animals?—563. What are the constituents of the contents of an egg? What is said of the formation of the bird in the egg?—564. What of gelatin?—565. Into what two classes are the various kinds of food divided? State what is said of the heat-making class.—566. What relation has climate to food?—567. How is the warmth of some hibernating animals maintained in their torpid state? What is said of the fat of the body in disease?—568. What of corpulency? What of the butter in milk? What of fattening animals?—569. What apparent discrepancy is there in regard to the food and the animal heat of carnivorous and herbivorous animals? State in full what is said to clear up this discrepancy.—570. What is said of the relation of food to labor? What is said of the manna of the Israelites? What of the proportion of nitrogenous to heat-making food? What of the use of an excess of animal food?—571. What of the mingling of the two kinds of food? What is said of feeding animals on some single substance alone?—572. What of the combination in milk? What error is frequently committed in the diet of children?—573. State in full what is said of the proportions of the two classes of food in different articles.—574. What is said of the chief objection to Liebig's classification?—575. What is said of the amount of animal heat?—576. What of the uses of fat in the system?—577. What is said of phosphorus in animals and in their food? What of sulphur?—578. What of the diffusion of lime in nature? What is said of the thickness of the shells of mollusks? What of the shells of hens' eggs?—579. What of the presence of iron in animals? What of its presence in food? What of its offices in the blood?—580. What is said of the presence of salt in animals? What of its use as an accompaniment of food?—581. State in full what is said of water as an ingredient of animal and vegetable substances?—582. Explain in full endosmose and exosmose.—583. Give in full what is said of the circulation of matter? Also what is said of its interchange. And what is said of the harmony of creation in the midst of all its change.

[illegible]

[illegible]

[illegible]

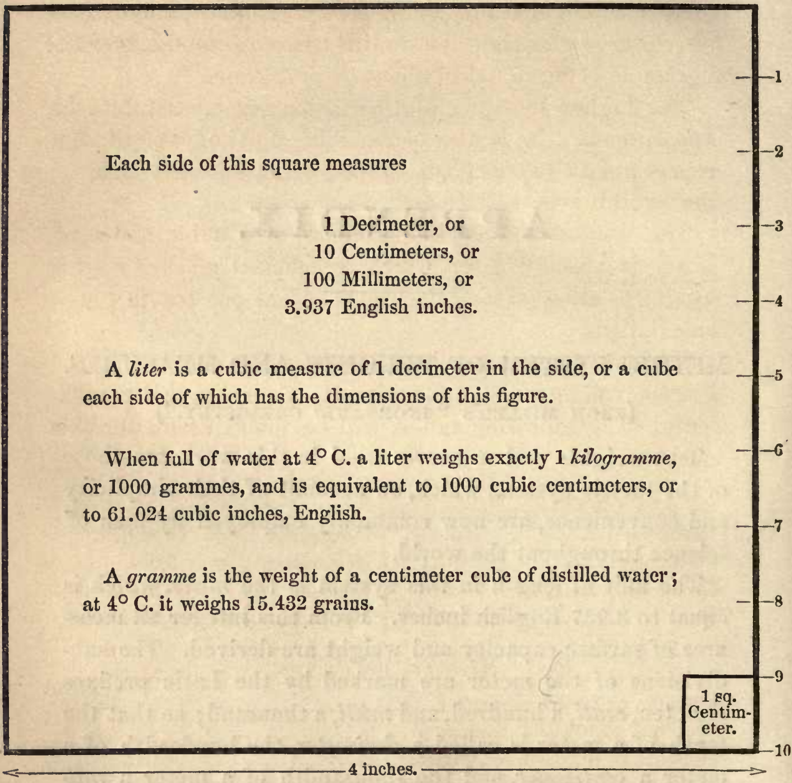
APPENDIX.

METRIC SYSTEM OF WEIGHTS AND MEASURES.

(FROM MILLER'S "INORGANIC CHEMISTRY.")

The weights and measures used in this work are those of the metric system, which, on account of their simplicity and convenience, are now commonly employed by men of science throughout the world.

The unit of length in this system is the *meter*, which is equal to 3.937 English inches. From this integer all measures of surface capacity and weight are derived. The subdivisions of the meter are marked by the Latin prefixes *deci*, ten, *centi*, a hundred, and *milli*, a thousand; so that the tenth of a meter is called a *decimeter*, the hundredth of a meter a *centimeter*, and the thousandth of a meter a *millimeter*. The higher multiples are indicated by the Greek prefixes *deca*, ten, *hecto*, one hundred, *kilo*, one thousand; but the prefix *kilo*, or multiple by one thousand, is almost the only one used in practice. For instance, the higher multiple, or 1000 meters, is called a *kilometer*. It is used as a measure of distance by road, and represents about 1094 yards, 16 kilometers being equal to nearly 10 English miles.



Each side of this square measures

1 Decimeter, or
10 Centimeters, or
100 Millimeters, or
3.937 English inches.

A *liter* is a cubic measure of 1 decimeter in the side, or a cube each side of which has the dimensions of this figure.

When full of water at 4° C. a liter weighs exactly 1 *kilogramme*, or 1000 grammes, and is equivalent to 1000 cubic centimeters, or to 61.024 cubic inches, English.

A *gramme* is the weight of a centimeter cube of distilled water; at 4° C. it weighs 15.432 grains.

The *measures of capacity* are connected with those of length by making the unit of capacity in this series a cube of one decimeter, or 3.937 English inches, in the side; this, which is termed a *liter*, is equal to 1.7637 imperial pints, or to 61.024 cubic inches.

Finally, the *system of weights* is connected with both the preceding systems by taking as its unit the weight of a cubic centimeter of distilled water at 4° C.: it weighs 15.432 English grains. The *gramme*, as this quantity is called, is further subdivided into tenths or *decigrammes*, hundredths or *centigrammes*, and thousandths or *milligrammes*, the milligramme being equal to about $\frac{1}{65}$ of a grain.

The higher multiple of 1000 grammes constitutes the *kilogramme.* It is the commercial unit of weight, and represents 15,432 English grains, or rather less than $2\frac{1}{4}$ lbs. avoirdupois.

The weight of 1000 kilogrammes, or a cubic meter, of water, is 0.9842 of a ton, which is sufficiently near to a ton weight to allow of its being reckoned as one ton in rough calculations.

Various plans have been devised for converting the French weights and measures into their English equivalents. The following tables will be found useful for this purpose:

MEASURES OF LENGTH.

		English inches.			English inches.
Millimeter.........	=	.03937	Decameter....	=	393.70790
Centimeter........	=	.39371	Hectometer...	=	3,937.07900
Decimeter.........	=	3.93708	Kilometer	=	39,370.79000
Meter	=	39.37079	Myriameter...	=	393,707.90000

MEASURES OF VOLUME.

		Cubic inches.
Milliliter, or 1 cubic centimeter......................	=	.06103
Centiliter, or 10 cubic centimeters....................	=	.61027
Deciliter, or 100 cubic centimeters...................	=	6.10271
Liter, or 1 cubic decimeter, or 1000 cubic centimeters.	=	61.02705
Decaliter..	=	610.27052
Hectoliter...	=	6,102.70515
Kiloliter..	=	61,027.05152
Myrialiter...	=	610,270.51519

MEASURES OF WEIGHT.

		English grains.			English grains.
Milligramme.......	=	.01543	Decagramme..	=	154.32349
Centigramme......	=	.15432	Hectogramme.	=	1,543.23488
Decigramme.......	=	1.54323	Kilogramme..	=	15,432.34880
Gramme...........	=	15.43235	Myriagramme.	=	154,323.4880

The temperatures given in this book are expressed throughout in degrees of the Centigrade thermometer, unless otherwise specified. The following is a short comparative table of the two scales, Centigrade and Fahrenheit.

C.	F.	C.	F.	C.	F.	C.	F.
−20°	−4°	15°	59°	45°	113°	75°	167°
−15	+5	20	68	50	122	80	176
−10	14	25	77	55	131	85	185
− 5	23	30	86	60	140	90	194
0	32	35	95	65	149	95	203
5	41	40	104	70	158	100	212
10	50						

The formula for converting degrees on Fahrenheit's scale to corresponding degrees on the Centigrade scale is $\frac{5}{9}(\mathrm{F.}^\circ - 32) = \mathrm{C.}^\circ$; and for converting Centigrade to Fahrenheit, $\frac{9}{5}\,\mathrm{C.}^\circ + 32 = \mathrm{F.}^\circ$. For further data with regard to thermometer scales, see Part I.

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